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ADAPTATION OF OHIA POZZOLAN SOIL ON CEMENTED LATERITIC SOIL AS BASE MATERIAL IMPROVEMENT

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EXTENDED ABSTRACT

Le pavimentazioni stradali e le altre strutture di fondazione di base subiscono continue rotture e non soddisfano i requisiti di progettazione desiderati, nonché le condizioni di performance quotidiane, generando continue difficoltà ed ostacoli alla mobilità ed al trasporto in generale. Questo è dovuto all'utilizzo di materiali di fondazione scadenti che non migliorano adeguatamente le proprietà richieste e conseguentemente non consentono di ottenere efficienti prestazioni ingegneristiche. È stato osservato che i materiali di sottofondo e di base delle strade sono fondamentalmente terreni compattati in situ o presi in cave di prestito ad alto contenuto in argilla. Questo sottopone i materiali di fondazione a fenomeni di rigonfiamento e conseguente ritiro al variare delle condizioni di umidità, in particolare per le fondazioni legate idraulicamente. La geologia di questi terreni di fondazione è sempre influenzata da questo ciclo di aumento e diminuzione dell'esposizione all'umidità e influenza il comportamento strutturale dell'intera struttura. I terreni lateritici sono i principali geomateriali nella tecnologia delle fondamenta delle pavimentazioni, poiche sottostanti a tutti gli strati della struttura e responsabili della distribuzione dei carichi sulla formazione rocciosa di base. Nella maggior parte dei casi, I materiali di fondazione selezionati non soddisfano i requisiti fondamentali per il loro utilizzo come componenti strutturali, non superando le prove di carico. Per questo motivo particolare, le rotture delle pavimentazioni stradali sono frequenti con effetti disastrosi.

Il principale obiettivo di questa ricerca è il miglioramento della resistenza e delle capacità leganti di questi materiali da costruzione . A tale scopo è stato studiato l'effetto di Ohia nanostrutturato, presente naturalmente nella pozzolana (argilla caolinica), sulla resistenza a compressione del terreno lateritico Umuntu Olokoro, per l'uso come miglioramento del materiale di base per le strade del sud-est.

I terreni pozzolanici presenti in natura sono stati strutturati alla nanoscala mediante polverizzazione, setacciati attraverso un setaccio con maglie di apertura di 100 nanometri e caratterizzati col metodo dello spettrofotometro UV-Vis. In secondo luogo, sono state condotte sperimentazioni preliminari in conformità ai requisiti della British Standard, agli standard dell'American Association of State Highway and Transportation Officials e alle Specifiche Generali nigeriane per determinare l'indice, la classazione, la compattazione e le proprietà di consistenza del terreno lateritico naturale. I risultati mostrano che il terreno lateritico era un terreno A-2-7, cioè terreni fini a comportamento più plastico secondo il sistema di classificazione AASHTO e scarsamente classato (GP) secondo il sistema USCS. Presenta anche il 25,4% di passante al setaccio n. 200. Il terreno ha anche registrato un indice di plasticità del 21,85%, identificandolo come un terreno altamente plastico perché maggiore del 17%. Il peso specifico del terreno era 2,67 g/cm^3. Dai risultati dei test di compattazione, il contenuto di umidità ottimale osservato è stato del 13%, mentre la densità massima secca è stata ugualmente osservata pari a 1,84 g/cm^3.

I risultati preliminari hanno mostrato un valore del California Bearing Ratio pari al 14% e valori di resistenza a compressione uniassiale di 194,26 kN/m^2, 219,11 kN/m^2 e 230,77 kN/m^2 considerando, rispettivamente, 7, 14 e 28 giorni di stagionatura proprietà di materiali di sabbia argillosa limosa e materiale rigido. Inoltre, l'additivo pozzolanico è stato introdotto in proporzioni del 3%, 6%, 9%, 12% e 15% in peso, è stato correttamente miscelato con il terreno trattato, sottoposto a test di compressione e l'effetto comportamentale delle proporzioni variabili sul terreno lateritico di elevata plasticità è stato osservato in condizioni di laboratorio. I risultati mostrano che l'introduzione della pozzolana ha migliorato notevolmente la resistenza a compressione del suolo fino a un massimo di 369,9 kN/m^2 con una proporzione del 9% in peso di pozzolana nella miscela solida dopo 28 giorni di indurimento. La nanostruttura dell'additivo cementizio ha svolto un ruolo molto importante nello sviluppo della resistenza a causa della sua maggiore superficie reattiva dovuta alla nanosizzazione. È anche possibile che l'aggiunta di tale materiale naturale come la pozzolana possa influire sulle prestazioni già note del normale cemento Portland (OP) che fungeva da legante secondario. Avendo soddisfatto le proprietà del materiale per l'uso come materiale di base (200-400 kN/m^2) secondo le Specifiche Generali nigeriane, la pozzolana è considerata un ottimo materiale di aggiunta nella stabilizzazione e reingegnerizzazione di terreni lateritici da utilizzare come materiale di sottofondo per la costruzione di pavimentazioni stradali. Inoltre, la pozzolana che è un materiale ecologico ad alto contenuto di alluminosilicati può sostituire il normale cemento Portland come geomateriale cementizio supplementare. Ciò ridurrà anche l'emissione di ossidi di carbonio durante l'uso di cemento nelle opere di ingegneria civile e salverà ulteriormente l'ambiente dall'esaurimento.

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/m^2, 219.11 kN/m^2 and 230.77 kN/m^2 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 (200-400 kN/m^2), pozzolan is a very good admixture material in the stabilization of lateritic soils for use as a subbase material for pavement construction.

Keywords: *soil stabilization, nanostructured pozzolan, subgrade soil, base improvement, pavement purposes*

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 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 alii*, 2013; Chang-Jun *et alii*, 2010; Bao *et alii*, 2011; Anitha *et alii*, 2014; Anamika *et alii*, 2012; Ali *et alii*, 2011; Mercier *et alii*, 2002; Chien-I *et alii*, 2008; Ershadi *et alii*, 2011; Fan *et alii*, 2015; Hall et al, 2000; Kalpana *et alii*, 2009; Kannan, 2010; Kavitha *et alii*, 2015; Laila *et alii*, 2010; Masaki *et alii*, 2006; Osinubi *et alii*, 2009; Reenu et alii, 2014; Satish *et alii*, 2015; Xiao *et alii*, 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 byproducts. 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 alii*, 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.

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 alii*, 2013; Chang-Jun *et alii*, 2010; Bao *et alii*, 2011; Anitha *et alii*, 2014; Anamika *et alii*, 2012; Ali *et alii*, 2011; Mercier *et alii*, 2002; Chien-I *et alii*, 2008; Ershadi *et alii*, 2011; Fan *et alii*, 2015; Hall *et alii*, 2000; Kalpana *et alii*, 2009; Kannan, 2010; Kavitha *et alii*, 2015; Laila *et alii*, 2010; Masaki *et alii,* 2006; Osinubi *et alii*, 2009; Reno *et alii*, 2014; Satish *et alii*, 2015; Xiao *et alii*, 2005). Meanwhile Norazlan *et alii* (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.

MATERIALS AND METHODS

Materials

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 5 km 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); 4.36 mm, 2.36 mm, 1.18 mm, 300 µm, 212 µm, 150 µm, 75 µm.

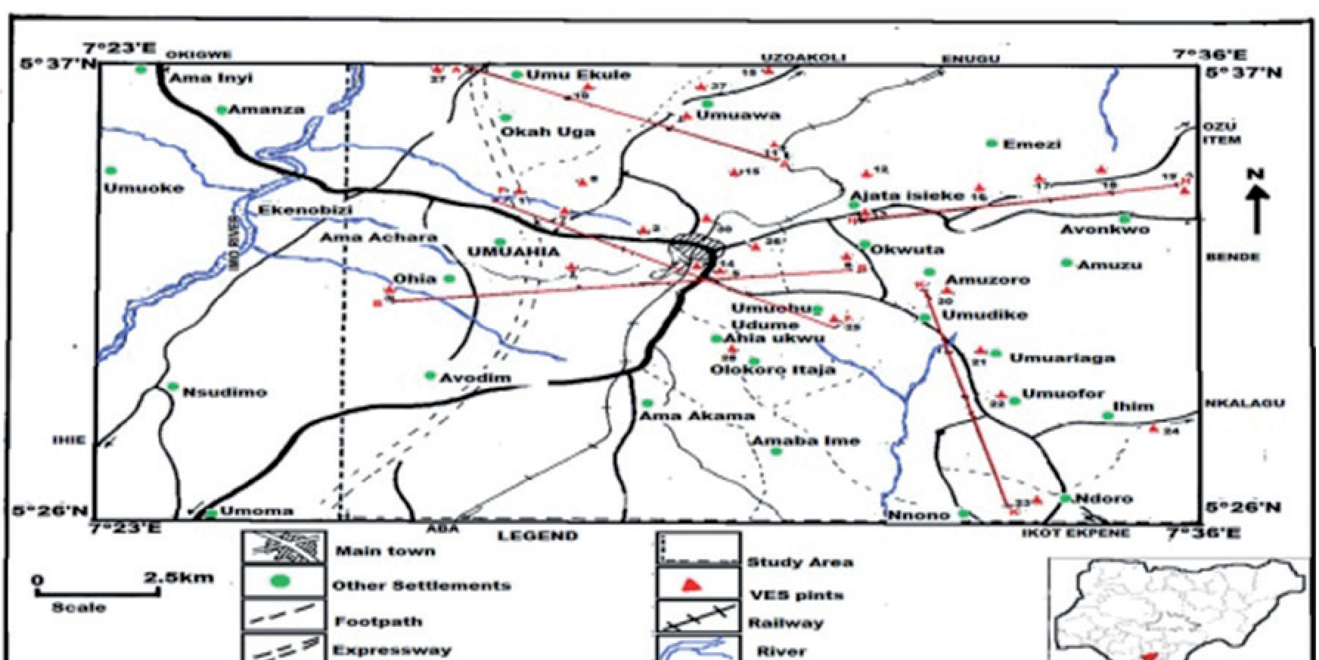

Fig. 1 - Map of Umuahia Showing Olokoro and Ohia

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

Pozzolan Soil and Ordinary Portland Cement

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 200 nm 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.

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 (Casagrande apparatus), Unconfined Compressive Str ength(UCS) Test, Specific Gravity Test, and Chemical Composition Test on the natural soil sample and results were obtained.

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 Figures 3 (a & b).

RESULTS AND DISCUSSIONS

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

- has a plasticity index of 21.85% > 17% and that condition

Fig. 3 - Nigerpet laboratory unconfined compressive strength (a) and (b) CBR test setup

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 & 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 & 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 & Rao, 2011).
- has optimum moisture content (OMC) of 13% and maximum dry density (MDD) of 1.84 g/cm^3.
- has Unconfined Compressive Strength (UCS) of 230.77 kN/m^2 at 28 days curing time, which falls between 200 and 400 kN/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 & Rao, 2011; NGS/FMWH, 1997).
- has California bearing ratio of 14 which makes it good for the subgrade material (NGS/FMWH, 1997).

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 1.154 nm at the wavelength of 800 cm.

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 days	*219.11*
7 days	*194.26*

Tab. 1 - Geotechnical Properties of the Test Soil

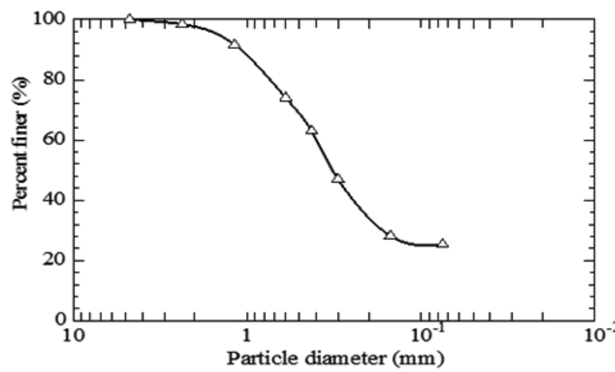

Fig. 4 - Particle size distribution curve of the lateritic soil sample

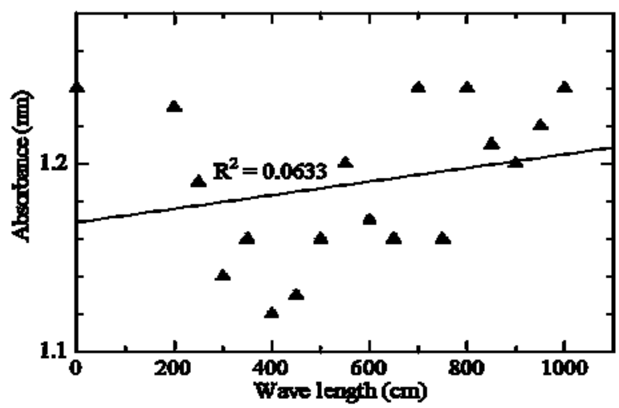

Fig. 5 - Variation of Absorbance against wavelength for the lateritic soil using UV/VIS Spectrophotometer at 25°C

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 194.26 kN/m^2 at control experiment to 192.8 kN/m^2, 273.1 kN/m^2, 286.5 kN/m^2, 300.4 kN/m^2 and 341.6 kN/m^2 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 357 kN/m^2 at 15% by weight proportion of pozzolan.
3. While the strength improvement at 28 days curing time

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

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

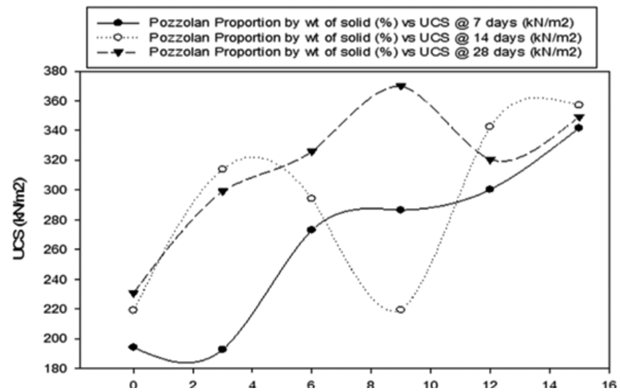

Fig. 6 - Effect of Nanostructured Pozzolan on UCS

recorded a maximum of 369.9 kN/m^2 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.

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.

ACKNOWLEDGEMENTS

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CONFLICT OF INTEREST

There are no conflicts of interest in this article.

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

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