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Nanostructured Clay (NC) and the Stabilization of Lateritic Soil for Construction Purposes

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Abstract
The use of Nanostructured Clay additive in lateritic soil stabilization and their effect at different percentages on the natural soil was investigated. The preliminary tests on the soil showed it was an A-2-7 soil, according to AASHTO classification. The soil sample was also observed to be silty clayey sand and the general rating as a sub-grade material was 'GOOD'. The consistency limits result shows that the value of the LL for the natural soil is 47% and 25.15% was recorded for the plastic limit (PL) and finally the PI was 21.85% i.e. highly plastic soil. Further, the effect of the addition of NC in the proportions of 3%, 6%, 9%, 12% and 15% by weight of the stabilized Umuntu Olokoro lateritic soil was investigated. The consistency limits results showed that the addition of variable proportions of NC considerably improved the plasticity of the stabilized soil which gave 13.8%; a medium plastic material at 15% NC addition, compared to the preliminary result of 0% by weight additive which gave 21.85%; a highly plastic material. The strength properties' test showed significant improvements with the addition of NC; CBR test result recorded 29% at 15% by weight proportion of NC which satisfies the material condition for use as sub-base material and the UCS test results similarly improved consistently and recorded a maximum UCS of 340.18kN/m^2 at 15% by weight proportion of NC addition which satisfies "very stiff" material consistency for use as sub-base material. With the foregoing, the addition of various proportions of NC to the stabilized lateritic soil has presented to be a Geotechnical solution to the varied environmental failures on the road pavements. Hence NC satisfies all the material conditions for use as a sub-base material for the stabilization and improvement of the strength characteristics of lateritic soils. Finally, we call on the relevant agencies to use NC as an additive in stabilizing weak lateritic soils for use as either sub-grade or sub-base materials to save both cost and the structural failures on the roads in south eastern Nigeria.
Keywords: Environmental Geotechnics; Pavement Geotechnics; Soil Stabilization; Weak Lateritic Soil; South Eastern Nigeria.

1. INTRODUCTION

The effect of the nanosized clay (NC) as admixture on the Geotechnical properties of stabilized Umuntu Olokoro lateritic soil for use as a base material in pavement construction in south eastern Nigeria has been investigated by the present research work. However, there are different methods used for strengthening soil bases, which are categorized under soil treatment and stabilization methods. The desired performance of treated soils is a major factor in selecting the most useful method for soil stabilization (Arabani and Karami, 2007; Nikookar et al, 2012). All ground improvement techniques seek to improve those soil characteristics that match to desired results of a project, such as an increase in density and shear strength in order to aid problems of stability, reduction of soil compressibility, influencing the permeability to reduce and control ground water flow or to increase the rate of consolidation, or to improve soil homogeneity (Moseley and Kirsch, 2004). Stabilization is one of ground improvement techniques that were developed in Japan during the 1970s and 1980s. The treated soil has greater strength, reduced compressibility and lower hydraulic conductivity than the original soil (Raison, 2004). The conventional method of soil improvement is to replace the soft soil by suitable imported fill materials. However, this practice is naturally very expensive due to the cost of excavation, dumping and the filling material (Kazemian and Huat, 2010). Engineered soils are highly moisture sensitive and their stability is influenced considerably by the degree of densification achieved during compaction. Nanoparticles of usually 1 to 100 nm are the smallest particles in soil environments and exist in one of the three different forms; nanoplatelets, nanowires or nanotubes, and nanodots.

Due to their tiny size, soil nanoparticles usually exhibit special enhanced surface properties and hence interact more actively with other soil particles and solutions. Owing to the extremely large specific surface area, surface charges, and sometimes nanoporosity, these particles, even present at a small fraction, may significantly affect soil physico-chemical behavior and engineering properties (Zhang, 2007). Modifying behavioral parameters in different soils are one of the major problems facing researchers in Geotechnical engineering. Adding some additives to soil has been always considered as one of effective methods to improve some behavioral quantum size limitation, wavelike transportation and overcoming surface phenomenon (Goitoz, 2005). Although there have been done a few studies to estimate advantages of adding some types of nano-materials to soils, but there is a major problem in doing empirical experiments and applicable data. Adding the obtained nano-soil of ball mill process to a variety of fine-grained soils and doing Atterberg Limits tests on them indicate increasing toughness and liquidity limits as well as decreasing toughness range. Adding nano-soil to the stabilized samples with cement has increased their compressive strength (Mirkazemi, 2010; 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). Clay nano-particles, which they are used in business affairs frequently, are one of nano-materials that there have been performed many studies about it. Nano-clays are clay powders, which they are filtered many times and are used to increase strength, resistance against UV, increasing thermal strength and absorbing environmental pollutants (Owhadi, 2011; Speeding, 2005). According to the resulted data of compressive experiment on windy ash, increasing organosilan in nano dimensions led to decrease optimal humidity and increase maximum dry special weight. Field studies indicated that soil reform with organosilan led to increase strength, decrease swelling potential and decrease hydraulic conductivity significantly (Dynels, 2009). Toughness behavior of fine-grained engineering soils plays a decisive role in many Geotechnical constructions such as mud dams. Some of them include effect to reduce cracking, prevent piping and ultimately, increasing stability of mud dams with clay core. Improving uniaxial strength in fine grade soils can increase soil load bearing capacity and foundation load bearing capacity (Moghaddam et al, 2011). As there have not been carried out comprehensive studies about the effect of nanoclay on mechanical specifications of clays under freezing, the results of the research can provide a better understanding about nanoclay behavior in soil; in this way, nanotechnology can be used in Geotechnical engineering effectively. A proper understanding of the Geotechnical properties of soils is a pre-requisite for its use in engineering construction works. Studies on the engineering properties of these materials have made geologists and engineers aware of a wide range of properties. However the relative abundance of soil notwithstanding, its suitability for various purposes can be enhanced through the modification of its properties by stabilization. Various stabilization techniques are available to improve soil properties by the addition of materials like cement, lime, bitumen, clay, etc. Nanoparticles are one of the newest additives and researches are going on to find its effect on the properties of soils. Nanotechnology is a rapidly emerging technology with vast potential to create new materials with unique properties and to produce new and improved products for numerous applications**.** At scales of nanometer range, materials can exhibit unique properties different from their bulk state. Nanotechnological achievements provided a modern approach in Geotechnical engineering also. Nanotechnology can be applied in geotechnical engineering by studying the soil structure in nanometer scale to gain a better understanding of soil nature (Taha, 2012; 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). In most countries, sanitary landfills are nowadays the most common way to eliminate Municipal Solid Waste (MSW). Landfill liners are designed and constructed to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. This is done to prevent the uncontrolled release of leachate into the environment. For a landfill liner hydraulic conductivity must be in the range of 1 x10-7cm/Sec (Benson, 1994). The presence of nanoparticles, even at a small fraction, can dramatically influence the engineering properties. They usually cause the formation of very porous aggregated structure, thus affecting the index, consolidation, and strength properties (Bahari, 2013). At the nanoscale, a higher ratio of surface to volume and, in turn, a higher cation exchange capacity exists. Therefore, they interact very actively with other particles and solutions such that very minute amounts may lead to considerable effects on the physico-chemical behavior and engineering properties of soil (Zhangn, 2005). Careful selection of materials to attain a low permeability barrier is essential in engineered waste disposal. The liner material should be strong enough to sustain the static load exerted by an overlying body of waste. Lateritic soils and kaolinite clay found in their area might not meet the properties listed for their use in waste containment applications. Hence, they have to be treated with proper additives so that they meet all the requirements for a landfill liner. The aim of this work is to investigate the effects of nanoclay on the Geotechnical properties of Umuntu Olokoro engineering soil. Specifically, the main objectives of this research work were; **(i)** To determine the effect of nanosized clay on the moisture content and dry density of stabilized olokoro engineering soil, **(ii)** to determine the effect of nanosized clay on the CBR of stabilized olokoro engineering soil, **(iii)** determine the effect of nanosized clay on the consistency behaviour of stabilized olokoro engineering soil, **(iv)** determine the effect of nanosized clay on the grading behaviour of stabilized olokoro engineering soil, and **(v)** determine the effect of nanosized clay on the compressive strength of stabilized umuntu olokoro engineering soil.

2. LITERATURE REVIEW

Engineering (weak) soils can usually be found in areas with high water content, approaching that of the liquid limit, which results in high settlement potential with low shear strength. Thus, a stable state should be achieved to satisfy pre-construction and post construction settlement and to ensure stable strength and deformation. Construction on soft soils in many civil engineering projects has prompted the introduction of many approaches for soil improvement particularly stabilization. Soil stabilization is a traditional strategy used to enhance soils to fulfill the specifications of different kinds of projects (Kolias, *et al*. 2005). A number of studies have focused on stabilizing soft soils using various additives. Traditional materials such as cement, lime and mineral additives such as fly ash, silica fume and rice husk ash were used for improving soils (Al-Rawas and Goosen, 2006). Nanotechnology revolves around the creation of a varied collection of Nanomaterials (NM). This basically encompasses Nano-Particles (NP) along with nano objects. NM is known to be 100 nm lower in terms of their dimension, whereas nano objects fall two dimensions lower than the same. The idea of nanotechnology was first introduced in the year 1959 in a lecture delivered by Feynman (1960) which was titled "there's plenty of room at the bottom". It is important to note though that at that time the term 'nanotechnology' did not exist yet. It was years later that this technology made a rapid and significant progress in the sciences (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). The word Laterite describes no material with reasonable constant properties. To those in the temperate countries, it could be described as a red friable clay surface. To those in the hilly tropical countries, it could be described as a very hard homogenous vascular massive clinker – like materials with a framework of red hydrated ferric oxides of vascular infill of soft aluminium oxides of yellowish color and in the less hilly country, it could exist as a very hard, or soft coarse angular red. Lateritic soils as a group rather than well-defined materials are most commonly found in a leached soils of the humid tropics. Laterite is a surface formation in hot and wet tropical areas which is enriched in iron and aluminum and develops by intensive and long lasting weathering of the underlying parent rock. In order to fully appreciate the usefulness of lateritic soil, its problems (in both field and laboratory) would have to be identified and useful solutions applied. The mechanical instability, which may manifest in the form of remolding and manipulation, results in the breakdown of cementation and structure. The engineering properties affected by this mechanical instability include particle size, Atterberg's limits, and moisture-density distribution. Thermal instability is shown through sensitivity drying to be described as potentially self-stabilization. The affected engineering parameters are Atterberg's limits, particle size distribution. The effects of these problems, therefore, affect the strength of the material. The designs of earth structures require knowledge of the behavior and stress-related deformability of soils that will support the structure and the geological conditions of the soil under consideration. The Geotechnical properties of a soil such as grain size distribution, plasticity, compressibility, shear strength, permeability, soil compaction, California bearing ratio, shear strength and so on, are used in predicting the behavior of soil when subject to loads. These properties can be assessed by proper laboratory or in situ tests. In situ determination of these properties avoids the sample disturbances that occur during field exploration. However, under certain circumstances, all of the needed parameters cannot be determined or are not determined because of economic or other reasons. Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of parent rocks under tropical and subtropical climatic conditions. This weathering process primarily involves the continuous chemical alteration of minerals, the release of iron and aluminum oxides, and the removal of bases and silica in the rocks. The Geotechnical properties of lateritic soils are influenced by climate, drainage, geology, the nature of the parent rock and the degree of weathering or linearization of the parent rock. These factors also differentiate laterite from other soils that are developed in the temperate or cold regions. Some lateritic soils are thought to have been transported from their place of origin by wind or other action, but most of those with which are used for road construction is likely to have been formed in situ. Lateritic soils contribute to the general economy of the tropical and subtropical regions where they are in abundance because, they are widely utilized in civil engineering works as construction materials for roads, houses, landfill for foundations, embankment dams, etc. As a 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. They can also be used in other works in agronomic, mining research (iron, aluminum and manganese) deposits, etc. Lateritic soils are economically convenient in road construction, in the sense that they are cheaper than other materials that can achieve comparable strength with them and they are more available than those materials. In some states in Nigeria, laterite is a major road construction material that is used for the sub-grade and, occasionally, the sub-base and base courses of the roads. Adequate information on its Geotechnical properties is important because the durability and strength of the road depend on this information. Such Geotechnical parameters include the strength, the maximum dry density (MDD), the amount of fines (clay, silt, sand and gravel) as well as its compaction performance. Stabilization processes are very complex because many parameters come into play.

The knowledge of soil properties can help to better consider what changes, the economic studies (cost and time), as well as production and construction techniques to use. The simplest process consists of taking soil and drying it in open-air. Soil stabilization is seen as a means of enhancing aspects of engineering and other elements, including the conductivity of hydraulics, compressibility, strength, and the density. Methods relating to soil stabilization can be categorized in numerous ways, including surcharge load, vibration, enhancing support for structures at hand with structure fill, grouting, and other techniques (Kazemian and Huat, 2010). Many techniques can be used for different purposes by enhancing some aspects of soil behavior as well as the basic makeup and potency of the soil (Edil, 2003). Soil stabilization is any treatment applied to a soil to improve its strength and reduce its vulnerability to water, if the treated soil is able to withstand the stresses imposed on it by traffic under all weather conditions without deformation, then it is generally regarded as stable. This definition applies irrespective of whether the treatment is applied to a soil in situ or after the soil has been removed and placed on a pavement or embankment (O'Flaherty, 2002). Soil stabilization methods can be divided into two categories, namely mechanical and chemical. Mechanical stabilization is the blending of different grades of soils to obtain a required grade. Chemical stabilization is the blending of the natural soil with chemical agents. Several blending agents have been used to obtain different effects. The most commonly used agents are Portland cement; asphalt binders and lime.

2.1 Nanotechnology and Geo-nanotechnology

Recently, nanotechnology is being used or considered for use in many applications and it has received increasing attention in building materials, with potential advantages and drawbacks being underlined. Various nanomaterials are being studied for use like nanosilica. However, there is a limited knowledge about the mechanism by which nanosilica (NS) affects the flow properties, setting times, consistency, workability, rheological, micro structural, mechanical properties etc of cementitious mixes (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) . Furthermore, the literature appears to be contradictory about the influence of NS on the development of such materials. A contribution to the development of building materials comprises adding synthetic silica to concrete and cement mortars, whereby the resulting product displays improved aging properties with regard to strength gain, sulphate attack and alkali silica reaction. Due to the high specific surface area for nano material sized colloidal nano silica (CNS) particles, they contribute a highly reactive siliceous material. However, it has not been established whether the more rapid hydration of cement in the presence of NS is due to its chemical reactivity upon dissolution (Pozzolanic activity) or to a considerable surface activity. Bjornstrom et al investigated the hydration process of tricalcium silicate (C_3S) cement and established the accelerating effects of colloidal silica and the role of water during hydration. From their study, it was observed that CNS accelerate the dissolution of C_3S phase, thereby renders the rapid formation of C-S-H phase. If the nano particles are integrated with cement based materials, the new materials might possess some outstanding properties. The cementitous activity of NS is more obvious than that of silica fume counterpart. NS can react with CH crystals, which are arrayed in the interfacial transition zone (ITZ) between hardened cement paste and aggregates and produce C-S-H gel. Thus, the size and amount of CH crystals are significantly decreased and the early age, strength of hardened cement paste in increased. Ji studied the water permeability resistant behavior and micro structure of concrete with NS3. The water permeability tests showed that NS concrete has a better water resistant permeability than control sample, and microstructure of the NS revealed that the uniform and more compaction of NS in concrete. A similar kind of study was carried out by Ye Qing et al, but with the comparison of micro silica [SF] and with the influence of NS, they found that the setting times and consistency for SF and NS incorporated concrete were different, but NS makes the cement paste thicker and accelerated cement hydration4. Compare to SF concrete, NS showed improved compressive strength and bond strength too. Jo et al studied the properties of cement mortar with NS particles and showed the importance of the NS addition towards strength characteristics, hydration progress and calorimetric investigations. Observations were also made from the heat of hydration values, which depicted the amount of CH formed by the addition of NS could increase the amount of heat evolved during setting and hardening of the cement. The reduced calcium leaching behavior of cement paste by the addition of NS were reported by (Gaitero et al., 1993) and revealed that the calcium leaching was a degradation process that consisted in the progressive dissolution of the cement paste as a consequence of the migration of Ca2+ ions to the aggressive solution. The results obtained showed that NS increases the strength of the cement paste by about 30% of the ore samples and ultimately the observed results highlighted the introduction of NS particles modified the cement paste in three different ways, e.g. reduced porosity; transforming Portlandite (CH) into C-S-H gel by means of pozzolan reaction; and modified the internal structure of the C-S-H gel increasing the average chain length of the silicate chains.

2.1.1 Nanomaterials

Majed and Taha (2011) studied the effect of nano-materials' behavior of Geotechnical properties of engineering soils. They used three types of nano-materials (nano-calcium, nano-magnesium and nanoclay) in their investigation. They used nano-materials by 0.05% to 1% to make samples. Then they performed uniaxial and Atterberg Limits tests on samples. Results showed that the samples' Atterberg Limits will be reduced by increasing nano-materials, while the compressive strength of the samples will be increased. Dermatas and Meng (2003) increased compressive strength of sand samples by using nano-silica. Gutierrez et al. (2000) studied the effect of nano-silica on strength behavior and the permeability of cohesive soils. Ghazi (2011) investigated the effect of nano-silica on strength behavior and the permeability of cohesive soils under dynamic loads. Results showed that adhesive power would be increased by increasing the proportion of nano-silica. Ghazi et al. (2007), by using dynamic tests such as dynamic triaxial test, investigated the effects of nano-particles on embarking sand soil after earthquake loads in USA. Behnia et al. (2011) said that soil Atterberg limits will be increased by mixing nano-particles with soil. In 2007, he also studied strengthening effect of nano-particles with soil. His research results showed that mixing nano-particles with soil enhances samples' strengthening steadily. There are various widely known methods to produce nanomaterials other than by direct atom manipulation (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)

2.1.2 Nanofillers

Nanofillers can be either small spherical particles or rod shaped objects and flakes with at least one critical dimension below 100nm. In general, the properties of filler materials are determined through particle size, particle geometry and chemical coatings. Smaller particles provide new functionalities such as control of rheological properties, improved mechanical properties, an increased transparency or electrical conductivity. They can be also used to ensure the free flow of powders and to prevent the settling of pigments. Fillers are widely used in the construction sector in adhesives and sealants, in paints and coatings, but also in plastics, rubber and concrete production.

Synthetic fillers are now gaining more importance; they allow the production of smaller particle sizes with controlled surface chemistry or tailored chemical functionalisation. Ultra - fine grades or so called nanofillers are under investigation. Besides downsizing existing filler materials, completely new technological approaches can also be observed such as organic - inorganic hybrid materials in polymers or nanotubes as reinforcing filler material in concrete. However, the share of nanofillers in today's construction filler market is negligible. An example of well established nanofillers can be found in another sector; carbon black filled tires for longer life and improved performance. Nanoclays could serve as nanofillers in the production of concrete for construction purposes.

2.1.4 Nanoclays

Nanoclays are plate-like nanoparticles of natural occurring layered silicates. Clay minerals are divided into numerous classes such as bentonites or hectorites. Bentonites mainly consist of so called montmorillonites, the most widely used nanoclay in material applications today. Montmorillonites are build up of stacked nanoscopic aluminosilicate plates each around 1nm in height and 1 μm in diameter and are used as filler in plastics. Organically modified montmorillonites, so called organoclays, are used to increase the flame retardancy of polymers especially in cables; the flame propagation is significantly reduced and no dripping of burning polymer is observed. However, aluminium trihydroxide (ATH) currently dominates the world market for fire protection agents. Patel, 2012) investigated using nanoclay in cement mortars. He examined samples without nanoclay as well as samples containing 1% and 2% nanoclay under pressure and permeability tests. The results showed that the permeability constant of samples containing 1% and 2% nanoclay is 150% and 200% higher than samples without nanoclay. In equal conditions, samples containing nanoclay are dried sooner and they have higher compressive strength. Fakhri et al. (2012) examined effects of nanoclay on clay basic Geotechnical properties by using standard density and Atterberg Limits tests. They used kaolinite clay in their study, which it was CL type based on the unified classification. This type of soil has a low plasticity and therefore, different percentages of nanoclay were used to increase its plastic doughy properties. They built and tested samples containing 0%, 1%, 2%, 4% and 8% nanoclay by using the Monte Morillonite nanoclay. Results showed that adding nanoclay will increase water absorption as well as samples' plasticity because of increasing special surface of the samples and consequently, increasing electrical load. It can be expected that samples' permeability will be reduced by increasing plasticity, which the properties ARE very appropriate and expected in core of mud dams. Owhadi and Amiri (2012) investigated nanoclays' capability to uptake environmental pollutants. They used two commercial cloisite nanoclays in their studies. Their experiments' results showed that compounds containing cloisite have a higher power to uptake pollutants. It can be increased by adding carbonate to nanoclay. Ganji et al. (2012) examined changes in soil shear tension before and after applying nanoclay. Their examples included silty clay and the montmorillonite nanoclay. They examined the samples by using standard density and uniaxial compressive tests. The results of the standard density test showed that optimal special weight is decreased by adding nanoclay, while optimum moisture content is increased. The shear tension of the soil is increased by adding nanoclay, while its angle of refraction is reduced. Khosrawani and Ghorbani (2012) evaluated the effect of nanoclay on engineering properties of adhesive soils.

3. MATERIALS AND METHODS

3.1 Source of Materials

The laterite soil sample used for this project was a disturbed sample collected from a borrow pit at Olokoro, located between latitude $05^0$28'36.900"North and longitude $07^0$32'23.170"East from a depth of 2m a distance of 5km along Ubakala road from Umuahia Abia State Nigeria (www.google.com, 2015). The sample collected was in solid state and reddish brown in color. The soil obtained from this location was air dried in tray for six days, after which the soil was crumbled. The dried soil was pulverized, using a rubber covered pestle in the tray and sieve characterization with orderly arranged British Standard Sieve to (IS:2720-part XVI, 1999); 4.36mm, 2.36mm, 1.18mm etc.

Kaolin material was gotten from the same location at a depth of 3m from the topsoil, it was also air dried and synthesized by pulverization and X-ray characterization to Nanoclay which was used as the stabilizing agent.

The laterite soil sample used for this project work has the following characteristics.

- The soil has a particulate size less than 2 micrometers
- It increases in volume with the addition of water when partially saturated and shrinks when greatly dried and develops cracks on the surface.

And finally, the cement was a Dangote ordinary Portland cement that satisfies (ASTM C150, 2013) used as the binder.

3.2 Methods

Experimental tests were conducted as follows;

(a) Particle Size Distribution: This was conducted at the Geotechnical and Materials Engineering laboratory, Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike.

Aim: To determine the grading and particle size distribution of the lateritic soil sample in accordance to (BS 1377-2, 1990; BS 5930, 2015; Eurocode 7-2, 1997; NGS, 1997; ASTM D6913-04, 2009; ASTM D2487-11, 2015; ASTM D2488-09a, 2015).

Apparatus: Orderly arranged British Standard Sieves to BS410 (1976); 4.36mm, 2.36mm, 1.18mm, 600µm, 425µm, 300µm, 212µm, 150µm, 75µm; Lid and receiver; balance readable and accurate to 0.1g, drying oven, sieve brush and the mechanical shaker.

(b) ***Consistency Limits Tests:*** This was conducted at the Geotechnical and Materials Engineering laboratory, Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike. ***Aim***: To determine the liquid and plastic limits and hence the liquidity and the plasticity indices of the natural lateritic soil sample in accordance to (BS 1377-2, 1990; BS 1924, 1990; BS 5930, 2015; Eurocode 7-2, 1997; NGS, 1997; ASTM D4318-10, 2015; ASTM D2487-11, 2015; ASTM D2488-09a, 2015).

Apparatus: A flat glass plate (10mm thick and 500mm square) two (2) palette knives (200mm long and 30mm wide) Casagrande liquid limit apparatus, a grooving tool and gauge, an evaporating dish or a damp cloth, a beaker containing distilled water and a non-corrodible air tight container large enough to take about 250g of wet soil and the material soil sample.

(c) ***Soil Compaction Test***: This was conducted at the Geotechnical and Materials Engineering laboratory, Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike. ***Aim***: To determine the bulk density and dry density/moisture content relationship (2.5kg rammer method) in accordance to (BS 1377-2, 1990; BS 1924, 1990; BS 5930, 2015; Eurocode 7-2, 1997; NGS, 1997; ASTM D698-12, 2013; ASTM D2487-11, 2015; ASTM D2488-09a, 2015).

Apparatus: A cylindrical metal mould having an internal diameter of 105mm, internal effective height of 115.5mm and a volume of 1000cm^3 (the mould was fitted with a detachable base plate and a removable extension 50mm high), a metal rammer having a 50mm diameter circular face and weighing 2.5kg (the hammer was equipped with a suitable arrangement for controlling the height of drop to 300mm) a balance readable and accurate to 1g, a palette knife (100mm long and 20mm wide), a straight edge steel strip 300mm long, 25mm wide and 3mm thick with one beveled edge, 20mm BS test sieve and a receiver, large metal tray (600mmx500mm with sides 80mm deep), apparatus for moisture content determination.

(d) ***Specific Gravity Test:*** This was conducted at the Geotechnical and Materials Engineering laboratory, Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike.

Aim: To determine the specific gravity of the lateritic soil sample in accordance to (BS 1377-2, 1990; BS 5930, 2015; Eurocode 7-2, 1997; NGS, 1997; ASTM D854-14, 2015; ASTM D2487-11, 2015; ASTM D2488-09a, 2015; ASTM

D7262-09).

Apparatus: Two density bottles (pycnometers) of approximately 50ml capacity with stoppers, water bath maintained at constant temperature of 20°C within + 0.2°C, vacuum desiccators, thermostatically controlled drying oven (105-110°C) balance readable and accurate to 0.001g, a vacuum pump, spatula (150mm long, 3mm wide), plastic wash bottle containing air-free distilled water; sample divider of the multiple slot type (riffle box) with 7mm width of opening and a length of rubber tubing to fit the vacuum pump and the desiccators.

(e) ***CBR Test***

This was conducted at the Niger Pet Geotechnical Enginering laboratory, Uyo, Akwa Ibom State, Nigeria.

Aim: Determination of CBR of the natural soil sample as well as the stabilized samples with 3%, 6%, 9%, 12% and 15% percentage proportions of nano palm bunch ash in accordance to (BS 1377-2, 1990; BS 5930, 2015; Eurocode 7-2, 1997; NGS, 1997; BS 1924, 1990; ASTM D1883-99, 2003; ASTM D2487-11, 2015; ASTM D2488-09a, 2015).

Apparatus: Compressive machine, proving ring, dial gauge, stopwatch, sampling tube, split mold, vernier caliper, balance.

(f) Unconfined Compressive Strength Test

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; BS 1924, 1990; ASTM D2166/D2166M-13, 2015; ASTM D2487-11, 2015; ASTM D2488-09a, 2015; ASTM D2166-65, 2015) as shown in Figure 3.

4. RESULTS AND DISCUSSION

From Table 1, it can be deduced that the Umuntu Olokoro soil has the following properties in its natural state;

- 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)
- 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, well graded, GW on USCS, the group index of 0 and of silty, clayey gravel and sand material (Gopal and Rao, 2011).
- Optimum moisture content (OMC) was 13% and maximum dry density (MDD) was 1.84g/cm^3.
- 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 sub-grade material (Gopal and Rao, 2011; NGS/FMWH, 1997).
- California bearing ratio of 14 which makes it good for the sub-grade material (NGS/FMWH, 1997).

Table 1: Geotechnical Properties of the Lateritic Soil

Property/Unit		**Quantity**
% Passing BS No. 200 sieve		25.40
Natural Moisture Content, (%)		10
Liquid Limit, (%)		47.00
Plastic Limit, (%)		25.15
Plasticity Index, (%)		21.85
Coefficient of Curvature, $C_c = \frac{D_{30}{}^2}{D_{10} \text{ x } D_{60}}$		0.09
Coefficient of Uniformity, $C_u = \frac{D_{60}}{D_{10}}$		10
Specific Gravity		2.67
AASHTO classification		A-2-7
USCS		GW
Group Index		0
Material		Silty or Clayey Gravel 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
Color		Reddish Brown

From Figure 1 and Table 2, we can deduce that the soil is a well graded soil with Cc equals 0.09 and Cu equals 10 (Holtz, and Kovacs, 1981).

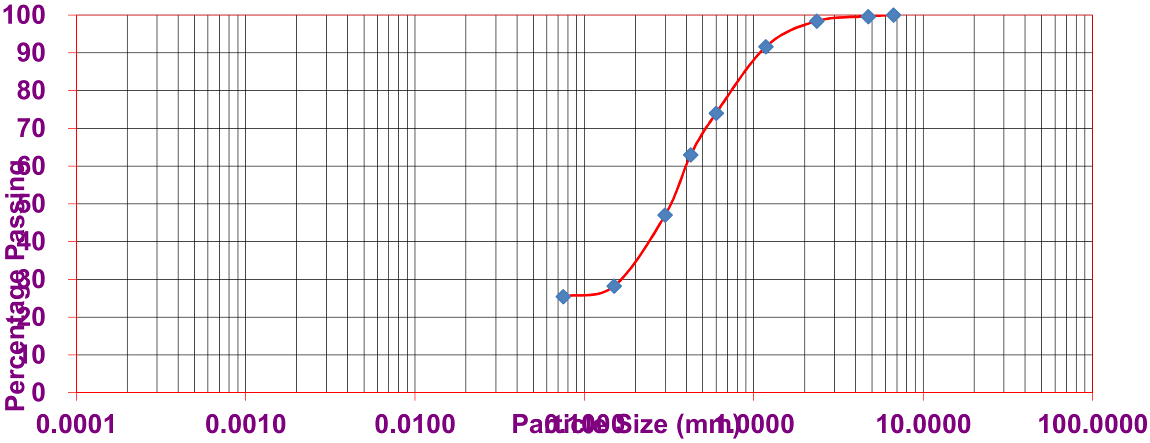
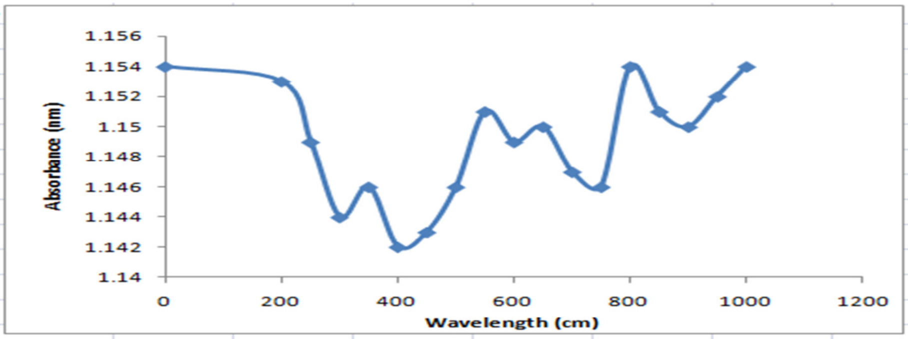


Figure 1: Particle size distribution curve of the lateritic soil sample

Waveleng	Absrbance
0	1.154
200	1.153
250	1.149
300	1.144
350	1.146
400	1.142
450	1.143
500	1.146
550	1.151
600	1.149
650	1.15
700	1.147
750	1.146
800	1.154
850	1.151
900	1.15
950	1.152
1000	1.154



Exp details:
Re: mouau/chemlab/UV-VIS/lateritic soil/exp.001
Date Printed: 29:03:2017
Number of Replicate: 1
Max. Absorbance: 1.154 nm at 800 cm wavelenght

Figure 2: Variation of Absorbance against wavelength for the lateritic soil using UV/VIS Spectrophotometer at 25^0C

Table 3 shows the bonding potentials of the nanosized clay (NC) which satisfies that material bonding is a very important factor in soil improvement and stabilization because the soil and the additive stabilizers need to form a cohesive bond. Material requirement for cementing materials is that the sum of the percentage composition of SiO_2, Al_2O_3, and Fe_2O_3 should not be less than 70%. The results of the analyzed NC shown in Table 3 show that the percentage of SiO_2 + Fe_2O_3 + Al_2O_3 is 99.03% greater than 70%, which makes the admixture a highly cementitious material. This property is of great advantage because it brought about a high degree of interaction and bonding between the studied soil and the additive.

Table 3: Chemical Composition of Nanosized Clay

Constituents	OH	Fe_2O_3	Al_2O_3	SiO_2	P_2O_5
% wt in NC	1.43	0.75	41.80	56.48	0.29

The soil specific gravity, Gs of 2.67 satisfies the material property of silt and silty clay sands (Gopal and Rao, 2011)

4.1 Effect of Nanosized Clay on the Consistency Limits of the Lateritic Soil

The results from consistency limits test conducted were shown in Table 4. The results of the Atterberg limits test conducted show a remarkable improvement in the soil consistency with the addition of varying proportions of nanosized clay. This property improved from 21.85%; a highly plastic material to 13.8% at 15% addition of NC; a medium plastic material. This improvement is due to the hydration of the highly pozzolanic additive with the stabilized mixture which reduced the PI consistently thereby producing a stiff mixture of stabilized soil. This behaviour agrees with Meegoda and Ratanweera (1994), which showed that if water is used as pore fluid, the influence of the mechanical factors would remain same with a general decrease in LL on addition of an admixture. However, if an organic fluid other than water is used, the physical properties of the fluid such as viscosity and density would influence the LL. With the varying behaviour with the addition of NC, it can be seen that the LL depends on the mechanical factors other pore fluid viscosity and density (Acar and Olivieri, 1990) and to a lesser degree on the physicochemical properties. The lowering of the LL and PI is therefore as a result of the mechanical and physicochemical factors of the soil such as a low dielectric constant resulting from high absorbance values which causes the clay particles to behave more like granular matrix with attendant reduction in adsorbed water and the physicochemical factors of the admixture such as carbon and hydroxide content which lead to the formation of carbon silicates and aluminates with soil when mixed as a stabilized mass.

Table 4: Effect of NC on the Consistency Limits of the Lateritic Soil

NC Proportion (%) by wt	0	3	6	9	12	15
LL (%)	47	48.6	49.7	50	51.2	54.3
PL (%)	25.15	28.86	33.39	34.51	37.22	40.5
PI (%)	21.85	19.74	16.31	15.49	13.98	13.8

4.2 Effect of Nanosized Clay on the Compaction of the Lateritic Soil

The results from compaction tests conducted were shown in Table 5. The result of the compaction test conducted on the stabilized Umuntu Olokoro lateritic soil with NC as admixture added in varying percentages shows that the MDD showed a slight improvement to 1.85g/cm^3 at 12% NC by weight (wt) addition from 1.84g/cm^3 recorded at 0% by weight addition of NC. This value dropped at 15% by weight addition of NC to 1.70g/cm^3. The OMC recorded higher values from the control value of 13% as shown in Table 5. This behavior is due to the reactive surface which increased as a result of the nanosization of the additive. At 12% by weight addition of NC where MDD recorded an increase beyond the control result, there was a possibility that the formation of new compounds occurred, which led to an increase in the MDD. The decrease in MDD at 15% by weight addition of NC could be as a result of further addition and replacement of soil, which is a denser material with an additive with lower density. This behaviour may also be due to cation exchange reactions and the admixture occupying the void within the soil matrix and in addition, the flocculation and agglomeration of the clay particles due to exchange of ions (Osinubi, 2000; Osinubi, 1999; Osinubi et al, 2009). The subsequent reduction in MDD may be due to the fact that for any soil/admixture, there is always water content to produce maximum strength. The trend is in conformity with the results reported by (Osinubi, 2000). An explanation that was offered for this trend is that there was increasing desire for water, which commensurate with the higher amount of additives because more water was required for the dissociation of admixtures with Ca^{2+} and OH^- ions to supply more Ca^{2+} for the cation exchange reaction. The decrease in the OMC with increased proportions of admixture content might be due to cation exchange also that caused the flocculation of clay particles. Moreover, the NC is a highly pozzolanic material and requires water for hydration thereby improving the strength gain of the NC + Soil mixture.

Table 5: Effect of NC on the compaction of the stabilized lateritic soil

NC proportion (%)	0	3	6	9	12	15
MDD (g/cm3)	1.84	1.77	1.79	1.82	1.85	1.70
OMC (%)	13.00	13.29	13.05	13.07	14.06	14.65

4.3 Effect of Nanosized Clay on the CBR of the Lateritic Soil

The results from the CBR test conducted are as shown in Table 6. The CBR behavior with varying proportions of NC on the stabilized Umuntu Olokoro lateritic soil showed a remarkable improvement in the California bearing ratio, which improved from 14% at control experiment to 19% at 3% by weight additive. This dropped to 18% at 6% by weight additive and increased consistently from 19 % at 9% by weight additive, 25% at 12% by weight additive to 29% at 15% by weight additive which satisfies the material condition for use as a subbase material. This behavior may be attributed to the admixture's increased reactive surface area, its highly pozzolanic behavior and lower density as a result of nanosization. With these results, the strength properties of the stabilized soil have been enhanced for use in pavements designs and construction. The soil + 12% NC and soil + 15% NC mixtures passed to meet the minimum CBR value of 20 – 30% specified by (BS 1924, 1990) for materials suitable for use as base course materials when was determined at MDD and OMC. This is close to the findings of Gidigasu and Dogbey (1980), which stated that the minimum CBR value of 20 – 30% is required for sub-bases when compacted at OMC. Increase in CBR, an implication of the increase observed in MDD is attributed to the compatibility of the grains for soil by the increased reactive surface by the ash pulverization and the high pozzolanic properties of the NC such that greater densification was achieved.

Table 6: Effect of NC on the CBR of the stabilized lateritic soil

NC proportion (%)	0	3	6	9	12	15
CBR (%)	14	19	18	19	25	29

4.4 Effect of Nanosized Clay on the UCS of the Lateritic Soil

The results from UCS test conducted are shown in Table 7. The effect of increasing proportions of NC on the compressive strength of the stabilized Umuntu Olokoro lateritic soil was remarkable. At different curing times, NC addition, improved the strength progressively. The highest values were recorded at 15% by weight additive at 7 days curing time, 14 days curing time and 28 days curing time which were 315.27kN/m^2, 316.82kN/m^2 and 340.18kN/m^2 respectively. This behavior is also attributed to the pozzolanic behavior of the additive and its increased reactive surface that encouraged bonding. A further observation was that the presence of the admixture in the soil increased the frictional angle of the stabilized mixture attributed to the physicochemical and highly pozzolanic properties of the admixture and to its ability to reduce adsorbed water thereby making soils with higher clay content to behave like granular soil. These values satisfy the "very stiff" material condition for use as a sub-base material for pavement construction.

Table 7: Effect of Nanosized Clay on the UCS of stabilized lateritic soil

NC Proportion (%)	0	3	6	9	12	15
UCS 7 days kN/m^2	194.26	238.87	250.06	260.32	268.41	315.27
UCS 14 days kN/m^2	219.11	241.01	266.61	271.97	303.04	316.82
UCS 28 days kN/m^2	230.77	260.28	273.84	254.29	303.04	340.18

5. CONCLUSION

From the foregoing, we can conclude the following;

1. That the Nanosized Clay has proved to be an excellent additive to the stabilization of lateritic soil by satisfying the consistency, compaction, CBR and compressive strength properties and conditions for use as excellent sub-base material for south eastern Nigerian roads.
2. That the high cementitious property of the studied admixture, NC was a plus to its bonding and improved Geotechnical properties of the stabilized lateritic soil.
3. That the cost of construction materials which poses a great constraint to the construction and rehabilitation of our roads in a deplorable state could be saved by applying NC as an additive.
4. That the government of the southeastern states of Abia, Imo, Ebonyi, Enugu and Anambra states whose roads are dilapidated should consult the results of this work to assist them in advising their constructors, contractors, designers, engineers and professionals in the works and infrastructures ministries to ensure that the sub-grade soils explored and hauled for construction purposes are improved with the abundance clay material occurring in its natural state at Ohiya, Umuahia, Abia State, Nigeria.
5. That the nanosized clay material gotten at no cost will go long ways in solving many of the environmental problems facing Nigerian roads.

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