Compression and Expansion Characteristics of Palm Kernel Shell Stabilized Black Cotton Soil on Basement Complex of Part of South-Western Nigeria

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Abstract: *Expansive soils are one of those kinds of soils whose volume change takes place while it comes in contact with water. It expands during the rainy season due to intake of water and shrinks during dry season. The properties of the black cotton soil may be altered in many ways through mechanical, chemical and other means. Therefore, it becomes very important to investigate the physical and engineering properties associated with the black cotton soil especially as a construction material or for foundation purposes. The black cotton (expansive) soil was obtained from a borrow pit on the basement complex at Igbo-Ora in Oyo State, South-Western Nigeria. The borrow site lies within the coordinates Longitude 7°24'45" latitude 3°18'34". The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The palm kernel shell wastes were taken from palm oil producing plant (Figure 1) along Ilaro-Owode Road, Ilaro, Ogun State, Nigeria. The quantity of water which was used to obtain optimum moisture content and maximum dry density for black cotton soil (i. e. control, 0%) was determined. This water was then used to run consolidation tests. The palm kernel shells were broken into pieces passing through 5mm sieve and then substituted for black cotton soil from 0% to 30% at 10% intervals for consolidation and settlement parameters determination while 0% palm kernel shell substitution served as control experiment. In line with BS 1377 (1990), 90% consolidation tests were conducted on composite materials of black cotton soil mixed with varying degrees of palm kernel shells to determine the compression and expansion characteristics for the 24-hour soaked samples. From the results, compression behavior is linear meaning, it is directly proportional to time for all the substitutions investigated while for the first 30 seconds, there is no remarkable and noticeable reduction during expansion while removing the load. The rate and magnitude of expansion is minimal for all the substitutions investigated.*

Keywords: *Black Cotton Soil, Expansion, Compression, Consolidation, Palm Kernel Shell..*

Introduction

Black cotton soil is referred to as expansive soils; it is characterized by cracks in dry season and heavens in rainy season for this reason, its geotechnical properties are important to be investigated before allowing any construction above it. The mineralogy of this soil is dominated by the presence of montmorillonite which is characterized by large volume change from wet to dry seasons and vice versa (Rajakumar, 2014; Ola, 1983). High percentage of montomorillonite in black cotton soil renders the soil poor for civil engineering project. The shrinking of the soil results in cracks in the soil without any warning. These cracks can sometimes extent to severe limit. Use of soil that contains montomorillonite for civil engineering project may cause severe damage to the construction as a result of change in atmospheric conditions (Mittal and Shukla, 2001). Black cotton soils can be found in semi–arid and arid regions, these areas are naturally categorized by noticeable parched and rainy periods with truncated rain, deprived of drainage as well as high afternoon temperatures. In this region the climatic condition is such that the annual evaporation exceeds the precipitations. Soil stabilization either by mechanical or chemical means is the remedy for shrinkage and swelling of black cotton soil to create an improved Soil material possessing the desired engineering properties. Soils may be stabilized to increase strength and durability of the black cotton soil. Regardless of the purpose for stabilization, the desired result is the creation of a soil material or soil system that will remain in place under the design use conditions for the design life of the civil engineering project. Due to expansive characteristics of black cotton soil, it forms a very poor foundation material for road construction. Black cotton soils are found in the northern and southern parts of Nigeria, the soils are said to be inorganic clays which are expansive in nature .They are also known for their shrinkage and swelling nature, Black cotton soils have been a highly challenging material for the construction engineers due to its high swelling rate as well as its shrinkage characteristics. Although, Black cotton soils tend to be strong in its dry state, when in a wet condition, it tends to lose its strength out rightly. The low strength and excessive volume changes of black cotton soil make their use in constructions very difficult. The high volume of axle loads on our roads is currently a challenge on the design of road pavement. Important factors such as durability, strength and economic need have to be paramount in the design and construction of road pavement (Safiuddin et al. 2010; Ola, 1983). To tackle these challenges head on at a reduced cost, investigation of potential use of various solid wastes in the production of construction materials should be put on high priority to reduce the cost of construction materials. The properties of the black cotton soil may be altered in many ways through mechanical, chemical and other means. Therefore, it becomes very important to investigate the physical and engineering properties associated with the black cotton soil especially as a construction material or for foundation purposes (Vinayak Kaushaland and Guleria, 2015; Ola, 1983). This study is aimed at investigating the engineering properties of black cotton soil from basement complex at Igbo - Ora, Oyo State, South-Western Nigeria, which is stabilized with palm kernel shell with a view to study its suitability for construction materials.

Background Study

Soil stabilization is widely employed for modifying the geotechnical properties of a soil to improve the engineering properties more so increase the strength of the soil, which in turn also reduce the construction cost of civil engineering projects. Black cotton soils are very poor and undependable subgrade material (Ola, 1983). When these soils come in contact with moisture its volume increase and decreases when water is withdrawn .The black cotton soils are very hard when dry but lose its strength completely when wet .Black cotton soils have thus become a global problem that poses several challenge to civil engineering projects. The soil absorbs water heavily during rainy season which results into swelling and softening of the soil. Consequently, it loses its strength and becomes easily compressible. The soil shrinks and cracks during the dry season. However, as a result, road built on black cotton soil experience early failure particularly in pavement with heavy traffic. In many situations, soils cannot be used directly as road service layers, foundation layers and as a construction material; hence the properties of those soils should be changed. Expansive soils are one of those kinds of soils whose volume change takes place while it comes in contact with water. It expands during the rainy season due to intake of water and shrinks during dry season. The wetting and drying process of a subgrade layer composed of black cotton soil result into failure of pavements in form of settlement and cracking. Therefore, prior to construction of a road on such subgrade, it is important either to remove the existing soil and replace it with a non-expansive soil or to improve the engineering properties of the existing soil by stabilization using additives such as egg shell powder and palm kernel shells which are source locally and menace to the environment. Stabilization of the expansive soil can be of great value in improving the strength or bearing capacity of soil through controlled compaction test with suitable admixtures or stabilizers (Ola, 1983). Soil is a naturally occurring material which needs to be stabilized to increase the strength and durability and design life of civil engineering projects. Properties of soil vary according to location, physical properties and so on, Different methods are available to stabilize the soil and the method should be first analyzed in the soil laboratory using the soil material before applying it on the field conditions. Chen (1975) concluded that expansive soils or Black Cotton Soils are normally found in semi –arid regions of tropical and temperate climate zones and further highlighted that such soil exist in abundant in those areas, where the annual evaporation exceeds the precipitation. It was further stressed that sticky plastic nature of black cotton soils particles causes them to pack up under wheels, animal’s feet and clog cultivation implements. They make the soil extremely difficult to extract or dislodge. The cracks measuring 70 mm wide and over 1 m deep were observed. The study has shown that these cracks can extend up to 3m or more in case of high deposits. Seehra (2008) also highlighted in his study that high swelling and shrinkage characteristics of the Black cotton soils are a challenge to the highway engineers.

Road infrastructure in India, according to Rajakiumar (2014), is developing at a very fast rate and a good pavement provides safe, comfortable and economical movement of traffic. The road thickness depends on various geotechnical properties of subgrade soil and traffic intensity. The pavement construction is becoming costlier because of very high cost of construction materials and transportation cost of such materials from long distances. The growing concern over environmental degradation due to borrowing of large quantity of soil and aggregates for construction of pavement has made the search for new techniques of stabilization. The subgrade soil should have high maximum dry density (MDD) and low optimum moisture content (OMC) so that it can take up the load of the overlying layers and the traffic. The high MDD and corresponding OMC can be achieved by stabilizing the soil using suitable stabilizer. The effect of using Nano Polymer called SoilTech MK III as a stabilizer to improve the properties of Black Cotton soil collected from Ranibennur region, Karnataka, India were determined. The laboratory experiments were conducted on the samples of soils with stabilizer for Compaction test, UCS (Unconfined Compression Strength) and CBR (California Bearing Ratio) tests. Various samples were prepared by taking soil with different percentage of SoilTech MK III Polymer (0.2%, 0.4%, 0.6%, 0.8% and 1.0%). Soil is an integral part of the road pavement structure as it provides the support to the pavement from beneath. If the stability of the soil is not adequate for supporting the wheel loads, the properties of soil should be improved by soil stabilization technique. Soil stabilization is the alteration of one or more soil properties by mechanical or chemical means to create an improved strength of existing soil. In situation where industrialization and urbanization is taking place and this has generated many wastes. This leads to depleting landfill space, soil contamination and many other hazardous effects, hence in this study utilization of waste (i.e. palm kernel shell) for improving the soil properties is made.

Palm kernel shells (PKS) are derived from the oil palm tree (elaeisguineensis), an economically valuable tree, which is native to western Africa and widespread throughout the tropics according to Omange (2001). These trees are used in commercial agriculture in the production of palm oil. The African oil palm is native to West Africa, occurring between Gambia and Angola. The basic name is derived from the Greek word for oil, elaion, while the species name has referred to its country of origin (Sulyman and Junaid, 1990; Ola, 1983). In Nigeria, about 1.5 million tons of PKS are produced annually; most of which are often dumped as waste products according to Nuhu-Koko (1990). The waste could be converted to wealth by using it as a stabilizer in black cotton soil due to the peculiar problems of swelling and shrinkage of the soil. Since few years ago, the use of local materials in the construction industry has been campaigned by the various governments to limit costs of construction. There have been several calls for the sourcing and development of alternative to lime for stabilization, agro-based and, non-conventional local construction materials in view to harness the maximum potential of agricultural waste in agricultural sector. Ola (1983) has done a lot of work on black cotton soil of North Eastern Nigeria, cement, lime etc were used to stabilize the expansive. Little work has been done on black cotton soil of South Western Nigeria which is the focus of this study. This is with a view to determining the consolidation parameters and settlement indices of stabilized black cotton (expansive) soils on the basement complex and sedimentary formation of part of South Western Nigeria.

Methodology

The black cotton (expansive) soil (Figure 1a) was obtained from a borrow pit on the basement complex at Igbo-Ora in Oyo State, South-Western Nigeria. The borrow site lies within the coordinates Longitude 7^{o}24'45" latitude 3^{o}18'34". The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The palm kernel shell wastes (Figures 1 b, c. and d) were taken from palm oil producing plant along Ilaro-Owode Road, Ilaro, Ogun State, Nigeria. The quantity of water which was used to obtain optimum moisture content and maximum dry density for black cotton soil (i. e. control, 0%) was determined. This water was then used to run consolidation tests. The palm kernel shells (Figure 1 d) were broken into pieces passing through 5mm sieve and then substituted for black cotton soil from 0% to 30% at 10% intervals for consolidation and settlement parameters determination while 0% palm kernel shell substitution served as control experiment. In line with BS 1377 (1990) and other relevant codes of practice, 90% consolidation tests were conducted on composite materials of black cotton soil mixed with varying degrees of palm kernel shells to determine the compression and expansion characteristics for the 24-hour soaked samples (Armand et al. (2021); Maail, et al. (2004); Ola, (1983); Head and Epps (2011); Omotoso et al. (2012); Head (2006); Indrawan et al. (2006); Hincke et al. (2012); Croft et al. (1999); Amu and Salami (2010); Amu et al. (2005); Gopal and Rao (2000); Craig (1987); Modi (2010) Fattah, Y.M. (2012); Leonards and Girault (1961); Sivakugan (1990); Skempton (1944); Terzaghi and Peck (1967); Wallace and Otto (1964); Wroth and Wood (1978)).

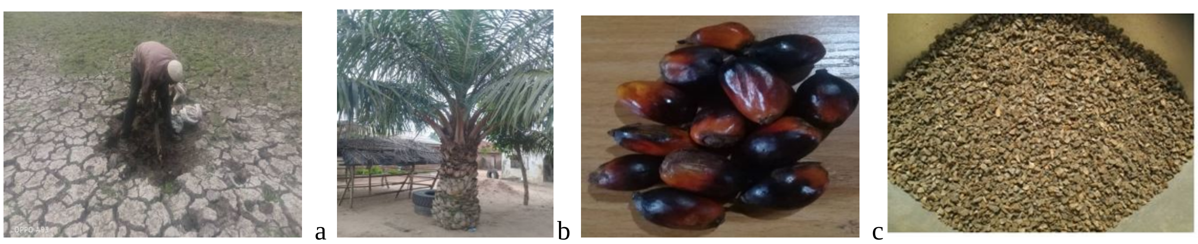
a b c d

Figure 1: (a) Black Cotton (Expansive) Soil (b) Palm Tree (c) Palm Fruits (d) Palm Kernel Shell

Results and Discussion

The results of dial gauge readings (for maximum pressure of 313.92 kN/m^2) against time (minutes) for various palm kernel shell substitutions in black cotton soils ranging from 0% (control experiment) to 30% substitutions are graphically presented in Figures 2 to 9 respectively. From the preliminary results (Figures 2 to 9), compression behavior is linear meaning, it is directly proportional to time for all the substitutions investigated while for the first 30 seconds, there is no remarkable and noticeable reduction during expansion while removing the pressure load. The rate and magnitude of expansion is minimal for all the substitutions investigated.

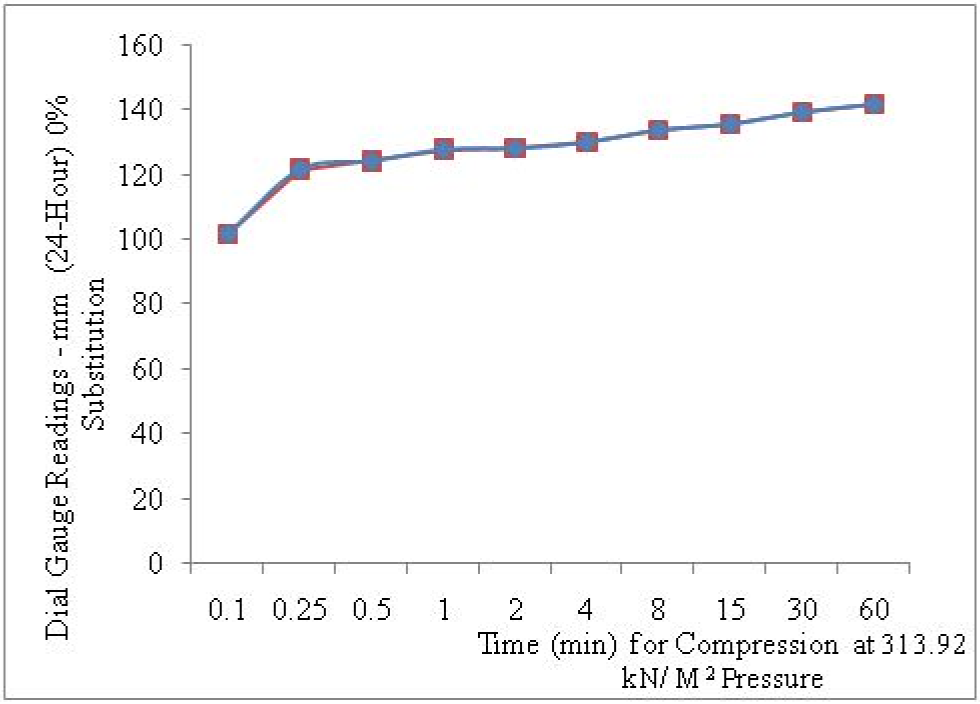

Figure 2: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (0% palm kernel shell substitution - compression)

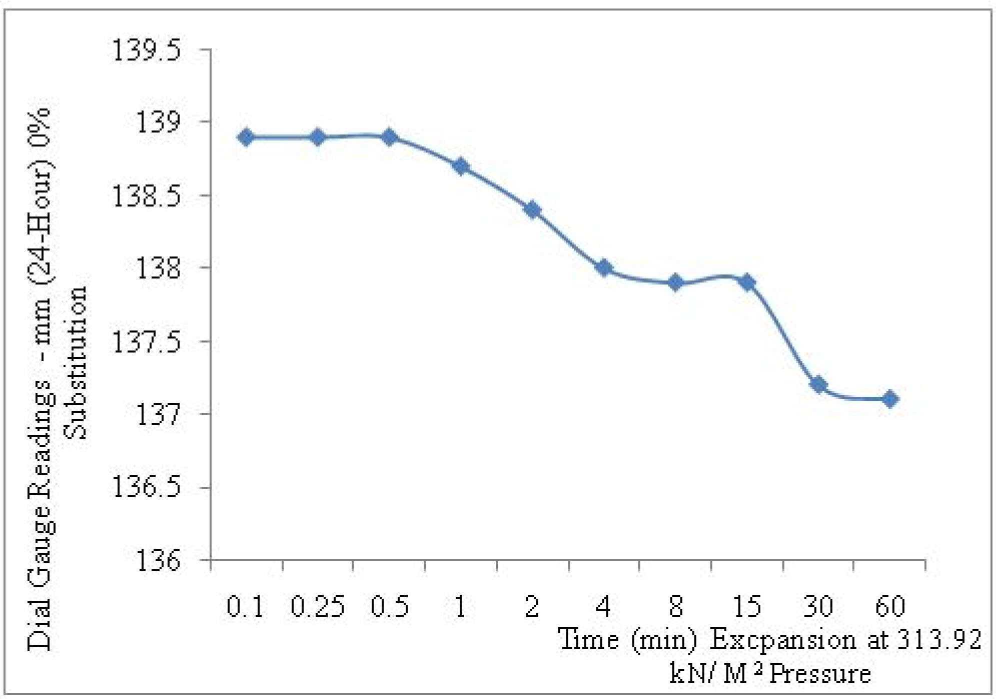

Figure 3: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (0% palm kernel shell substitution - expansion)

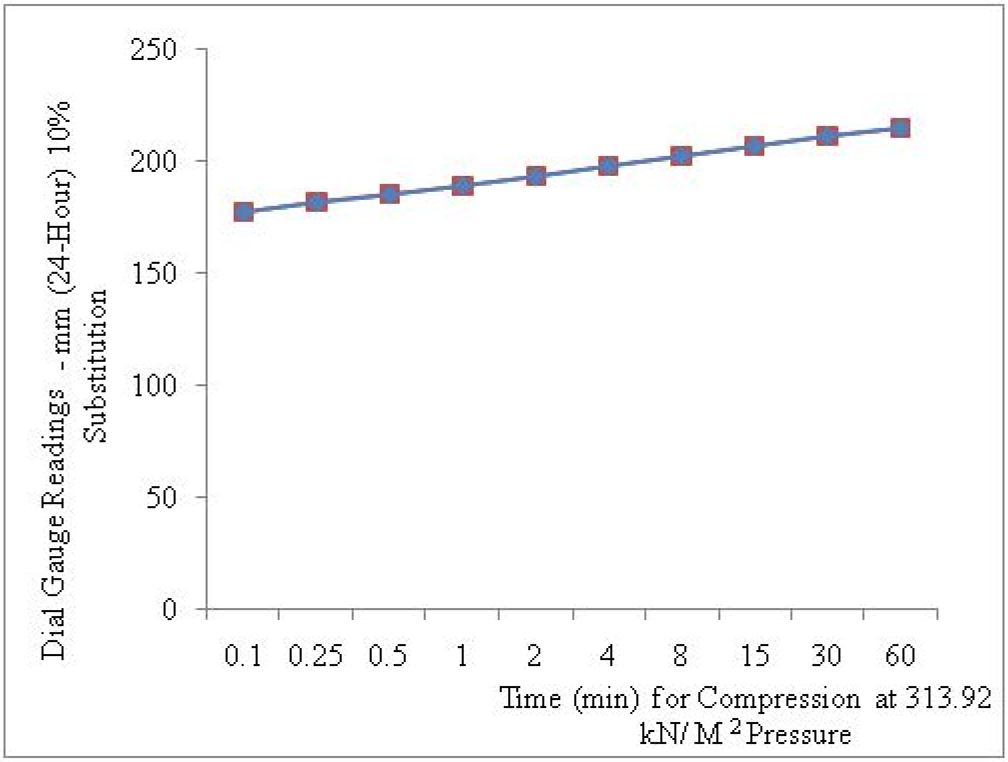

Figure 4: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (10% palm kernel shell substitution - compression)

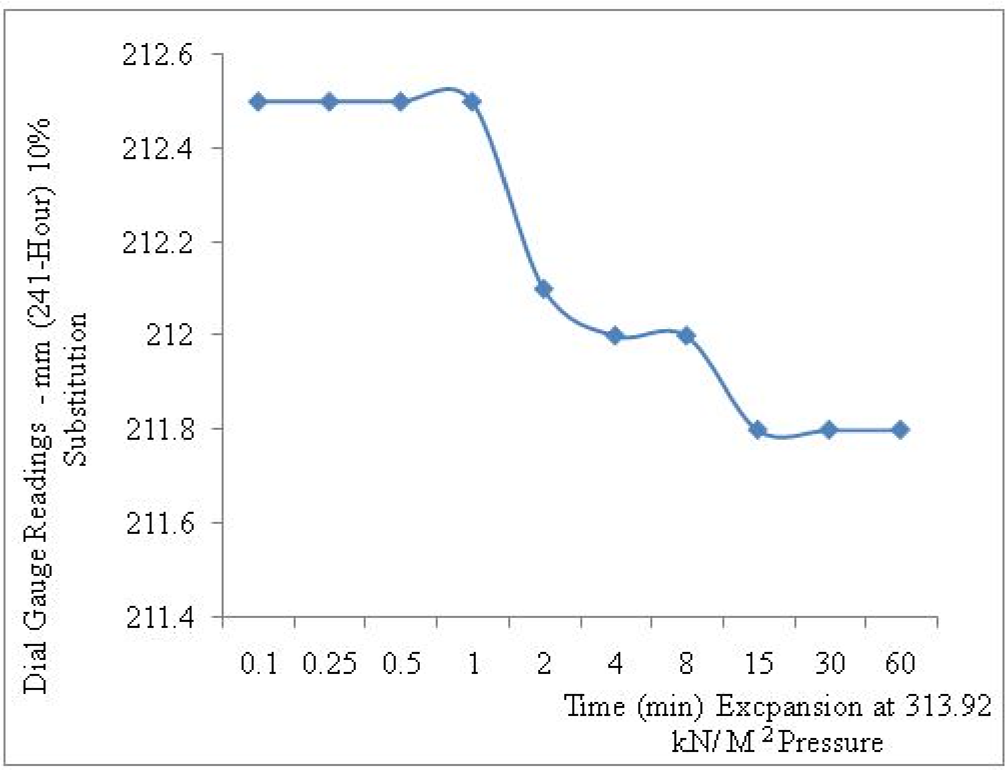

Figure 5: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (10% palm kernel shell substitution - expansion)

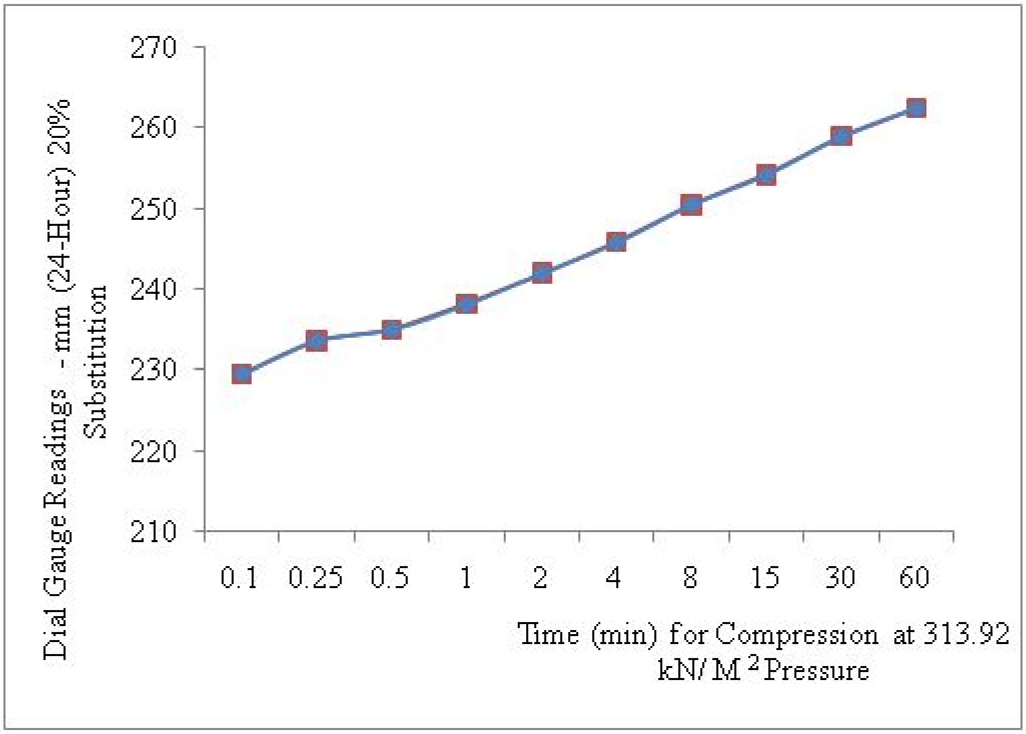

Figure 6: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (20% palm kernel shell substitution - compression)

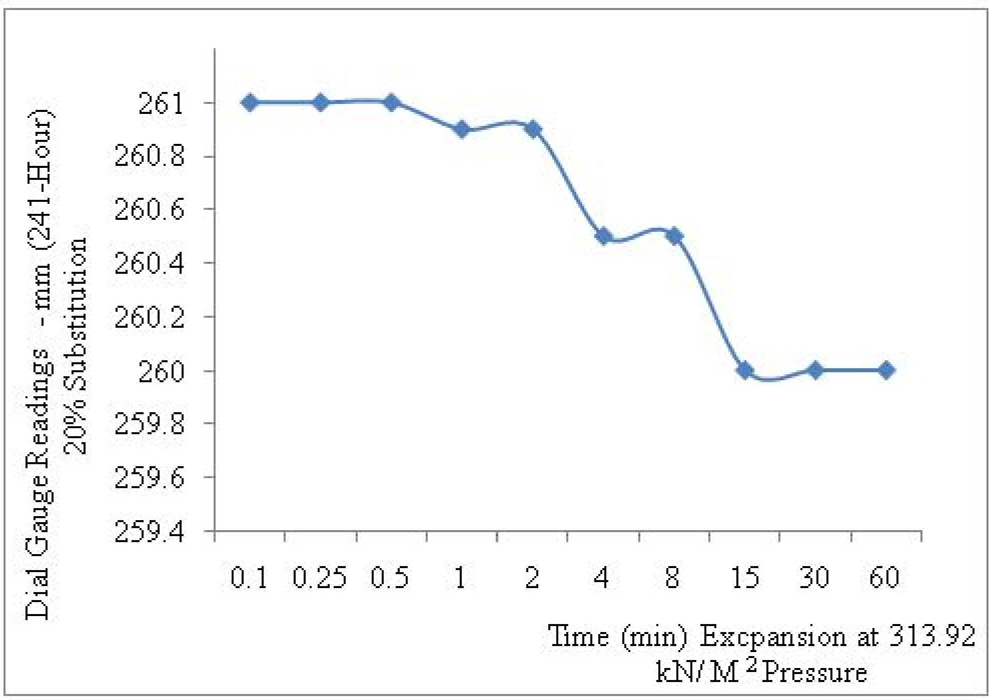

Figure 7: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (20% palm kernel shell substitution - expansion)

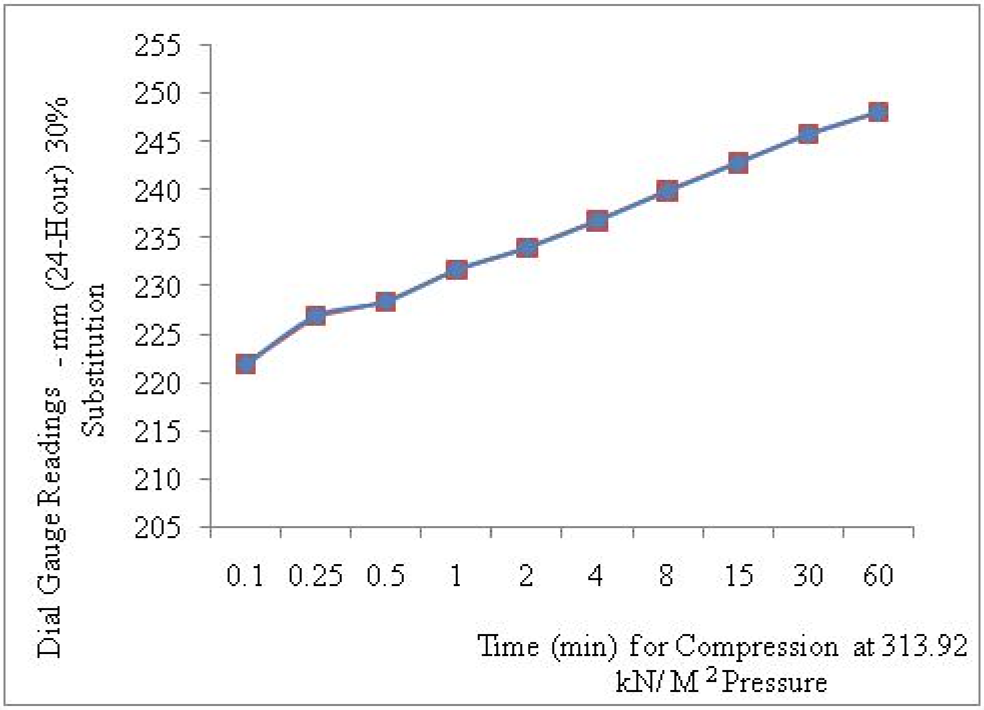

Figure 8: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (30% palm kernel shell substitution - compression)

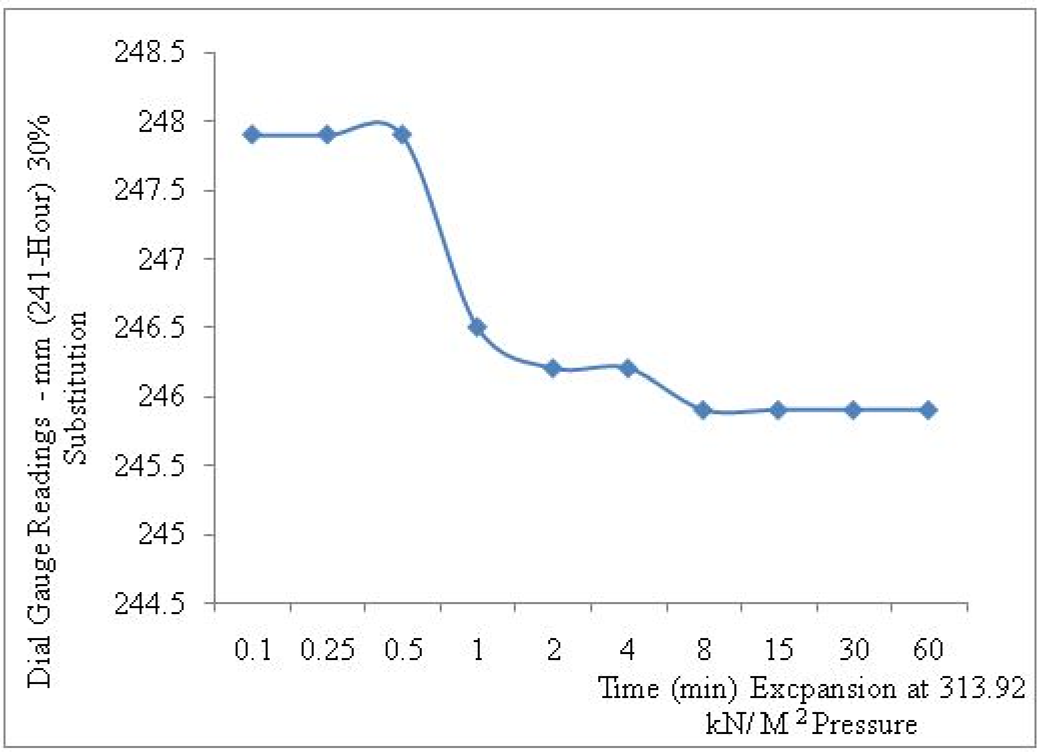

Figure 9: Results of dial gauge reading (mm) against time (min) for 24-hour soaked samples (30% palm kernel shell substitution - expansion)

Volumetric changes, swelling and shrinkage, of expansive soils in the presence and absence of water are undesirable from stability reasons. The consequence of swelling and shrinkage leads to an increase and decrease in volume till suction pressure comes to equilibrium as determined by the environment. The amount of swelling and shrinkage to satisfy the suction pressure depends on the magnitude of the vertical loading and soil properties that include soil composition, natural water content and density, as well as soil structure. The rate of swelling and shrinkage depends on the coefficient of permeability (hydraulic conductivity), thickness, and soil properties. If a structure is founded on such expansive soils, then its presence along with the foundation prevents this volume increase (swelling) and decrease (shrinkage) as a consequence, leads to swelling and shrinkage pressure. This swelling and shrinkage pressure has serious consequences in the form of cracks and distress on the structures founded on such expansive soils. Lightweight structures are severely affected due to high swelling and shrinkage pressure exerted by the black cotton soil. The preliminary results of compression and expansion of the black cotton soil of Igbo-Ora in South Western Nigeria is extensively discussed below. Figure 2 shows a linear graph for the compression of 24 hours soaked samples for pressure of 313.92KN/m³ at 0% palm kernel shell substitution. Where there is 40mm change in the dial gauge reading for time duration of 60 minutes. Figure 3 shows a constant dial gauge reading for a short duration of 0.5 minute for the case of expansion of 24 hours soaked samples for the same pressure load of 313.92KN/m³ at 0% palm kernel shell substitution (control experiment) where there is 1.6mm change in the dial gauge reading for the time duration of 60 minutes. In addition to this, Figure 4 shows a linear graph for the compression of 24 hours soaked samples for the same pressure load of 313.92KN/m³ at 10% palm kernel shell substitution, where there is 25mm change in the dial gauge reading for time duration of 60 minutes. Furthermore, Figure 5 shows a constant dial gauge reading for a short duration of 0.5 minute for the expansion of 24 hours soaked samples for the same pressure load of 313.92KN/m³ at 10% palm kernel shell substitution. In this case, there is 0.7mm change in the dial gauge reading for time duration of 60 minutes. In the case of Figure 6 which shows a linear graph for the compression of 24 hours soaked samples for pressure load of 313.92KN/m³ at 20% palm kernel shell substitution. In this case, there is 32mm change in the dial gauge reading for time duration of 60 minutes. In addition to this, Figure 7 shows a constant dial gauge reading for a short duration of 0.5 minute for expansion of 24 hours soaked samples for pressure of 313.92KN/m³ at 20% palm kernel shell substitution, where there is 1.0mm change in the dial gauge reading for time duration of 60 minutes. Figure 8 shows a similar trend, which is a linear graph for the compression of 24 hours soaked samples for pressure load of 313.92KN/m³ at 30% palm kernel shell substitution. There is 25mm change in the dial gauge reading for time duration of 60 minutes. Finally Figure 9 shows a constant dial gauge reading for a short duration of 0.5 minute for expansion of 24 hours soaked samples for pressure of 313.92KN/m³ at 30% palm kernel shell substitution and there is 0.5mm change in the dial gauge reading for time duration of 60 minutes. The preliminary results figures shows much resistance against volume decrease when the expansive soil stabilized with palm kernel shell is subjected to a mechanical load and for this reason, the palm kernel shell can be recommend as a good stabilizer for black cotton soil. The difference in the dial gauge readings for compression and expansion for 60minutes in the each of the preliminary results in Figures are hereby summarized; Figure 2 is 40mm; Figure 3 is 1 mm; Figure 4 is 37.5 mm; Figure 5 is 0.7 mm; Figure 6 is 33 mm; Figure 7 is 1 mm; Figure 8 is 26.2 mm and finally Figure 9 is 2 mm (Ola, 1983).

Conclusion

Compression and expansion characteristics and behavior of stabilized black cotton soil on basement complex has been investigated. From the preliminary results, compression behavior is directly proportional to time for all the substitutions investigated while for the first 30 seconds, there is no remarkable and noticeable reduction during expansion while removing the load. The rate and magnitude of expansion is minimal for all the substitutions investigated. Efforts are still on-going to determine the relevant consolidation parameters and settlement indices of stabilized black cotton soil on basemen complex as well as sedimentary formation. The materials used for stabilization of these black cotton soils are palm kernel shell and eggshell powder.

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