Strength Development in Lateritic Soil Stabilised with Coconut Shell Ash for Highway Pavement Construction

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Abstract
Lateritic soil has found wide usage in highway pavement construction in the tropics, however, there are instances that they are unsuitable because of their properties, hence the need for improvement through stabilisation. This research focussed on the utilisation of coconut shell ash for stabilising of lateritic soil for highway pavement construction. The lateritic soil was treated with 3 to 12% coconut shell ash (CSA) to assess its effect as a soil stabilising admixture on the geotechnical properties of the lateritic soil while the soil with 0% CSA is the control. The percentage passing sieve no. 200, liquid limit and plasticity index reduced with increase in the CSA content, this indicates that the susceptibility of the soil for water has been reduced. However, the maximum dry densities of the treated soil increased with increasing content of CSA but the strength index, California bearing ratio (CBR) decreased. Coconut shell ash though is a good pozzolan cannot therefore be used as a stand-alone stabilizer for treating lateritic soil however, the stabilized soil could be used as a subgrade foundation material in road pavement construction.
Keywords: Coconut shell ash, Lateritic soil, Stabilization, Highway Pavement, Compaction, California bearing ratio

1. Introduction

Lateritic soil is tropical soil and it is rich in oxide of iron and aluminium with silica as primary base. It has found its use as foundation material in the construction of road and the production of bricks. This might result from its availability as a common naturally-occurring material, high cost of procuring good crushed stone and high cost of construction (Amu et al., 2011). However, it may be deficient in morphological properties thereby limiting its suitability as construction material, such soil is termed problematic soil because they have low strength, high compressibility and settlement (Ho and Chan, 2011; Huat, 2006; Kazemian et al., 2011; Yohanna et al., 2015). The variation in the morphological properties of engineering soil which also influences the geotechnical properties of soils is determined by the content of sesquioxides, level of weathering, extent of desiccation in the soil, fine content, clay mineralogy and clay-size content. This makes the definition of engineering soil based on the ratios of silica (SiO_2) content to sesquioxides (Fe_2O_3 + Al_2O_3) content to be more acceptable. The ratios are less than 1.33 for laterites, between 1.33 and 2.0 for lateritic soils and greater than 2.0 for non-lateritic soils (Bell, 1994).

Improvement of the mechanical properties of the soil by admixing it with either conventional or non-conventional binding medium either before or during construction process has been recognised to have long term beneficial effect on the durability and serviceability of soil construction material. This process known as soil stabilization is based on the pozzolanic activities of the soil and admixture used, chemical state of the soil moisture content (pH level) and strict adherence to the construction procedure for maximum benefit. It is noteworthy that soil stabilization can save millions in contrast to cutting and replacing the unstable material (Amu et al., 2010).

Cement and lime are the major conventional admixtures used right from ancient periods in construction industry (Ola, 1983; Balogun, 1991; Matawal and Tomarin, 1996). Cement is a substance which sets and hardens independently, and therefore is considered as primary stabilizing agent or hydraulic binder due to the fact that it can be used alone to bring about the stabilizing action required (Sherwood, 1993). The most important use of cement is the production of mortar and concrete resistant to normal environmental effects (Nagarajan et al., 2014) and in the stabilization of weak lateritic soil for road construction using its binding properties. However, the excessive cost of production of cement and adverse environmental consequences association with its production coupled with its corrosive action when working with it in the field has made sourcing for alternatives imperative. This has made researchers (Mohammedbhai and Baguant, 1990; Osinubi, 1998a, b; Osinubi and Medubi, 1997; Medjo and Riskowiski, 2004; Osinubi et al., 2009; 2011; Oluremi et al., 2012; 2016) to focus on the use of industrial and agricultural by-products with pozzonalic potential counted as waste but of economic importance as stabilizing agents. One of these agricultural residues is coconut shell produced as a residue during the production of coconut.

The coconut palm (Cocos nucifera L.) is an important and useful palm in the world (Uwubanmwen et al., 2011). It belongs to the palm family known as Arecaceae and it is the accepted species of the genus Cocos (Hahn, 1997;

Amu et al., 2011). In Nigeria they are mostly cultivated in the coastal regions of the country however, More than 90% of the nation's coconut belt is a continuation of the plantations or groves along the West African coast running from Cote d'Ivoire and southeast towards Ghana, Togo and Benin to Lagos state in Nigeria The landed area for the cultivation of coconut globally was estimated at approximately 12.28 million hectares in 2013 with global coconut production of approximately 64.3 billion nuts (Arancon, 2013) as shown in Table 1. In Nigeria, an estimated 36,000ha is presently under cultivation mostly in Lagos and Rivers states and an estimated 1.2 million hectare of land is suitable for coconut cultivation (NIFOR, 2008; Uwubanmwen et al., 2011).

Coconut is a versatile produce with multiple uses. Virtually all the part of coconut as shown Figure 1 is useful; the copra (nut) is an edible part of the coconut fruit which can be used for production of oil as well. The husk and the shell are sources of energy if pyrolysed at suitable temperature but they are hardly used for this purpose. As a result, coconut shells have little or no economic value and their disposal is not only costly but may also cause environmental problems. It has been estimated about 65 to 75% of its contents are volatile matter and moisture which are removed during the carbonization process to ash (Nagarajan et al., 2014). When properly dried, it contains cellulose, lignin, pentosans and ash in varying percentage (Amu, et al., 2011). Its excellent natural structure makes it a suitable material for the production of carbon black and ash (Nagarajan et al.,2014) and this had been investigated by different researchers using different agricultural by-products such as coconut shell, apricot stones, sugar-cane bagasse, nutshells, forest residues and tobacco stems (Rahul, 2012).

Therefore, replacement of the Portland cement with coconut shell ash in soil stabilization will help alleviating its environmental pollution impact on the environment (Oluremi et al., 2012) and if found useful will serve as modifier for improving mechanical properties of lateritic soil of which its strength, stability and durability cannot be guaranteed under load especially in the presence of moisture.

Table 1. Coconut Area (1000Ha) and Coconut Production in Whole Nuts (1000 Nuts) by APCC Member Countries in 2012.

Country	Area ('000 Ha)	Whole Nuts ('000 nuts)
Federal State of Micronesia	17	40,000
Fiji	60	165,000
India	1890	16,943,000
Indonesia	3810	15,429,000
Kiribati	29	131,300
Malaysia	109	577,000
Mashal island	8	34,000
Papua new guinea	221	1,101,000
Philipines	3562	15,248,000
Samoa	99	20,000
Solomon island	38	100,000
Sri lanka	395	1,833,000
Thailand	216	845,000
Tonga	8	44,400
Vanuatu	96	307,700
Vietnam	155	940,000
kenya	205	169,599
Jamaica	51	96,000

Source: Hahn, 1997

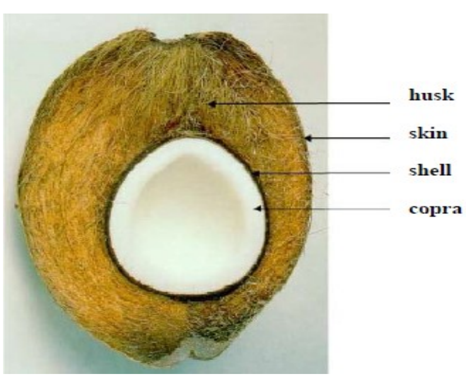

Figure 1. Typical cross-sectional appearance of Coconut

2. Materials and Methods

2.1 *Material Preparation*
Major materials used for this work include lateritic soil, coconut shell and water.
Lateritic Soil
Lateritic soil was collected from a used borrow pit at Aroje in Ogbomoso North Local Government Area, Ogbomoso, Oyo State, Nigeria. It was collected at depths not less than the 1.2 m below the natural ground level and the natural moisture content was determined. The sample was preserved in polythene bag and marked to indicate the soil description, sampling depth and date of sampling. The soil sample was later air dried to allow partial exclusion of natural water which may affect analysis, pulverized to remove the lump and then sieved with BS sieve No. 4 (4.76 mm mesh wire) to obtain the prescribed soil samples for the laboratory geotechnical tests.
Coconut Shell Ash
The coconut shell was collected from Badagry in Lagos state. The coconut shell was sun-dried to minimize the moisture content which could affect easy combustion of the material and the nature of ash formed. It was heaped up in bulk on galvanized iron sheet and burnt openly at a temperature between 650 – 750 ^{O}C so as to ensure good ash formation. The ash formed was sieved through BS sieve No 200 (75µm) and preserved in air and water-tight container to prevent pre-hydration of the ash. Oxide composition of the CSA as determined with the use of X-Ray Fluorescence Analyzer is given in Table 2. The content of pozzolanic oxides in the ash is 82.31% which is not comparable to Amu et al., 2011 in which content of pozzolanic oxides was 6.03%. The ratio of silica (SiO_2) to sesquioxides (Fe_2O_3 + Al_2O_3) is 1.43 which shows that the ash in its content is compatible with the lateritic soil which normally has ratio between 1.3 and 2.

2.2 Method
Laboratory geotechnical tests which include particle size distribution, plastic limit, liquid limit, California bearing ratio and unconfined compressive strength were carried out on the soil specimens formed by admixing CSA with lateritic soil in the proportion of 0, 3, 6, 9 and 12% by mass of the lateritic soil sample to characterized both the natural and the treated samples according to BS 1377 and BS 1924 both of 1990.

2.2.1 Sieve Analysis
Particle size distribution of the sample was determined using sieve analysis carried out on 200g of both natural and CSA admixed soil sample. The sample was sieved through nested sieves of size 4 mm to 75 µm. The percentage mass retained was determined for each and the percentage of sample passing each was determined from the data obtained. This was used to plot the graph of particle size distribution of the samples as shown in Figure 2.

2.2.2 Atterberg limit
200g of the CSA admixed soil sample sieve through sieve 425µm was taken and mixed with distilled water until a thick paste is formed. A portion from the previously mixed was taken and placed into the cup of the liquid limit apparatus at the point where the cup rest on the base and it was parted into approximately two equal parts using grooving tool. The crank lever of the apparatus was then turned and the number of blow which closes the groove was noted. The moisture content of the soil sample at the closed point was determined and this was repeated for varying moisture content. The liquid limit was determined from the graph of the moisture content against the number of blow plotted on a semi-logarithm scale.
For plastic limit, 150g of soil sample admixed with varying percentages of CSA was mixed with water until a paste of good consistency was formed. The paste was formed into a lump which was rolled between fingers and the palm on a glass plate until it formed a ribbon of about 3 mm diameter or broke. The process was repeated until the ribbon broke and the moisture content of the broken soil ribbons was determined as the plastic limit of the sample. Plasticity index was calculated as the numerical difference between the liquid limit and the plastic limit.

2.2.3 Compaction
Two major compactive efforts were used namely; British Standard light (BSL) and the West African Standard (WAS). For BSL, 3000g of lateritic soil admixed with 0 – 12% of CSA in step concentration of 3% was mixed thoroughly with 5% water relative to its natural moisture content and compacted in 3 layers inside 1000 cm^3 using 27 blows of 2.5kg rammer dropped at a height of 300 mm per layer. For WAS, compacted in 5 layers inside 1000 cm^3 using 10 blows of 4.5 kg rammer dropped at a height of 450 mm per layer. This process was repeated with increase in the mixing water content at the same rate for subsequent three trials to determine the maximum dry density and the corresponding optimum moisture content of the mix concerned.

2.2.4 California Bearing Ratio

6000g of samples admixed with various stipulated percentages of CSA was mixed with water based on the optimum water content of each mix and compacted in a CBR mould for BSL and WAS respectively. For BSL, the sample was compacted using 63 blows of 2.5kg rammer while 27 blows of 4.5 kg rammer was used for WAS. The compacted sample was thereafter tested in a loaded frame of CBR machine and the penetration of loading was recorded at interval of 0.5, 1.0, 2.0, 2.5, 3.5, 5.0 and 6.5mm after soaking according to Nigerian General Specification Road and Bridges (1997).

3. Results and Discussion

3.1 Natural Moisture Content and Specific Gravity

The average natural water content of the lateritic soil sample as determined from the laboratory was 11.38%. The average specific gravity of the lateritic soil was 2.54. These two parameters are used in expressing the phase relationships of air, water and solids in the given volume of soil.

3.2 Grain Size Analysis

The distribution at different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution and it is required in classifying the soil.

The particle size distribution curves of the natural and stabilised lateritic soils are presented in Figure 2. Generally, there were reductions in the fine content of the soil with increasing coconut shell ash content. The reduction of clay contents in the soil from 0 % to 3 % CSA was significant and worth noting. The general reduction in clay size fraction and increase in silt size content may be due to the pozzolanic reaction between the coconut shell ash and the clay fraction of the soil. However, the results did not satisfy the specified limit of 35% or less for road construction according to Road and Bridges Specification (Revised edition) of Federal Ministry of Works and Transport, Nigeria (1997).

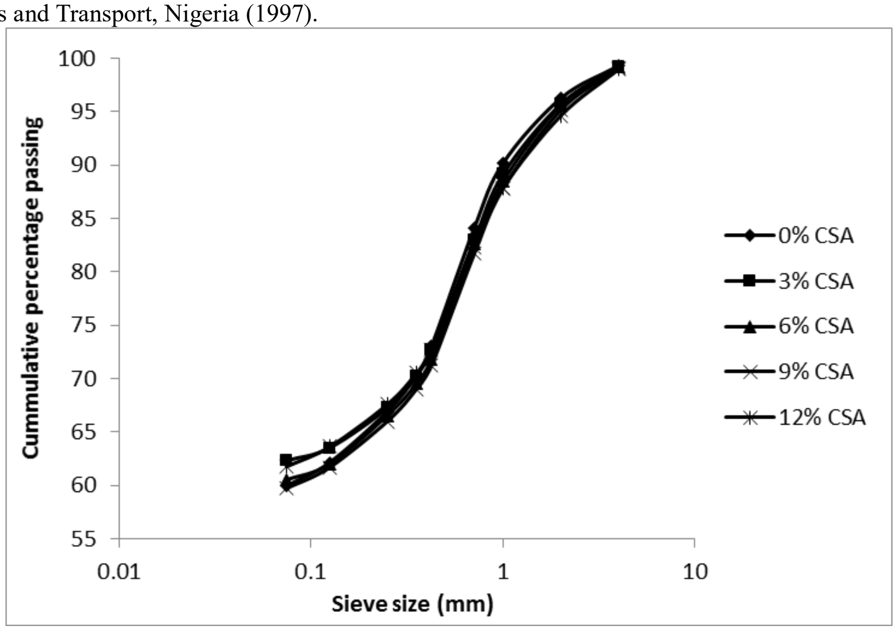

Figure 2 Particle size distribution of coconut shell ash stabilized lateritic soil

3.3 Atterberg limit

Figure 3 shows the relation between the atterberg limit with CSA content. There was reduction in the liquid limit, plastic limit with corresponding reduction in plasticity index as coconut shell ash content increased. The liquid limit, plastic limit and plasticity index ranged from 50.2 to 28%, 43.8 to 24% and 6.5 to 4%, respectively. All the sample are of intermediate plasticity (Whitlow, 1995) and the lower consistency limits of all treated lateritic soil substantiate that mineral transformation takes place during process which mainly occurs in sesquioxides (Azam et al., 2005).

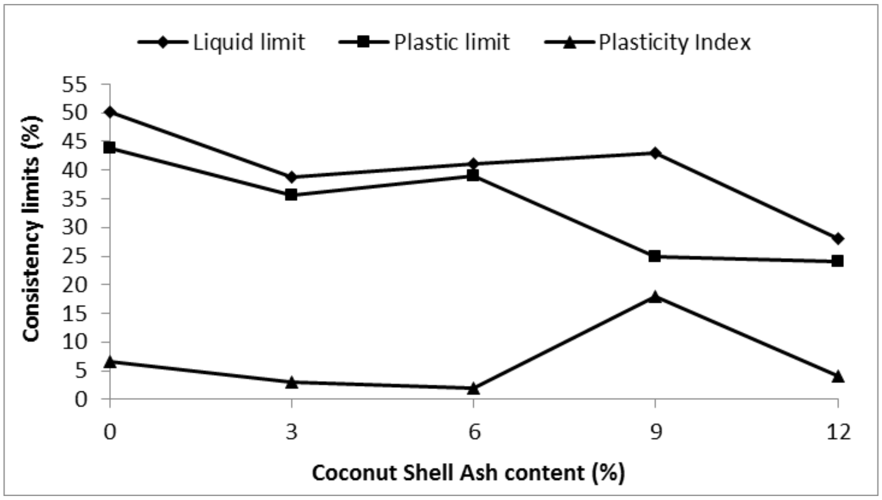

Figure 3 Variation of atterberg limits with coconut shell ash content

Nigerian Federal Ministry of Works and Transport (1997) specification for road works recommended liquid limits of 30% maximum and plasticity index of 12% maximum for sub-base and base materials. The soil did not satisfy these conditions; however, it could be used as a fill material for subgrade course formation. This indicates that coconut shell ash is unfit for improving soils with high liquid limit.

3.4 Compaction

The maximum dry densities (MDD) of the stabilized lateritic soil increased while the optimum moisture content (OMC) decreased with increasing CSA content for the two compactive efforts used as shown in Figure 4. The increase in MDD might result from agglomeration of the fine soil particles to form pseudo-size material of increased specific gravity which made the system to require less moisture content for the completion of hydration process of the lateritic soil-CSA system.

It is found that MDD increased with decreasing content. The maximum density of 1.52 Mg/m^3 and 1.54 Mg/m^3 was recorded at 0% CSA whereas the minimum of 1.63 Mg/m^3 and 1.7 Mg/m^3 was recorded for 12% coconut shell ash for the BSL and WAS compactive effort respectively. Although compaction characteristic of the both the natural and the CSA treated soil as reflected in the increased MDD and decreased in OMC showed improvement in the lateritic soil behaviour, this could not be used as final judgement of the improved strength characteristics.

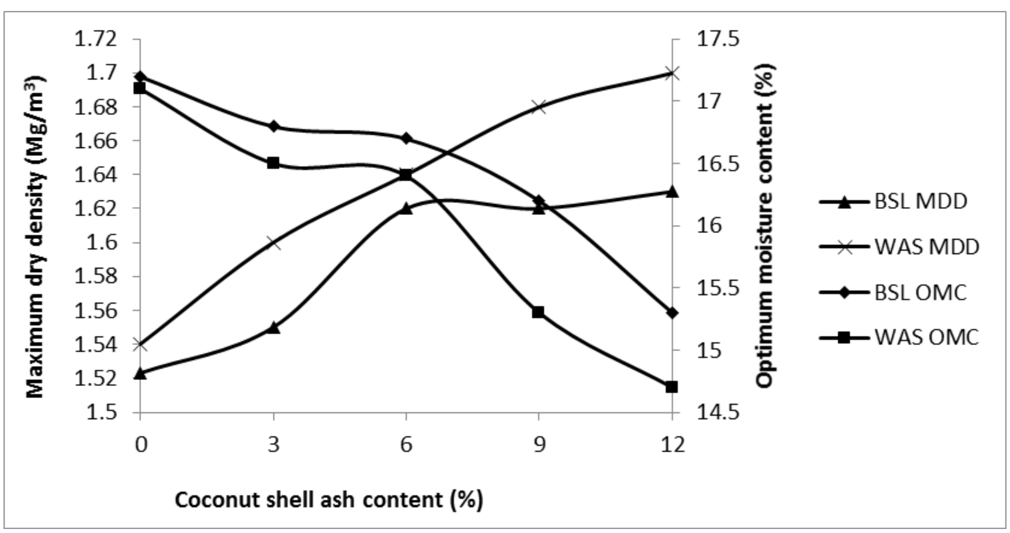

Figure 4 Compaction characteristics of the stabilised soils

3.5 California Bearing Ratio

Generally, CBR decreased with increase in CSA content for the two compactive efforts, BSL and WAS used under unsoaked and soaked condition. From the result it was observed that the WAS unsoaked has an average value 42.15 at 0% and 25.61 at 12% than the BSL unsoaked which has an average value of 22.16 at 0% and 13.29 at 12%. This occurred has a result of the difference in rammer used and the level of compaction; likewise, for the soaked, the WAS has average value of 12.36% and 6.18% at 12% CSA while BSL has an average value of 11.29 at 0% and 3.14 at 12% CSA. Gidigasu and Dogbey (1980) proposed a minimum CBR value of 60-80% required for base course and 20-30% for subbase course of flexible pavement both when compacted at optimum moisture content and 100% West African standard. Based on this, the CSA modified soil could not be used for either of the courses; it could only be used as subgrade course in its natural state.

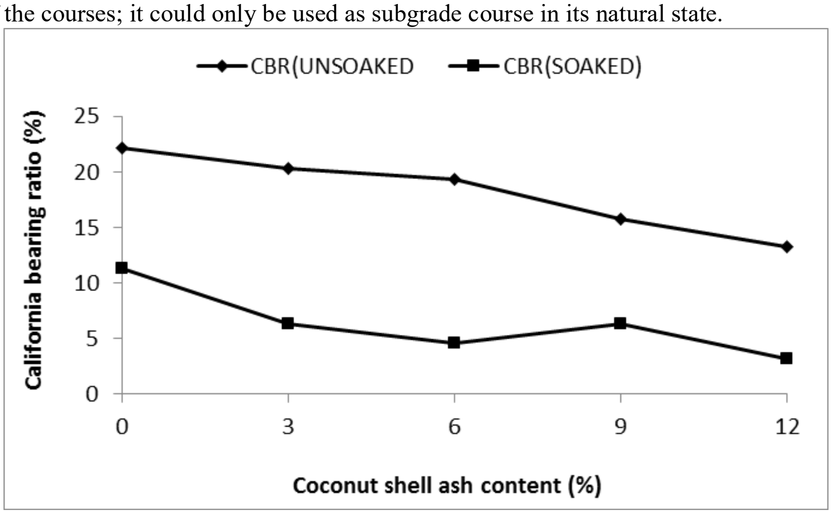

Figure 5a Variation of California bearimg ratio (BSL) with coconut shell ash content

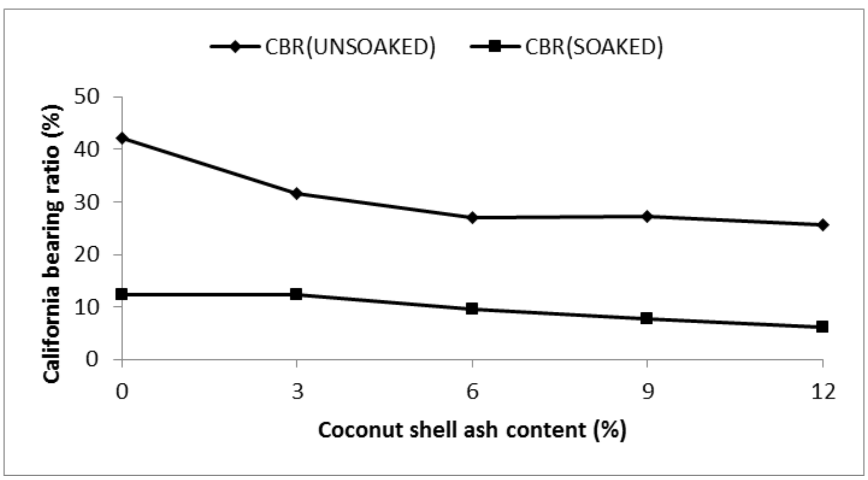

Figure 5b Variation of California bearing ratio (WAS) with coconut shell ash content

4. Conclusion

The effect of coconut shell ash has been evaluated on the geotechnical properties of the lateritic soil and the following are conclusion:

i. Addition of CSA improved the classification characteristics of the lateritic soil under investigation. There was significant reduction in the fines contents of the soils which resulted in the reduction of clay and silt size content. Also, there was a general reduction in the plasticity characteristics of the soils resulting in transition from inorganic clay material of intermediate plasticity for the natural soils to inorganic soil material of low plasticity. However, the improvement did not satisfy its use as subbase course material in road construction.

ii. Although there was improvement in the compaction characteristic of the stabilized soil, this failed to be replicated in the strength index that is CBR, of the stabilized lateritic soil. The CBR of the stabilized soil decreased with increase in the CSA content. Therefore, coconut shell ash cannot effectively stabilize lateritic soil under consideration as a stand-alone admixture though it is a good pozzolan.

iii. Hence, CSA cannot be used as a stand-alone stabilizer for the improvement of the geotechnical properties of lateritic soil. It should be considered in combination with other conventional stabilizers such as cement or lime.

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