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ORIGINAL RESEARCH ARTICLE

STABILIZATION OF LATERITE SOIL WITH EGGSHELL POWDER AND SODIUM SILICATE USED AS FILL MATERIAL IN ROAD CONSTRUCTION

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ABSTRACT

The investigation carried out in this paper was to evaluate the effect of eggshell powder and sodium silicate as stabilizers to laterite soil used as fill material for the purpose of constructing light traffic pavement. The laterite soil used in this study was collected from Ikorodu North Local Government Area in Lagos State, Nigeria and treated with eggshell powder (ESP) and sodium silicate (SS) blend in stepped concentrations of 3% ESP + 2% SS, 6% ESP + 4% SS, 9% ESP + 6% SS, 12% ESP + 8% SS and 15% ESP + 10% SS by dry weight of the soil. Results from the tests carried out showed a general improvement on the engineering properties of the laterite treated with ESP and SS blend. Optimum California Bearing Ratio (CBR) tests results for un-soaked and soaked samples were recorded as 51% and 22% at 12% ESP + 8%SS content. Peak Unconfined Compressive Strength (UCS) values of 355 KN/m^2 and 570 KN/m^2 were recorded at 7- and 28-days curing periods respectively at an optimum blend of 12% ESP + 8%SS content. From the results obtained in this research, an optimum blend of 12% ESP and 8% SS using the West African Standard (WAS) compactive effort can be used to stabilize laterite soil material for use as fill material for the construction of light traffic roads. An advantage of applying the ESP is the decrease in the deleterious environmental impact of eggshell waste.

1.0 Introduction

According to Hainin et al. (2011) a low volume road is a road that is said to have a low Average Daily Traffic (ADT). They also stated that it could also be referred to a road with a cumulative number of Equivalent Standard Axel Load (ESAL) traversing over the design life of the roads. Roads in the rural areas and within some Estates are mostly classified as low volume or low traffic roads. It is therefore important to know how much the subgrade and fill soil can support the volume of traffic expected without any failure on or within the pavement structure.

In geotechnical engineering, deficient soils are soils, which do not meet certain requirement for their intended geotechnical use. The intended use could either be for road construction (as in this case), embankment construction, construction of liners for leachate containment etc. In Nigeria and other tropical regions of the world, the dominant soil material available for the construction of subgrade, fill, sub-base and base courses for both flexible and rigid pavements is the laterite soil however; the natural properties of these soils need to be improved so as to meet engineering specifications for the required engineering purpose. Figure (1) shows the map the of laterite-abundant zones in Nigeria.

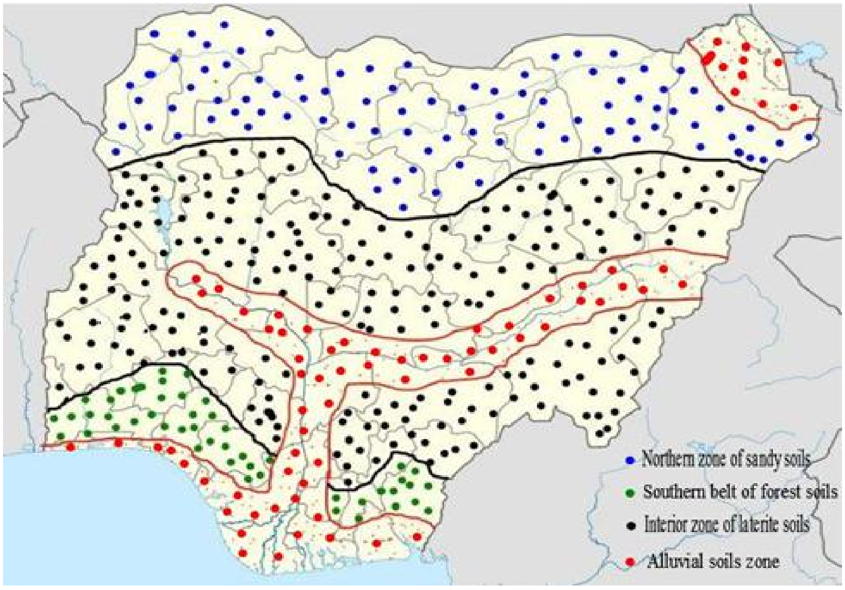

Figure 1: Map showing laterite abundant zones.

One of the major methods of soil improvement according to Alayaki (2012) is through a process known as stabilization. He went further to show that the process of soil stabilization involves improving the engineering properties of deficient soils so as to meet engineering requirements for construction purposes. Another research (Gofar and Kassim, 2007) also showed that stabilization as a method of soil improvement is usually carried out to increase the strength of the pavement layers in order to provide a suitable platform for the intending traffic This practice of stabilization is widely used in road construction with the aim of increasing its strength by making it less compressible, permeable and porous, which results in higher bearing capacity, and decreased volumetric change (Osinubi and Mustapha, 2009).

Sherwood, (1995) reported that stabilization could be carried out with additives such as, cement, lime and fly ash. These additives known as the conventional stabilizers have been used in stabilizing weak soils on road construction in order to provide a firm base or sub-base for all types of paved areas as well as improve foundation conditions. Other researchers; Nalbantoglu, (2004), Osinubi et al. (2007), Mahto and Duggal (2015) also confirmed the usefulness of some other additive such as fly ash, RBI grade 81, bagasse ash as stabilizers which can also be used to improve the strength of deficient soils. They all reported that when these additives were added to expansive clay soils, the plasticity index, amount of the clay size particles, as well as their swell potentials reduced.

However, the over dependence on the utilization of these industrially manufactured conventional soil stabilizers or additives (cement, lime etc.); have continually kept the cost of construction of stabilized road high (Musa and Mohammed, 2015). This hitherto, have continued to deter the underdeveloped and poor nations of the world from providing accessible roads to their rural dwellers who constitute the higher percentage of their population who are mostly agriculturally dependent (Alhassan and Mustapha, 2007) and so, the improvement in the strength and durability of laterites with locally sourced materials that are readily available has become imperative as a result of the high cost involved in the construction of roads for which

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cheaper means of building them are essential (Neville, 2000; Odula, 2010). This has resulted some researches into using stabilizers that can be sourced locally at a very low-cost using sugarcane straw ash (Amu et al. 2011, Ogunribido, 2012), rice husk ash (Alhassan and Mustapha, 2007), bamboo leaf ash (Amu and Adetuberu, 2010) and oil palm empty fruit bunch ash (Oke and Osinubi 2019). In addition to the high cost involved in the construction of roads, indiscriminate dumping of wastes has led to environmental issues and so, this has in addition prompted these researches on the use of local materials as alternatives to the conventional additives as construction materials. These local materials can be classified as either agricultural or industrial wastes (Amu et al, 2011).

Different types of soils may be suitable for use in the construction of an embankment or fill for the purpose of a road construction, ranging from granular soils (sand and gravel), which are more preferred, to the more finely sized soils (silt and clay), which usually lack the required engineering properties hence a need for stabilization. In Nigeria, laterite soils, which contain silts and clays, are usually used as fill material on road projects and so its stabilization is necessary. Regardless of the type(s) of soil(s) to be used as fill material, the material should be well graded, capable of adequate compaction, be within a proper range of moisture to optimize compaction, and be free of unsuitable or deleterious materials, such as grasses, tree roots, branches, stumps, sludge, waste etc.

This study was aimed at stabilizing laterite soil used as fill material with eggshell powder and sodium silicate for the purpose of constructing light traffic roads.

Location and Geology of the Study Area

The laterite used in this study was obtained from borrow pits along Itokin Road, Adamo, Ikorodu North Local Government Area in Lagos state, Nigeria. The borrow site lies within the coordinates of latitude 6° 39' 0"N and longitude 3° 35' 0"E.

2.0 Materials and Methods

2.1. Materials

2.1.1. Soil

The laterite soil used in this study (Figure 2a) was obtained from a borrow pit along Itokin Road, Adamo, Ikorodu North Local Government Area in Lagos state, Nigeria. The soil was obtained using the disturbed sampling method from an average depth of about 1.5-2.5m below existing ground level to avoid organic topsoil.

2.1.2. Eggshell

The eggshells were obtained as waste from bakeries, restaurants and individual homes. For ease of pulverising, they were further dried naturally and thereafter, pulverised and sieved through 0.075mm BS sieve (Figure 2b). The powder obtained was then stored in airtight buckets to prevent hydration or other form of contamination.

2.1.3. Sodium silicate

A new liquid stabilizing agent, with a commercial brand name of “TX-85” had been introduced in the construction industry for improving the strength and reliability of soils for construction of building and road. This liquid stabilizer was obtained from chemical dealers in Lagos State.

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(a) (b)

Figure 2: (a) Laterite soil sample. (b) Eggshell powder

2.2. Methods

2.2.1. Index properties

Index properties (Atterberg limits, sieve analysis, specific gravity) tests were carried out in accordance with the procedures outlined in BS 1377 (1990) on the natural laterite. For Atterberg limits, air-dried samples were crushed and sieved through the No. 40 sieve (0.425mm) and mixed with different eggshell powder (ESP) and sodium silicate (SS) content to establish the effect of the stabilizers on the Atterberg limits. Deionized water was also used in all samples to avoid any distraction or contamination by chemicals.

2.2.2. Compaction

To simulate the variation in compactive effort that may be expected from field operations, the West Africa Standard compaction was carried out to study the moisture-density relationship of compacted laterite and laterite – ESP+SS blend. Air-dried laterite samples passed through BS No. 4 sieve were mixed with 3% ESP + 2% SS, 6% ESP + 4% SS, 9% ESP + 6% SS, 12% ESP + 8% SS and 15% ESP + 10% SS by dry weight of soil. 8% of water by dry weight of soil was used for the first compaction. Five (5) layers of the treated laterite was placed into the mould, with each layer receiving 10 blows uniformly distributed with a 4.5kg hammer dropped from a height of 450mm and the resulting dry unit weight was measured. The procedure was repeated subsequently with a stepped increment of 2% of water to establish a relationship between the dry unit weight and the water content of the natural and treated soil mixtures.

2.2.3. Strength Tests

California bearing ratio (CBR)

The laterite soil was mixed with ESP and SS in their respective blends (3% ESP + 2% SS, 6% ESP + 4% SS, 9% ESP + 6% SS, 12% ESP + 8% SS and 15% ESP + 10% SS), compacted and tested. For un-soaked samples, they were tested immediately after compaction. For the soaked samples, after compaction, they were soaked for 48 hours. After 48 hours, they samples were removed from the water tank and allowed to sit for 15 minutes before testing.

Unconfined Compressive Strength (UCS)

For the unconfined compressive strength (UCS) test, the samples were mixed with the ESP and SS additives (3% ESP + 2% SS, 6% ESP + 4% SS, 9% ESP + 6% SS, 12% ESP + 8% SS and 15% ESP + 10% SS), compacted and left to cure for 7, 14 and 28 days respectively. All strength tests were carried out in accordance with BS 1377 (1990) Part 4, BS 1924 (1990) and Federal Ministry of Works and Housings, FMW&H (1997).

3.0 Results and Discussion

Table1 shows the properties of the natural laterite used in the study while Tables 2 and 3 show the chemical composition of the additives and the laterite soil respectively.

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Table 1: Properties of natural soil

S/No	Properties	Results
1	Colour	Reddish brown
2	Percentage passing sieve No 200	52.3
3	Liquid Limit (%)	46.15
4	Plastic Limit (%)	17.6
5	Plasticity Index (%)	28.55
6	Linear Shrinkage (%)	8.59
7	Sesquioxide ratio	1.26
8	Specific Gravity	2.61
9	AASHTO Classification [GI]	A-7-6 [12]
10	Unified Soil Classification System	CL (clay of intermediate plasticity)
11	Maximum Dry Density (Mg/m^3)	1.656
12	Optimum Moisture Content (%)	14.15
13	California Bearing Ratio: 48 hours soaked (%)	11.55
14	California Bearing Ratio: un-soaked (%)	22.3
15	Unconfined Compressive Strength (KN/m^2) at 28 days	45

The eggshell powder as shown in Table 2 has a high calcium oxide content of about 52%. This oxide component has contributed to the strength gain exhibited in the treated samples (Bello et al. 2015).

Table 3 shows the oxides present in the natural soil. The sesquioxide ratio: $SiO_2/(Fe_2O_3+Al_2O_3)$ as calculated from the table gives a value of 1.26. This value implies that the soil used for the study is a true laterite (Joachin and Kandiah, 1941)

Table 2: Chemical compositions for eggshell powder and sodium silicate

Components (%)	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O
Eggshell powder	0.001	0.034	0.002	0.58	52.4	0.002	0.004
Sodium Silicate	26.59	0.001	0.002	0.002	0.004	0.003	28.24

Table 3: Chemical composition of laterite soil

Component (%)	SiO_2	Fe_2O_3	Al_2O_3	MgO	Na_2O	K_2O	CaO	SO_3
Laterite soil	43.92	0.025	34.89	0.039	0.045	0.16	1.42	0.00

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3.1. Index Properties

3.1.1. Grain size distribution

Figure (3) shows the grain size distribution of the natural laterite used in the study. The soil was classified to be A-7-6 (12) soil using the AASHTO classification system. From the graph, it is observed that the percentage retained on Sieve No 200 was 47.3% and percentage passing was 52.3% in the soil. This was then used for hydrometer test to determine the silt content as shown in the graph in Fig. (3).

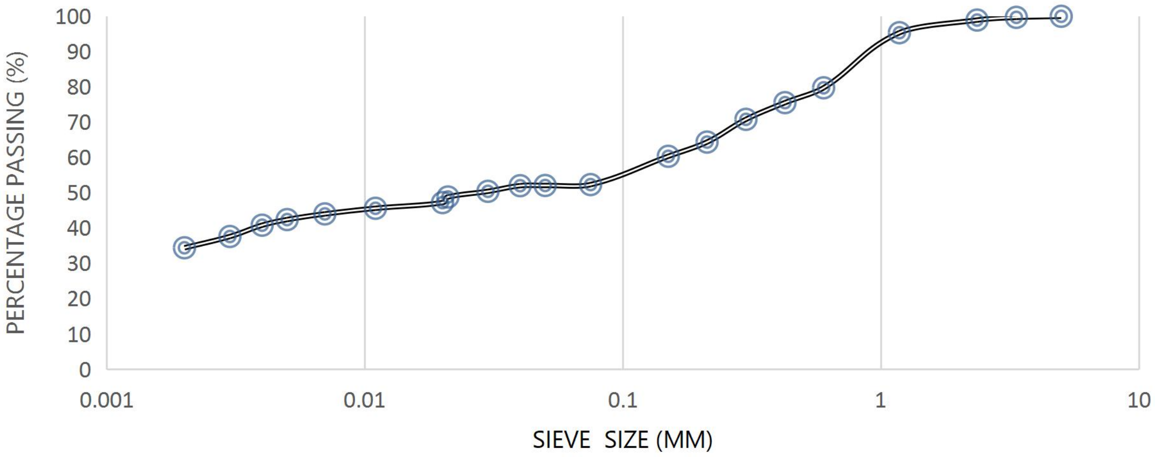

Figure 3: Grain size distribution curve.

3.1.2. Atterberg Limits (Liquid Limit: LL, Plastic Limit: PL, and Plasticity Index: PI)

Figure (4) shows as a variation of Atterberg Limits with varying ESP + SS content used to mix the soil to get a homogeneous paste. A similar trend was observed for the Atterberg limit test results i.e. LL, PL and PI. There was a sharp drop observed in LL, PL and PI with an initial addition of 3% ESP + SS. Thereafter, further increase in the ESP and SS content resulted in an increase in LL, PL and PI at a decreasing manner. This may be due to the fact that the quantity of ESP was not initially sufficient to endothermicaly combine with SS. This inconsistency of results can be attributed to the differences in stabilizing mechanisms of the two additives, i.e. the eggshell powder causes flocculation due to lime content (calcium oxide) while sodium silicate did the opposite by making montmorillonite particles repel one another. This finding is in agreement with the research carried out by Muthu and Tamilarasa (2014).

The LL of 29% and PI of 10% meets with the requirement specified in the Federal Ministry of Works & Housing (1997) for fill material which is given as LL: 0-45% and PI: 0-20%.

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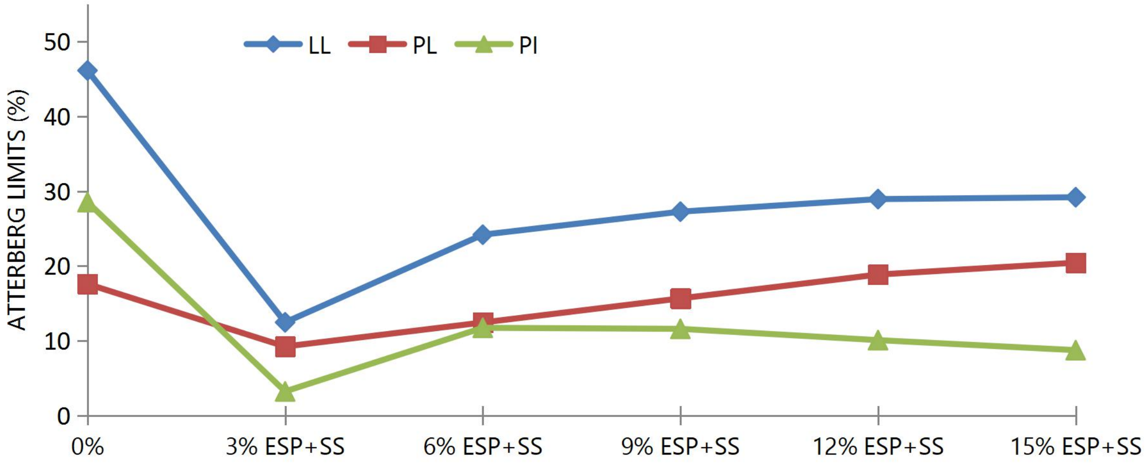

Figure 4: Variation of Atterberg Limits with the varying ESP + SS content

3.2. Compaction Characteristics

3.2.1. Optimum Moisture Content (OMC)

Figure (5) shows a variation of OMC with varying ESP and SS additives. The compaction result showed that there was an increase in the optimum moisture content (OMC) with higher ESP and SS content up from 14.15% for the natural soil to a maximum value of 21.2% at 15 % ESP and 10 % SS combination. This could be attributed to the increase in fines content due to the inclusion of ESP which has a larger surface area that required more water to react or complete its hydration reaction, thus this stepped up the rate of hydration reaction which rapidly continued to use up the water in the system as reported by Osinubi (1999) and Musa (2008). These trends are also in agreement with established trend for stabilization of laterite with cement and lime, (Ola, 1983a), South Chicago Clay with lime-kiln dust (Daita et. al, 2005), laterite with rice husk ash (Alhassan, 2008) and laterite with bamboo leaf ash (Amu and Adetuberu, 2010).

Also, research findings reported by Osinubi (1999), Osinubi et al. (2007) and Oke and Osinubi (2019) explains that the increase in OMC with increasing amount of treatment is as a result of an increasing desire for water commensurate with the higher amount of the additives because more water was required for the disassociation of admixtures with Ca^{2+} and OH^{-} ions to supply more Ca^{2+} for the cation exchange reaction. Another reason could be due to the increasing surface area caused by the higher amounts of additives that require more water for the lubrication of the entire matrix.

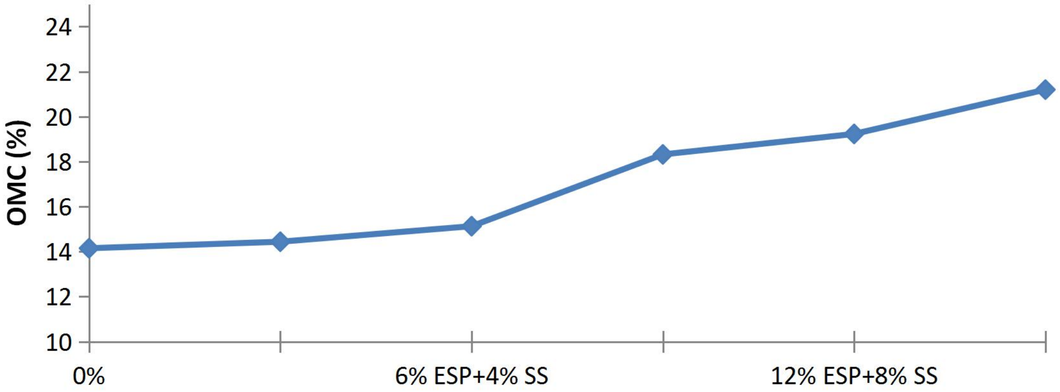

Figure 5: Variation of OMC with varying ESP and SS additives

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3.2.2. Maximum Dry Density (MDD)

The variation of maximum dry density (MDD) with varying content of ESP and SS is shown in Figure (6). The MDD in this case decreased from 1.66 Mg/m^3 for the natural soil to 1.57 Mg/m^3 at 10% SS and 15% ESP content. This explanation is considered to hold true for ESP given that K_2O and CaO contents of the ESP that add up to 52.4% could combine with any naturally occuring CaO in the lateritic soil to initiate cation exchange, flocculation and agglomeration of the soil, in a manner similar to the effect of lime stabilization (Alao, 1983; Daita et al, 2005). The decrease in dry densities may also be due to the flocculated and agglomerated clay particles occupying larger spaces leading to corresponding decrease in dry densities. This trend is in agreement with Lees et al. (1982). Osinubi et al. (2000) also connects this to the initial simultaneous flocculation and agglomeration of clay particles caused by cation exchange as well as the additives occupying the voids within the soil matrix. Ola (1983) also showed that the process led to an increase in air voids and thereby giving rise to a decrease in dry density.

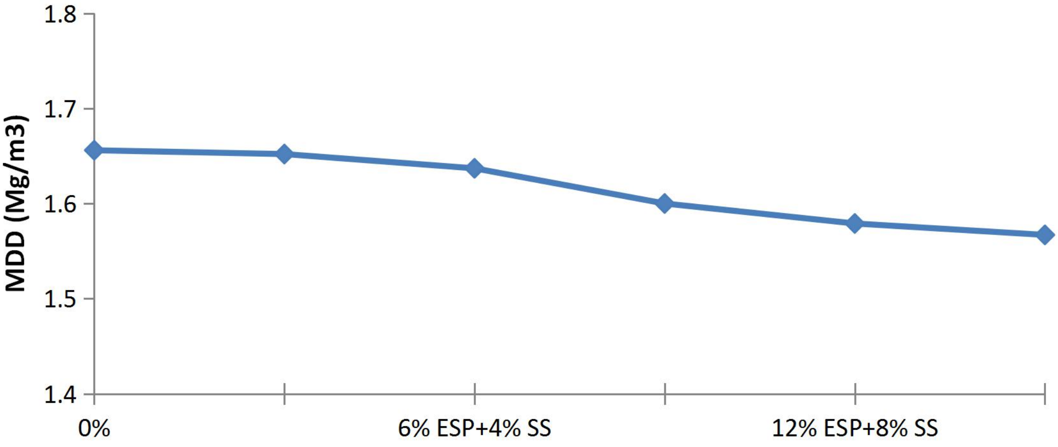

Figure 6: Variation of MDD with varying ESP and SS additives

3.3. Strength Characteristics

3.3.1. California bearing ratio

The variation of CBR value with varying ESP and SS content under the soaked and un-soaked conditions are shown in Figure (7).

Un-soaked Condition

The variation of value with ESP and SS content under the un-soaked condition shows that CBR values increased from 22.3% for the natural soil to an optimum value of 51.8% at 12% ESP + 8%SS combination and then decreased to 40.72% at a maximum combination of 15% ESP + 10%SS. This increase in the CBR could be as a result of the presence of adequate amounts of calcium required for the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which are the major compounds responsible for strength gain (Bello et al. 2015).

The FMW&H (1997) recommends a CBR value of 180 % to be attained in the laboratory for cement-stabilized material to be constructed by the mix-in-place method. Usually, a minimum CBR value of 80 % is required for base specification and 20-30 % for sub-base specification and a minimum of 10% for fill material specification both when compacted at optimum moisture content and 100 % West African Standard (Gidigasu and Dogbey, 1980) and (Gidigasu, 1982). In accordance with the specification, the minimum un-soaked requirement of 10% CBR for fill and

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minimum un-soaked requirement of 30% for sub-base construction was achieved. A value of 51.8% at an optimum blend of 12% ESP + 8%SS was obtained. This value of 51.8% meets with requirements stated above which makes the optimally treated laterite soil material suitable as a fill material when compacted with the WAS energy.

Soaked Condition

The variation of CBR value (48 hours soaked conditions) for natural and ESP/SS-stabilized laterite using the WAS compactive efforts shows that there was a gradual increase of CBR values from 11.55% for the natural soil to peak value of 21.8% at the optimum 12% ESP + 8%SS combination and then a decrease to 13.5% at a maximum combination of 15% ESP + 10%SS. The lower values recorded in comparison to the un-soaked CBR values were due to ingress of water into the specimen, which led to a reduction in strength. Relating with the required specifications for sub-grade and fill construction materials, which should have a value of 10%, it meets with the specification.

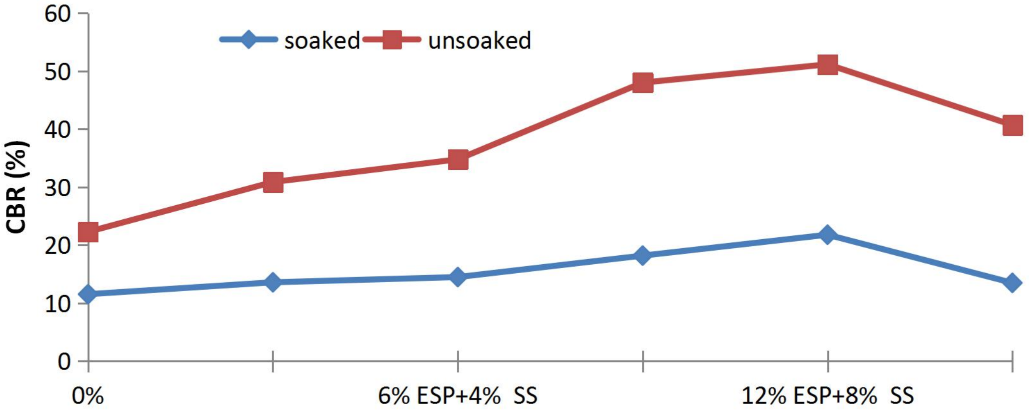

Figure 7: Variation of CBR values with varying ESP and SS content

3.3.2. Unconfined compressive strength

Figure 7 shows the variation of UCS value with varying ESP and SS content. The unconfined compressive strength (UCS) results indicated that the unconfined compressive strength of the soil after curing for 7, 14 and 28 days with the increasing proportions of ESP + SS, increased gradually with the days of curing and the peak values for each combination was recorded at 28 days of curing. The optimum strength achieved was recorded as 570 KN/m2 obtained from a combination of 12% ESP + 8%SS at 28 days of curing. However, it was observed from the result that a further increase in the ESP + SS combination to 15% ESP + 10% SS rather showed a decrease in strength.

These result as reported by Osinubi et al. (2007) and Oke and Osinubi (2019) can be attributed to the progressive increase in the amount of calcium oxide as a result of the gradual increase in the amount of eggshell powder added to the mixtures, thus increasing the cementitious compounds formed for increased strength properties.

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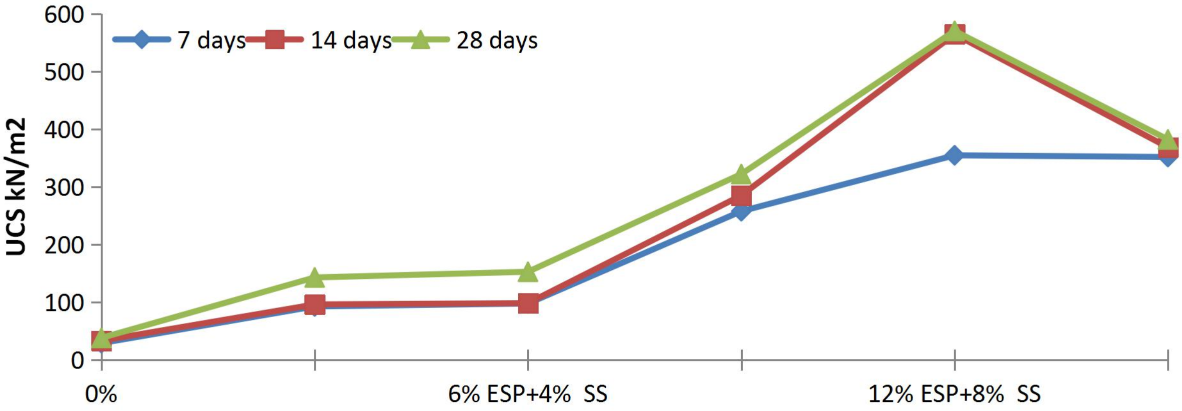

Figure 8: Variation of UCS value with varying ESP and SS content

4.0 Conclusion and Recommendations

From the results obtained in this research, using an optimum blend of 12% ESP and 8% SS, soaked and un-soaked CBR values of 22% and 51% were obtained and these values meet with the 10% requirements for fill material stabilization for light traffic pavement. It can therefore be concluded that an optimum combination of 12% ESP and 8% SS, can be used to stabilize laterite soil material for the construction of the fill layer of light traffic roads. The optimum blend is also recommended as an additive or stabilizer to the subgrade layer of light traffic roads during rehabilitation works.

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