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Strength Characteristics of Oyster Shell Ash and Periwinkle Shell Ash Stabilized Lateritic Soil for Pavement Construction

***J. A. Oke*[1*]*, N. O. Obaji*[2]* and A. A. Ikoya*[3]**

[1,2,3] Department of Civil & Environmental Engineering, University of Lagos, Akoka, 100213, Lagos State, Nigeria.
*Corresponding author email: idaraobong2013@gmail.com

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Abstract

With an aim of contributing to the reduction of the greenhouse gas effect resulting from the incorporation of ordinary Portland cement as a binder material in construction and to further encourage the building of environmentally conscious structures using alternative binders, the strength characteristics of oyster shell ash and periwinkle shell ash as environmentally friendly additives to lateritic soil for pavement construction was investigated. Naturally occurring lateritic soil having a reddish-brown color was obtained from a borrow pit located at Ikorodu Local Government Area of Lagos State, Nigeria. The soil sample classified as SC and A-7-6 (5) using the Unified Soil Classification System (USCS) and AASHTO system respectively was treated with up to 15% oyster shell ash (OSA) and periwinkle shell ash (PSA) blend in a mix ratio of 60%: 40% by dry weight of soil and compacted using the West African Standard compaction effort. The results showed that consistency limits, compaction characteristics (optimum moisture content; OMC and maximum dry density; MDD) as well as strength properties (unconfined compressive strength; UCS, California bearing ratio; CBR, and Durability) improved with the addition of the OSA-PSA blend treatment. Peak UCS value of 556.44 kN/m^2 at 28-days air-curing was recorded at an optimal 9% OSA-PSA blend. Maximum unsoaked and soaked CBR values of 53.35% and 32.17% respectively were also recorded at an optimal 9% OSA-PSA blend. As specified in the Nigerian General Specifications for CBR values, the lateritic soil optimally stabilized with 9% OSA-PSA content and compacted using the WAS compaction energy can be utilized as a standalone stabilizer for fill material used for the rehabilitation of low-volume pavements. Additionally, the 9% OSA-PSA optimum blend can also be used as a standalone subgrade/base stabilizer during the construction of concrete/interlocked paved walkways. Furthermore, the utilization of OSA-PSA additive in the construction industry would significantly lead to a reduction in the challenges faced by the indiscriminate disposal of these shell wastes into the environment.

1. Introduction

Efficient transportation infrastructure has been identified as a major facility that aids the development of any nation to a very great extent. Road networks occupy an important position in the economy of any nation, especially in underdeveloped and developing ones, where good roads are required for the transportation of goods and services [1]. Due to the excess burden placed on roads as the most used means of transportation in Nigeria, the roads have over time gradually advanced to a dilapidated condition and have now remained a lingering problem for the nation thereby causing construction industries to overly depend on the conventional soil stabilizing additives. These additives which include cement and lime, in turn, have kept the cost of constructing, re-constructing, and/or rehabilitating these dilapidated roads financially high [2,3]. The increase in road failures in Nigeria has become quite perturbing in recent times and has led to increasing concern among the stakeholders in the maintenance of Nigerian highways [4]. In order to measure up with the huge propensity for durable roads, alternative construction materials that are cheaper should be considered [5] hence, keeping the cost of constructing roads considerably low will depend on the amount of durable alternatives that can easily be assessed conveniently [6]. For this purpose, it has become crucial to research further into seeking cheaper, locally sourced, and readily available alternative construction stabilization additives without compromising key factors such as stability and how environmentally friendly these additives are.

In humid tropical regions of the world for which Nigeria is included, the abundant soil type which is available for use in constructing subgrade, subbase, and base layers for both rigid and flexible pavements is the lateritic group of soils. This is because it is abundant and cheap [7,6]. Hence, the common use of lateritic soils for constructing roads is derived from their vast accessibility within the country [8]. Though having poor geotechnical properties, research has shown that lateritic soils could be improved to possess very favorable engineering properties [9]. There are various methods of soil improvement but chief among them often used for highways is stabilization using additives [10].

In a bid to provide economically, socially and environmentally sustainable materials for construction purposes, preserve natural resources, reduce heaps of voluminous wastes and ultimately reduce construction cost, the applicability of several agricultural waste materials have been investigated over time. Several scholars have reported the suitability of some agricultural wastes as alternative construction materials. The applicability of these wastes and by-products have been in various forms ranging from fiber, powder, calcinated ash, shell forms, etc. for various construction purposes. These agricultural waste materials include among others Rice Husk [11], Coconut Shell and Coir [12], Sugarcane Bagasse [13], Egg Shell [14,15], Cassava peel [16], Groundnut Shell [17], Palm Kernel Shell [18], Fly Ash [19] and Oil Palm Empty Fruit Bunch [6, 9].

This study is also a contribution to previous studies that have been carried out but, in this case, the use of locally sourced oyster and periwinkle shell wastes has been utilized as stabilizers to lateritic soils. These shell wastes are commonly found in aquatic locales, such as brackish water freshwater, saltwater, etc., and are made of calcium carbonate embedded in an organic matrix [20]. Due to the high calcium carbonate content of these shells, the suitability of their ash/powder for use as binders for improving lateritic soil in pavement construction is investigated.

1.1 Lateritic Soils

Soils that are poor in engineering properties and fail to meet required geotechnical engineering criteria are termed deficient soils. In tropical regions, some examples of these deficient soils are the lateritic soils or the black-cotton soils [21,22,23]. Lateritic soils are sedimentary materials formed by the chemical weathering of pre-existing rocks and soils [24,25]. They are highly weathered rusty-red materials that are rich in minor oxides of either aluminum, iron, or in some cases, both having a low proportion of silica, formed in wet, hot tropical environments. They are developed by intense and long-lasting chemical weathering of underlying pre-existing rocks such as gneisses, granites, schists, quartzites, shales, sandstones, limestones, and clays [26,25]. Typical lateritic soil is claylike with the inclusion of pores. It is made up of oxides of iron minerals such as goethite (FeO_2H), hematite (Fe_2O3), and lepidocrocite (FeO[OH]). Furthermore, it is also made up of titanium oxides as well as hydrated oxide of aluminum, for which the most common and abundant is gibbsite ($Al[OH]_3$) [27,28].

Some lateritic soils are made up of swelling clay minerals like montmorillonite and illite that leads to a reduction in the shear strength of such soils, and increase the pore pressure as well as the swelling potentials when compared to other lateritic soil which majorly contains kaolinite and chlorite minerals [21,22,17]. In addition, large amounts of swelling clay minerals like vermiculite, montmorillonite, and hydrated halloysite as well as fines may exist in some lateritic soils. The presence of such clay minerals which has no guaranteed stability and bearing capacity when used especially in moist condition makes lateritic soils deficient in their engineering properties for use as road pavement layer materials [29].

Failures experienced in the subgrade layer of pavements are usually caused by the collection and percolation of water into the cracks on pavement and the consequent downward migration of the water to the layers beneath. Other sources of water infiltration into pavement foundation are through laterally failed areas of the pavement and through failed drain facilities [30,31,32,33,34]. Commonly, the foundation of the pavement is usually made up of lateritic or clayey material which when exposed to moisture reacts by exhibiting volume changes through swelling and shrinking [33,35,34]. When these volume changes occur, they usually exceed the admissible thresholds for flexible pavements and so lead to eventual failure of the pavement. Soon after the failure of the subgrade, the overlying layers begin to experience the effect of the moving loads resulting from traffic movements. In some cases, when pavements are susceptible to the consequences of erosion, the subgrade layers are eroded as well thereby opening the pavement to added danger of failure [33,32,34].

1.2 Potentials of Oyster and Periwinkle Shells as Stabilizers

Shells are protections of shellfish and are also the by-products of aquaculture. The shellfish are usually consumed as food which leaves the inedible shells to be disposed of as waste. These shells mostly have little or no market value and are ceaselessly dumped in the open or into landfills, thereby creating an unsightly appearance in addition to the unpleasant smell they exhume.

To reduce the cost of constructing durable roads, potentials have been identified in the use of lateritic soil and wastes for the construction of these pavements. Furthermore, the incorporation of these wastes in pavement construction will lead to a decrease in the adverse effect caused by the disposal of wastes to the environment. Therefore, the potential of seashell wastes is investigated in this study due to their abundant availability in certain regions and countries. China has been identified as the world's largest producer of shellfish whereby about 10 million tonnes of seashell wastes which include clam, oyster, mussel, and scallop shells are dumped into landfills annually [36] out of which a small fraction of the waste is re-used to produce fertilizers. Over time after their disposal, the untreated shells produce foul odors resulting from the decay of the remaining flesh within the shells which is further made worse by microbial decomposition of salts into gases, such as NH_3, H_2S, and amines [37].

The disposal of oyster shell waste is a predominant challenge in many countries, especially countries within the Asian continent such as China, Taiwan, and South Korea. [36] estimated in their research that about 370-700g of waste shell is produced from every 1 kg of oyster shellfish. Furthermore, [38] reported that in China, approximately 300,000 tonnes of oyster shells are available yearly while [39] stated in their research that an excess of 160,000 tonnes of oyster shell wastes was generated annually. Galicia, which is in Spain has been identified as the second-largest producer of mussels in the world after China, and annually, about 25,000 tonnes of mussel shell waste is generated in the region with over a million tonnes available globally [40]. In addition to the foul smell produced by these shell wastes, the microbial breakdown of the wastes could also lead to health issues [41]. Likewise in Peru, a yearly amount of scallop shell waste amounting to about 25,000 tonnes is produced and dumped in open areas thereby leading to environmental pollution issues [42].

In Nigeria, majorly along the coastline which runs through Lagos, Ondo, and particularly the south-south and south-eastern states like Akwa-Ibom, Bayelsa, Cross River, Delta, and Rivers, periwinkle and other abundant bivalve mollusk shell wastes like oysters are thrown away after consuming the flesh - a class of protein for the locals. The shellfishes are predominantly found in these riverine areas because of the annual rainfall and the annual mean temperature hence, the abundance of their shells in these areas [43]. The indiscriminate dumping of these shell wastes can cause problems that could adversely affect the quality of life of the inhabitants living close to these areas thereby resulting in environmental pollution issues [43]. The associated abundance of these seashell wastes in coastal regions globally as highlighted above provides a basis for the use of seashells in engineering and thus gives the prospect of reducing the usage of conventional stabilizers if found successful in this study.

According to previous research, seashells which include oyster shells [44,43], scallop shells [45], mussel shells [41], cockle shells, and clam shells [46] have been discovered to primarily be composed of calcium carbonate ($CaCO_3$) that are formed naturally, for which the mineral phase was termed as Calcite. [20] stated that naturally, seashells are high in calcium carbonate content however, their thermal decomposition in the absence of air (calcination) can lead to the production of calcium oxide with carbon (IV) oxide being given off. The reaction is illustrated in Equation 1.

$$CaCO_3^{heat(>700℃)} \rightarrow CaO + CO_2 \qquad (1)$$

Calcium oxide (CaO) is the major chemical composition in seashells in addition to other oxides that are present in tiny fractions. In oyster and other mollusc shells, the percentage of CaO was discovered to range between 48.0% and 86.8% with a high loss on ignition (LOI) which ranged between 23.2% and 51.0% [44,47,41,48,46,38,49,40]. This agrees with the presence of calcite in the XRD pattern of the oyster shell material which was reported by [49], and LOI which resulted from the partial decomposition of calcite to form carbon dioxide and CaO. The difference in the CaO composition reported by researchers could be a result of the varying temperatures at which the oyster shells were heated before the chemical composition test. In the investigation carried out by [38,49], the oyster shells were calcined to temperatures ranging between 850 – 950 ℃ and 500 ℃, respectively. The higher heating temperatures resulted in higher CaO content when compared to other studies whereby the oyster shells were heated to about 105 ℃ [44,48]. This similarity was also observed in the study when mussel shells were reported to have high CaO content of 87.2% due to a high calcining temperature of 1100 ℃ when compared to those that were calcined at lower temperatures which saw the CaO content to be about 53.0% [46]. Generally, seashells of all types, including cockle and clam shells, can be reported to have similar CaO contents, under the condition that the calcining temperatures employed are similar and within the same range for the shell wastes.

Specific gravities (SGs) of seashell aggregates (oyster, mussel, crepidula, cockle, and scallop shells) have been reported to range between 2.09–2.73 and since seashell waste is majorly comprised of $CaCO_3$, it is expected that their SGs should be close to that of calcium carbonate [50]. In another research by [51] a SG of 2.81 was observed for an unspecified type of seashell aggregate. Furthermore, [37] reported that, as the degree of crushing increased and the size of oyster shells decreased, the SG would increase from 2.35 to 2.47, which would be approaching that for calcium carbonate. This was confirmed by [44] who reported that the SG of crushed oyster shells with particle sizes ranging between 0.074 and 2 mm was 2.41 in comparison to those that had particle sizes ranging between 2 and 4.75 mm which resulted in specific gravities of 2.38.

2. Materials

2.1 Lateritic Soil

The lateritic soil investigated in this study was sourced from a borrow pit along Itokin – Epe Road, Aleke Town, Ikorodu Local Government Area in Lagos State, Nigeria at a bearing of latitude 6º 39' 50" N and longitude 3º 36' 20" E using the disturbed sampling method at depths of 1.8m -2.5m below the existing ground level to prevent top-soil organic contamination.

2.2 Oyster and Periwinkle Shell Ash

The shells in the study were obtained from Makoko seafood and Oyingbo markets all in Lagos State, Nigeria. The oyster and periwinkle shells were carefully washed separately with a brush and warm water to remove the dirt, silt, and debris. The washed shells were then sun-dried to eliminate moisture, pulverized with a grinding mill, and sieved through a 0.075mm BS sieve. The obtained powder from both shells was then calcined in a Vecstar heat treatment furnace at a temperature of 750 ℃ for 30 ± 2 mins. The ashes were then allowed to cool in the furnace before being transferred to airtight containers for storage.

2.3 Portable water

Potable water that was available in the Soil Laboratory was utilized for the experiments.

Figure 1. a) Washed Oyster Shell **b) Oyster Shell Ash (OSA)**

Figure 2. a) Washed Periwinkle Shell **b) Periwinkle Shell Ash (PSA)**

3. Methods

3.1 Chemical Oxide Analysis

Atomic Absorption Spectrometry (AAS) was utilized in determining the oxides in both the lateritic soil and ash samples.

3.2 Index Properties

Natural Moisture Content, Sieve Analysis, Specific Gravity, and Consistency Limit Tests (Liquid Limit: LL, Plasticity Index: PI, Plastic Limit: PL, and Linear Shrinkage: LS) were carried out on the natural lateritic soil and OSA-PSA treated samples to assess their index characteristics.

3.3 Compaction

Compaction assessments were performed on the natural and OSA-PSA treated lateritic sample to attain the interrelationship between the compacted dry density of the soil and the moisture content. To assume the variation in compaction effort that could be anticipated from field activities, the West African Standard compaction effort was adopted for this study in accordance with [52]. The Standard Proctor mould with a volume of 942.48 cm^3 was used. OSA-PSA stabilized lateritic sample was prepared using a mix ratio of 60%: 40% of OSA: PSA respectively in stepped concentrations of 3, 6, 9, 12 and 15% blend by dry weight of soil and compacted in 5 layers of relatively equal masses with each layer receiving 10 blows from a 4.5 kg rammer falling through a height of 450 mm.

3.4 Strength

3.4.1 Unconfined Compressive Strength (UCS)

UCS tests were carried out according to [52] on the natural and OSA-PSA treated samples, which were prepared at their specific optimum moisture contents (OMCs) and compacted using the West African Standard (WAS) compaction. The compacted samples (3 each) which had diameters and lengths of 50 and 100 mm respectively were extruded from their moulds and allowed to air-cure for 7, 14 and 28 days. When the curing durations had lapsed, the samples were placed centrally on the bottom plate of the compression-testing machine and a compressive force was applied to the sample using a strain guide at 0.10 % mm. Axial deformations viz-a-viz the axial force at regular intervals were recorded until the sample failed. The point on the stress-strain curve at which failure occurred was recorded as the UCS of the sample.

3.4.2 California bearing ratio (CBR)

CBR test is carried out to determine the bearing capacities of soils as well as their strength for the purpose of engineering the design of pavement structures for road construction. Soil samples treated with conventional stabilizers such as cement, lime, etc. are often used for constructing the sub-base and base layers of flexible pavements, hence, CBR is a test that is common and very important as it evaluates the strength of the compaction.

The CBR assessment was carried out in accordance with specifications for the untreated and OSA-PSA treated lateritic samples using the [52] as a guide. The CBR connoted as the force exerted by the plunger viz-a-viz its depth of penetration into the sample evaluates the correlation of the applied force viz-a-viz the penetration. Hence, the CBR test is necessary for pavement design where natural gravel materials are used.

5.0 kg of untreated / OSA-PSA treated lateritic samples were prepared at their respective OMCs in 2360 cm^3 moulds and compacted with each layer of the five layers receiving 25 blows using a 4.5 kg rammer falling through 450 mm height.

When the compaction was completed, the bottom plate for the un-soaked CBR sample was removed and the compacted sample in the mould was allowed to sit for 10 minutes then placed on the lower plate of the CBR machine. The plunger was set to penetrate the specimen at a rate of 1.3 mm/min until the sample failed. After failure occurred, the sample in the mould was brought out of the CBR machine, inverted, the bottom plate removed, and then the procedure was repeated but this time, the sample was tested from the bottom.

For the soaked specimens, after the completion of compaction, the bottom plates were removed, and the compacted specimens were transferred into water tanks to allow for soaking. After soaking the samples for 48 hours, the samples were brought out of the water tank and allowed to drain for 15 minutes and then tested using the testing procedure carried out for the un-soaked samples.

3.5. Durability

An accepted engineering test for determining the possible degradation characteristics of OSA – PSA treated lateritic soil is required to demonstrate a means of evaluating its long-term durability on road sections. The durability assessment when considering adverse field conditions of the soil sample was determined by the resistance to loss in strength when soaked in water. It is expressed as the ratio of UCS of the specimen wax-cured for 7 days and soaked (de-waxed top and bottom) for another 4 days to the UCS of the specimen wax-cured for 14 days.

3.6 Quantity of additive (OSA-PSA) required to stabilize 1m^3 of lateritic soil

For successful rehabilitation work, it is always imperative to know the quantities of materials that will be needed for the project. It is therefore important to ascertain the quantity of materials that will be needed prior to mobilization to the site hence the item of work that will be done must be listed out viz a viz the quantities of materials that will be required.

An overview of rehabilitation works includes the following:

a) scarifying or partially pulverizing the failed portion of the pavement and removal of failed materials. This is carried out such that a known volume of replacement material is needed to fill up the scarified portion.
b) spreading the lateritic soil that has previously been mixed with the stabilizing agent in this case, OSA-PSA additive,
c) incorporating water into the mix,
d) compacting the mix to maximum practical density,
e) curing before the placement of the subsequent layer.

In this research, calculations to obtain the quantity of stabilizing agent needed for the stabilization of 1m^3 of lateritic soil will be presented. This will give information in a situation where OSA-PSA blend is an option to be used for stabilization.

4 Results and Discussion

Table 1 highlights the properties of the untreated lateritic soil used in the study. Tables 2 and 3 highlights the chemical composition of the OSA-PSA and the lateritic soil respectively.

Table 1: Properties of untreated lateritic soil

Properties	**Results**
Colour	Reddish brown
Natural Moisture Content (%)	11.79
Sesquioxide Ratio $(\frac{SiO_2}{Fe_2O_3 + Al_2O_3})$	1.83 (Lateritic Soil)
Percentage Sand Content (0.075 – 4.75mm)	56.51
Percentage Silt Content (0.002 – 0.075mm)	15.49
Percentage clay content (< 0.002mm)	28
Liquid Limit (%)	41.30
Plastic Limit (%)	18.81
Plasticity Index (%)	22.49
Linear Shrinkage (%)	8.34
AASHTO Classification (GI)	A-7-6 (5)
Unified Classification System	SC (Clayey Sand)
Specific Gravity	2.59
Maximum Dry Density (Mg/m^3)	1.80
Optimum Moisture Content (%)	15.8
California Bearing Ratio (%) (Soaked)	15.4
California Bearing Ratio (%) (Unsoaked)	26.07
Unconfined Compressive Strength at 28 days (kN/m^2)	177.46

The chemical oxide compositions of OSA and PSA are encapsulated in Table 2. The blend make-up of SiO_2, Al_2O_3, and Fe_2O_3, in both additives despite not satisfying the nadir requirement of 70% specified to be categorized as a pozzolan [53] possess relatively high CaO content of 55.5% and 54.31% respectively, which was accountable for the high strengths reported in the study.

Table 3 highlights the chemical oxide make-up of the lateritic soil sample utilized in this research. From the results, the silica-sesquioxide ratio (SiO_2/ ($Fe_2O_3 + Al_2O_3$)) of the soil sample is calculated as 1.83. This value falls within the specified range of 1.33 and 2.00 for lateritic soils [54,6] hence, lateritic soil was utilized in this study.

Table 2: Chemical compositions for oyster shell ash, oyster shell powder periwinkle shell ash, and periwinkle shell powder.

Components (%)	**SiO_2**	**Fe_2O_3**	**Al_2O_3**	**MgO**	**Na_2O**	**CaO**	**K_2O**
Oyster Shell Ash (%)	18.03	0.86	8.94	6.70	3.54	55.50	2.21
Oyster Shell Powder (%)	18.72	15.92	12.62	6.85	3.62	51.14	2.93
Periwinkle Shell Ash (%)	17.50	2.31	8.65	6.59	3.82	54.31	4.25
Periwinkle Shell Powder (%)	16.87	1.92	10.87	6.72	2.34	52.80	2.56

SG (OSA): 2.67 SG (PSA): 2.68

Table 3: Chemical composition of the lateritic soil used

Components (%)	**SiO_2**	**Fe_2O_3**	**Al_2O_3**	**MgO**	**Na_2O**	**CaO**	**K_2O**	**SO_3**
Lateritic soil (%)	46.34	3.26	22.11	6.15	2.20	5.48	0.62	3.32

SG: 2.59

4.1 Index Properties

4.1.1 Particle size distribution

Figure 3 illustrates the particle size distribution of the lateritic soil utilized in this study. The lateritic soil was classed as A-7-6 (5) which is rated fairly-poor for subgrade in the AASHTO classification system. It was also classed as clayey sand denoted as SC according to the Unified Soil Classification System. It can be observed from the curve that the amount in percent retained on and passing through sieve 0.075mm (No 200) was 56.51% and 43.49% respectively with the latter used for the hydrometer analysis to ascertain the amount of silt in the soil sample as shown in Figure 3.

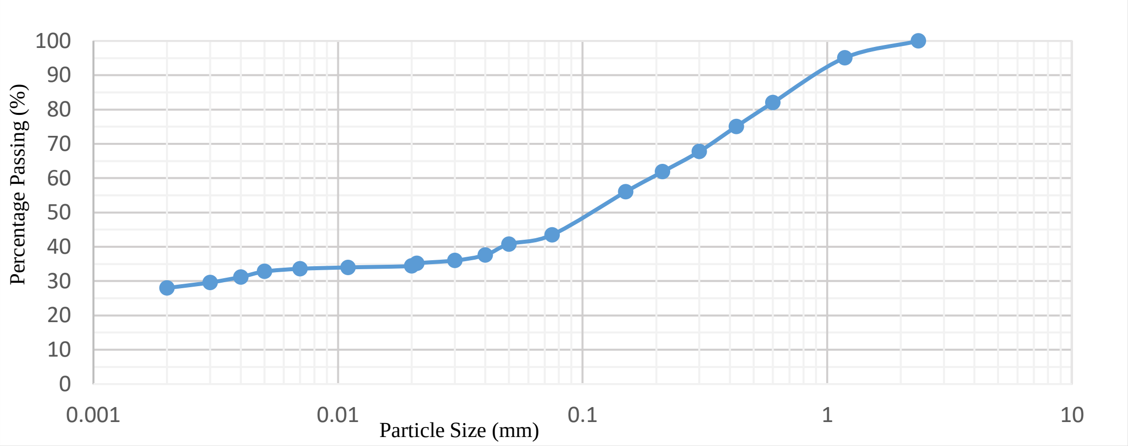

Figure 3. Gradation Curve of Natural Lateritic Soil

4.1.2 Consistency Limits (Liquid Limit, Plastic Limit and Plasticity Index)

In Figure 4, the differences in the consistency limits using OSA-PSA in a 60%:40% blend ratio for a stepped increment of 3%, 6%, 9%, 12% and 15% OSA-PSA content used in treating the soil to get a homogenous paste is highlighted. The liquid limit (LL), plastic limit (PL), and plasticity index (PI) values are generally reduced with the introduction of the OSA-PSA blend. This could be by virtue of the elevated calcium oxide (CaO) content of the OSA-PSA blend and the corresponding cation exchange reactions where Ca^{2+} in the ashes reacted with ions of secondary valence within the clay structure and so aided flocculation and agglomeration of the soil particles. This observed undulating trend agrees with the work of other researchers [55,10].

LL and PI of 33.14% and 16.56% respectively at a peak blend of 9% OSA-PSA content satisfies the requirements as stated in the Nigerian General specification for construction material used for fill which is specified as 0-45% and 0-20% for LL and PI respectively.

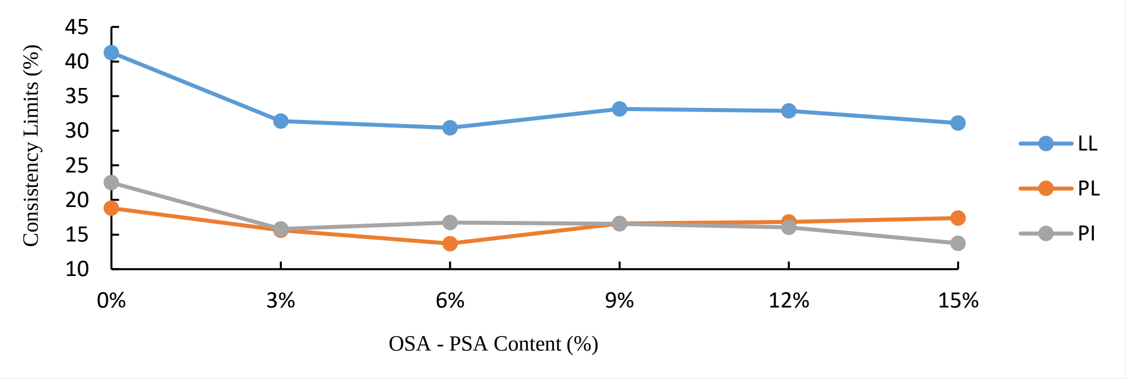

Figure 4. Consistency Limits of OSA-PSA Content

4.1.3 Specific Gravity Test

Figure 5 highlights the differences in specific gravity associated with increasing OSA-PSA content. Generally, a linear increase was observed with an increase in OSA-PSA treatment. This can be associated with the elevated specific gravities of the OSA and PSA which are 2.67 and 2.68 respectively replacing the particles within the lateritic soil sample which has a specific gravity of 2.59 [56,57,9].

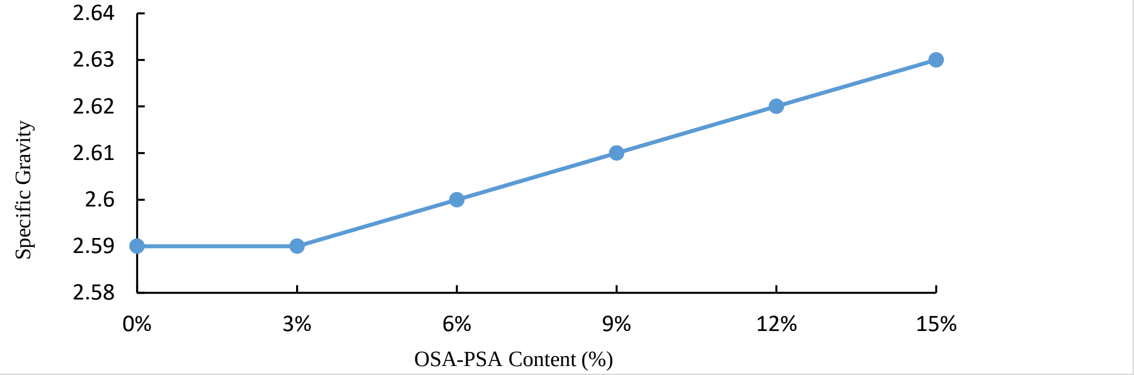

Figure 5. Varying Specific Gravity with increasing OSA-PSA

4.2 Compaction Characteristics

4.2.1 Optimum Moisture Content (OMC)

In Figure 6, the variation of OMC associated with increasing OSA-PSA content is shown. The result highlights a general decrease with increasing OSA-PSA content from 15.80% for the untreated lateritic soil to 14.40% at 15% SSA-PSA content. This observed decrease could be due to self-desiccation whereby the available molding water was immediately used up causing a decrease in hydration. Since there were no transfers of water either way from the OSA-PSA paste, the moulding water which was available was used up during the hydration reaction process up to the point that limited water was set aside to wet through the stabilized sample’s compacted surfaces thereby reducing the associated relative humidity within the matrix [58]. Another reason for the decrease in OMC noticed was because the OSA-PSA required just a little amount of water for the strengthening reaction between the clay and silt fractions of the soil sample [59-60]. This reaction is accountable for the improved strength of the treated soil since the calcium ions in the OSA and PSA react with the silica or alumina in the untreated soil thereby resulting in bond development of calcium silica hydrate or calcium aluminate hydrate or both [59-60].

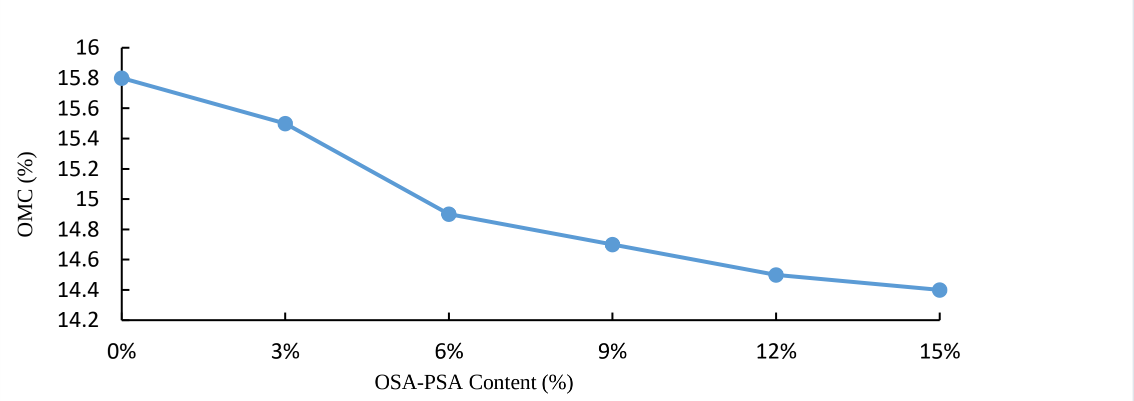

Figure 6. Varying OMC with increasing OSA-PSA Content

4.2.2 Maximum Dry Density (MDD)

Figure 7 represents the variance in MDD with increasing OSA-PSA content. There was an elevation in MDD values as the amount of OSA-PSA content increased. This observed increment in MDD could possibly be attributed to the fact that OSA and PSA have particles with higher specific gravities (2.67 and 2.68 respectively) which replaced that for the soil with a lower value of 2.59. The effect is filling of voids spaces with a resultant dense matrix of higher specific gravity [60-61]. According to [61-62], the elevation in MDD was also due to the increase in the additive particles that were involved in cation exchange hence filling up the void spaces and resulting in the packing of the soil particles together. Hence, an increase in MDD indicates an improved soil property.

This trend is consistent with those of other researchers who used varying additives ranging from conventional (cement, lime and bitumen) to industrial and agricultural additives such as tailings from iron ore, fly ash, polypropylene, kiln dust from cement, groundnut shell ash, concrete wastes and periwinkle shell ash [62-63,63-64,64-65,60-61].

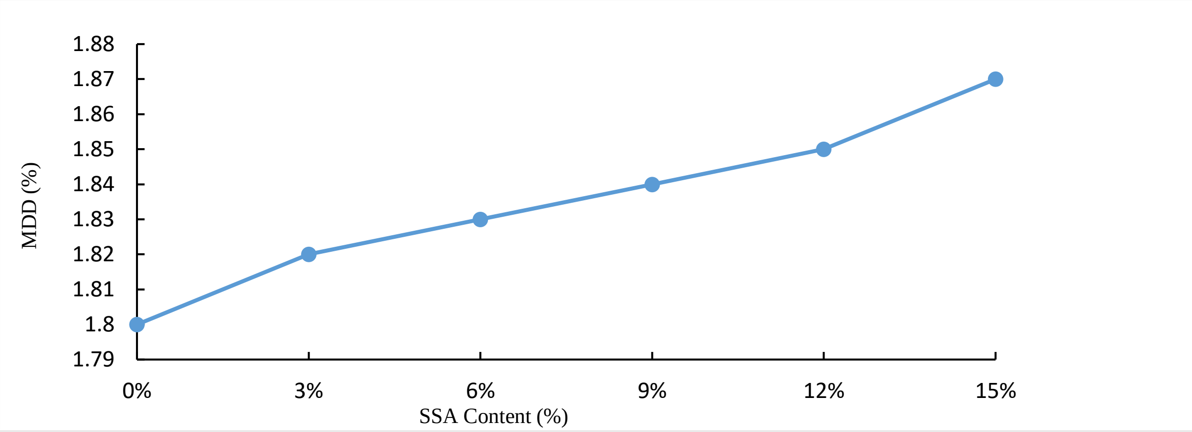

Figure 7. Varying MDD with increasing OSA-PSA Content

4.3. Strength Characteristics

4.3.1 Unconfined Compressive Strength (UCS)

Results of varying unconfined compressive strength (UCS) viz-a-viz increasing OSA-PSA content from 0% to 15% for 7, 14, and 28 days respectively are shown in Figure 8. The results show that an optimal 9% OSA-PSA content produced peak UCS values for the treatment periods considered. It was further observed that the strength values for each specimen tested increased with an increase in curing age.

The strength values for 7-days increased from 111.74 kN/m^2 for the natural sample to an optimum value of 173.49 kN/m^2 at 9% OSA-PSA treatment. At 14 days of curing, the strength values heightened from 126.82 kN/m^2 for the untreated sample to an optimum value of 278.22 kN/m^2 at 9% OSA-PSA content. At 28 days, the UCS values increased from 177.46 kN/m^2 for the untreated sample to a peak of 556.44 kN/m^2 at 9% OSA-PSA content.

The rise in strength values can be accredited to agglomeration and flocculation of the clay structure triggered by a cation exchange within the sample surface. This Ca^{2+} in the OSA-PSA blend reacted with the basal valence metallic ions present in the clay structure of the lateritic soil resulting in an increase in the packing of the clay particles in the lateritic soil which formed larger clogs [58,65-66]. The observed increase could also be because of the combined effects of structural microfabric changes imparted by compaction and the building up of cementitious compounds of calcium silica hydrate (CSH) or calcium aluminate hydrate (CAH) which were induced by hydration reactions of Ca, Si, and Al oxides in the OSA-PSA - lateritic soil mixture. Results obtained are consistent with the works of other researchers which found the crystalline products (CSH and CAH) of hydration reaction act as binding agents in the soil structure and are responsible for strength development with curing age [66-67,59-60,67-68,60-61].

Reduced values recorded with increasing OSA-PSA content beyond 9% could be associated with an increase in the fine content from added OSA-PSA which resulted in the formation of a larger surface area within the lateritic soil-OSA-PSA mixture which causes a buildup of weaker fusion between the lateritic soil and the cementitious compounds obtained. [68-69,60-61].

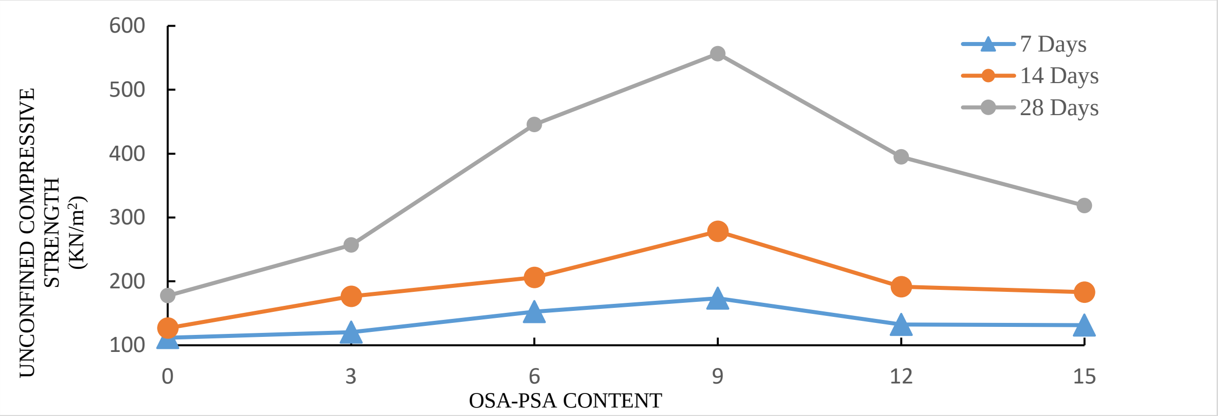

Figure 8. Varying UCS with increasing OSA-PSA Content

4.3.2. California bearing ratio (CBR)

Unsoaked and soaked CBR results for the untreated and treated lateritic soil samples with up to 15% OSA-PSA content are shown in Figure 9. The unsoaked and soaked CBR results increased with an increase in OSA-PSA content up to 9% with the soaked having lower values than the un-soaked. The general reduction in the CBR value of soaked samples when compared with the unsoaked values is attributed to the proliferation of water into the soaked samples thus weakening it and reducing its overall strength however in both CBR tests, the recorded CBR values reduced progressively with further OSA-PSA treatment beyond 9%.

The strength increase observed up to 9% OSA-PSA content in both cases (unsoaked and soaked) can be associated with the presence of calcium ions in the OSA and PSA which reacts with the silica or alumina in the lateritic soil thereby resulting in the development of either CSH or CAH or both cementitious compounds which are majorly responsible for strength gain [69-70,23,70-71]. This progressive reduction in strength values beyond 9 % in both cases with a further increase in OSA-PSA treatment could be attributed to the increased fine content resulting from additional OSA-PSA. This caused the formation of larger surface areas within the lateritic soil-OSA-PSA mixture thereby leading to reduced cohesive bonds between the particles of the clay. Furthermore, it led to a reduction in the interlocking friction within the soil structure and, a reduction in the shear strengths of the samples [60-61].

Peak unsoaked value of 53.35% at an optimal 9% OSA-PSA treatment did not meet up with the recommended 80% requirement for base course materials. However, the peak soaked value of 32.17% met the recommended 30% requirement for sub-base materials [71-72]. It is important to note that the specification stipulates that specimen for soaked CBR test should be soaked for 24 hours, but for this study, soaking was done for 48 hours to simulate cases of extremely worst condition in the field [71-72].

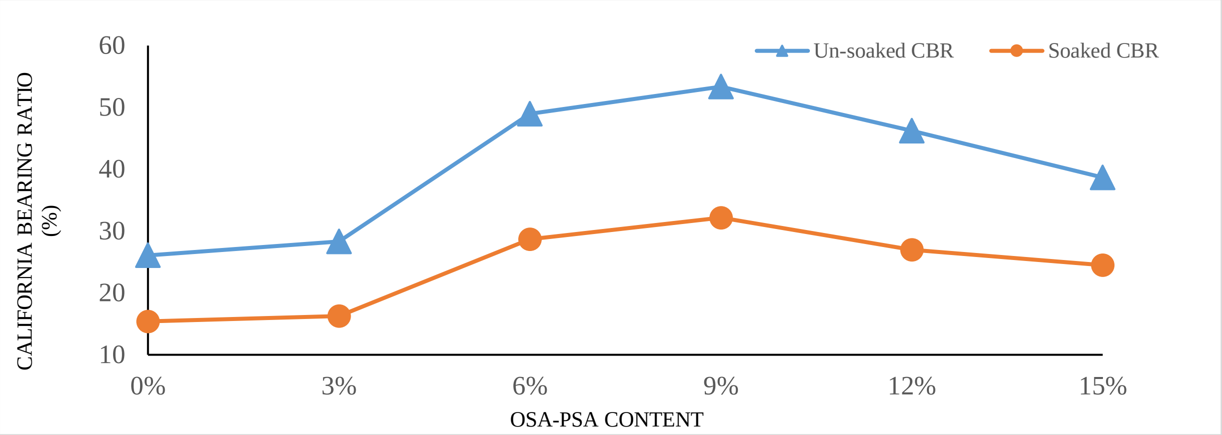

Figure 9. Varying CBR with increasing OSA-PSA Content

4.4. Durability

Figure 10 shows varying resistances to loss in strength associated with increasing OSA-PSA. The resistance to loss in strength progressively increased alongside increasing the OSA-PSA content up to 9% treatment thereafter, a reduction in values were observed.

A minimum resistance to loss in strength of 80% which implies an allowable 20% loss in strength should be achieved by the 7th day of air-curing and by the 4th day of soaking after dewaxing the top and bottom of the sample [72-73,73-74,74-75]. The durability test entails simulating some extreme conditions that may be encountered in the field. In this study, the resulting resistance to loss in the strength of the un-treated lateritic soil was recorded as 11.29% which steadily increased to an optimum value of 21.93% at 9% OSA-PSA content and decreased to 12.15 at 15% content. The optimum value was less than the recommended 80% requirement which infers that OSA-PSA blend may not provide a sustainable strength under adverse conditions if considered as a standalone stabilizer in road construction.

The recorded resistance to loss in strength of 11.29% that was recorded for the un-treated lateritic soil could have resulted from the self-cementing properties as well as the cohesive behavior of the lateritic soil. Furthermore, the observed increase in resistance to loss in strength incorporating the OSA-PSA treatment up to 9% could be attributed to the reactions amidst the calcium ions in the OSA and PSA and the silica or alumina in the soil. This led to the development of bonds of CSH and/or CAH or both which resulted in the significant hardening of the sample hence averting a speedy infiltration of water right through the soil structure [75-76,59-60,70-71,76-77].

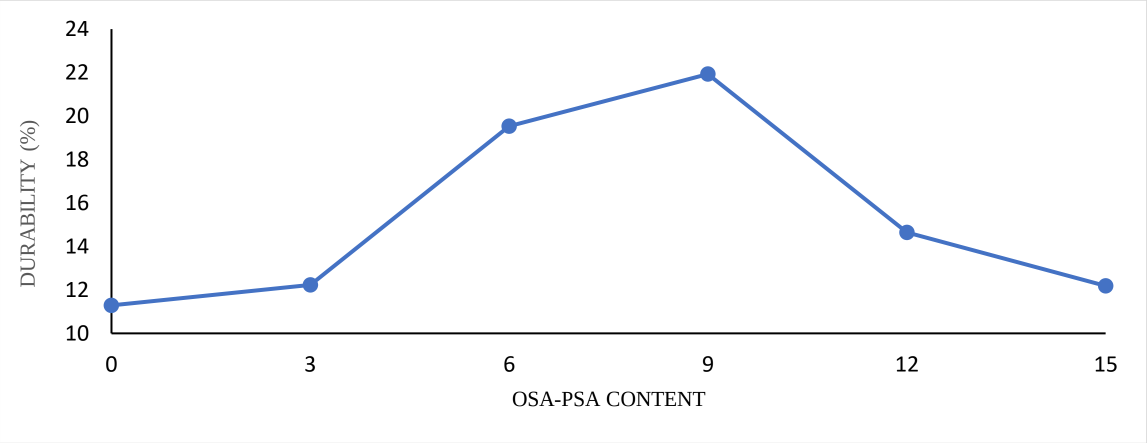

Figure 10. Varying Durability with increasing OSA-PSA Content

4.5 Amount of additive required to stabilize 1m^3 of lateritic soil.

Using the CBR results in Figure 9, the average quantity of OSA-PSA required for optimum stabilization of the samples in this study was estimated to be 9% hence, 9% OSA-PSA by dry weight of lateritic soil was considered in carrying out this analysis. This analysis was carried out based on volume [77], so the 9% by weight was converted to volume hence, 9% by weight is defined thus: Considering 100 kg of OSA-PSA-Lateritic soil material, 9 kg of OSA-PSA and 91 kg of lateritic soil will be required for the stabilization process.

For lateritic soil:

Specific gravity (SG) of lateritic soil = unit weight of lateritic soil/unit weight of water
unit weight of lateritic soil = SG of lateritic soil x unit weight of water
From the laboratory tests carried out,
SG of lateritic soil = 2.59
unit weight of water = 1000 kg/m^3
Therefore,
unit weight of lateritic soil = 2.59 x 1000 kg/m^3 = 2,590 kg/m^3
This implies that:
1m^3 of lateritic soil = 2590 kg of lateritic soil
Then, 1 kg of lateritic soil = 0.0003861m^3 of lateritic soil

For OSA-PSA additives:

SG of additives = unit weight of additives/unit weight of water
unit weight of additives = SG of additives x unit weight of water
From the laboratory tests carried out,
SG of OSA and PSA = 2.67 and 2.68
Taking an average of the two additives, SG = 2.675
unit weight of water = 1000 kg/m^3
Therefore,
unit weight of additives = 2.675 x 1000 kg/m^3 = 2,675 kg/m^3
This implies that:
1m^3 of OSA-PSA = 2675 kg of OSA-PSA
1 kg of OSA-PSA = 0.0003738m^3
But recall:
we need 9 kg of OSA-PSA for stabilization and 91 kg of lateritic soil.
i.e. 91 kg of soil => 9 kg of OSA-PSA
But
1 kg of soil = 0.0003861m^3
Therefore, 91 kg of soil = 0.0003861 x 91
So, 91 kg of soil = 0.035m^3
Also, 1 kg of OSA-PSA = 0.0003738m^3
Therefore, 9 kg of OSA-PSA = 0.0003738 x 9
So, 9 kg of OSA-PSA = 0.00336m^3
⇨ 0.035m^3 of soil = 0.00336m^3 of OSA-PSA
⇨ **1m^3 of soil = 0.096m^3 of OSA-PSA additive**

So, from the analysis above, 1m^3 of lateritic soil can be stabilized using 0.1m^3 of OSA-PSA additive as a stabilizing agent to get an optimum fill CBR strength of 32% (soaked conditions).

5. Conclusion

From the results obtained in this research, the following conclusions are made:

1. The result from the chemical analysis showed that seashell ash and periwinkle shell ash both had higher calcium oxide contents than their powder counterpart hence the ash was used in the study.
2. The consistency limits of the stabilized soil improved. The LL and PI values both decreased from 41.30% and 22.49% for the untreated lateritic soil to 33.14% and 16.56% respectively at an optimum blend of 9% OSA-PSA content.
3. CBR values improved from 15.4 and 26.07 % for the natural sample to 32.17 and 53.35 respectively at an optimal 9% OSA-PSA content for both soaked and un-soaked CBR samples.
4. Recorded UCS values generally improved with an increase in curing age and OSA-PSA content. Peak UCS values were recorded as 173.49, 278.22 and 556.44 kN/m^2 at 7, 14, and 28 days curing durations respectively at an optimal 9% OSA-PSA content.
5. An increase was recorded in the resistance to loss in strength from 11.29% for the natural lateritic soil to an optimum value of 21.93% at 9% OSA-PSA content.

6. Recommendation

Results from this study showed that OSA-PSA blend calcined at 750℃ for 30 ± 2 mins which was used to stabilize lateritic soil at optimal 9% content generally improved the engineering properties of lateritic soil.

Hence, it is recommended that OSA-PSA blend at an optimum content of 9% can be utilized as a standalone additive for stabilizing fill material used for low volume pavements rehabilitation works. In addition, the OSA-PSA optimum blend of 9% can also be used as a standalone subgrade stabilizer for material used directly under a concrete walkway or as stabilized compacted soil used directly underneath the gravel base layer when constructing an interlocking paved walkway.

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