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Case study

Ameliorating effect of milled eggshell on cement stabilized lateritic soil for highway construction

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ABSTRACT

This case study outlined the outcomes from the laboratory assessment of a lateritic soil stabilized with milled eggshell, cement and mixture of both in ratio 1:1 for potential use as a highway construction material. The stabilizing binders were added to the soil at varying percentages of 0, 2, 4, 6, and 8% by weight of the soil and afterwards subjected to various laboratory tests to determine its ameliorating effect. The test results showed that both unsoaked and soaked California bearing ratio (CBR) values increased with higher stabilizing binder content. The unconfined compressive strength (UCS) values just like the CBR values also increased with higher stabilizing binder content. The 8% milled eggshell and cement stabilized samples recorded peak UCS value of 760.7 kN/m^2, unsoaked CBR value of 87% and soaked CBR value of 45%. This peak UCS value met the condition by Nigerian General Specifications for highways of 750–1500 kN/m^2 for use as subbase material for light trafficked highways. The microstructural analysis gave a possible explanation for an increase in the strength and decrease in Atterberg limit of stabilized samples. The durability of some stabilized soil samples was satisfactory, the percentage resistance to loss in strength was not below the recommended maximum of 80%. An 8% by soil weight of milled eggshell and cement mixture in ratio 1:1 stabilized lateritic soil could be used as a potential subbase material for highway construction.

1. Introduction

A common antecedent for pavement failure of most roads (especially in Nigeria) is the poor quality of the lateritic soil used in its construction. This soil type is mainly differentiated by its poor workability, low shear strength, high compressibility and poor bearing capacity [1,2]. Stabilization with an additive will help ameliorate this type of soil for use in pavement construction rather than replace them with good quality soil which is uneconomical [3]. There is an increase in the soil strength through binding of its particle bunch like the cementing of aggregates in concrete [4]. Stabilization will also reduce soil compressibility [5], modify the soil drainage characteristics [6], increase its bearing capacity [7] and workability

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[8]. Stabilization ameliorates both physical and chemical properties of the soil [9]. Cement and lime are the two most widely known stabilizing binders, they could be used alone or both combined [10]. However, these two are gradually being replaced due to their cost and environmental impact during production [11,12]. There is a need for geo-environmental engineers to protect the environment from the tons of waste that are generated from this agrarian revolution. One such way is recycling these wastes into materials for highway construction [13]. Several agricultural wastes like nanosized palm bunch ash and pulverized cow bone had been researched on as pozzolans for potent soil stabilization [14,15]. These pozzolans could be used alone as a stabilizing binder in improving soil properties or alongside primary binders like lime and/or cement for building [16] and highway construction [17,18] as well as waste containment structures [19].

Recently among other wastes that are calcium based and largely generated in Nigeria, specific studies are being carried out on eggshell for its various civil engineering uses. Eggshell had been studied as partial replacement of cement in concrete [20], as a fine aggregate in concrete [21], as a filler in hot mix asphalt [22]; as a stabilizing binder for soil improvement [23]. These various engineering applications of eggshell had led to environmental sustainability through the production of a low-cost raw material and waste management. A detailed knowledge of materials behaviour, as well as their utilization, is an important aspect of road design and construction [24]. The use of milled eggshell as a stabilizing binder by Olarewaju et al. [25] showed that it had very low binding property inferred from the minor improvement in the geotechnical properties of the soil. The milled eggshell like other pozzolans will possess a better binding property when combined with a primary binder (cement, lime). Okonkwo et al. [26] used the ash from the incineration of eggshell along with cement for the stabilization of lateritic soil. Apart from the environmental concerns that resulted from the burning process, the stabilized soil did not measure up to standard. Hence the purpose of this study which attempts the use of milled eggshell, milled eggshell combined with cement and cement alone as a stabilizing binder. Their effects on the lateritic soil and their potential for use as highway construction materials.

2. Materials and methods

2.1. Materials

The materials used in this study were lateritic soil, Milled Eggshell (MES) and Ordinary Portland Cement (OPC). The lateritic soil used in this study was collected from Ora Ayoka permanent site along Omu-Aran Ilofa road, Kwara State, Nigeria. Relatively undisturbed samples of the soil were collected from the trial pit between the depths of 1.2 and 1.5 m. The milled eggshell was prepared from the eggshells collected in the Landmark University farms. The eggshells were air dried and milled into powder form which was sieved through sieve #200 with 75 μm aperture. The uniform powdery form of the sieved milled eggshell allows for faster and effective chemical reaction because of its large surface area. A grade 42.5 OPC that met the requirements of ASTM C150 [27] was purchased from a retailing outlet.

2.2. Sample preparation and experimental program

After determination of the engineering properties of the lateritic soil samples, the soil was air dried due to the evident alterations in compaction characteristics of soil when oven dried [28]. Three modes of stabilizing binder were added to the air-dried lateritic soil samples they include (i) Ordinary Portland Cement (OPC), (ii) milled eggshell (MES), and (iii) mixture of milled eggshell and Ordinary Portland Cement in ratio 1:1 (MES&OPC). The stabilizing binders were added to the lateritic soil samples in varying percentages of 0, 2, 4, 6, and 8% by weight of the soil. The selected percentages were in the range of those used by previous researchers [25,26]. The soil mixtures were mixed thoroughly before subjecting them to the standard Proctor compaction test. The test which is to determine the optimum moisture content (OMC) and the maximum dry density (MDD) were conducted at the standard Proctor energy level in accordance with ASTM D698 [29]. Unconfined compressive strength (UCS) tests were conducted on samples compacted at OMC in moulds having a diameter of 40 mm and height of 81 mm. The UCS test was conducted on samples cured under controlled conditions (constant room temperature of 23 °C and relative humidity condition of 100%) for 7, 14 and 28 days in accordance with the provisions of ASTM D2166 [30] using a triaxial machine. California bearing ratio (CBR) was conducted on unsoaked and soaked (24 h) samples at their MDD and OMC in accordance with the guidelines stated in ASTM D1883 [31]. Atterberg limits which consist of plastic limit (PL), liquid limit (LL) and plasticity index (PI) were conducted on the prepared samples in accordance to ASTM D4318 [32]. Durability assessment was performed by ascertaining stabilized samples resistance to loss in strength. This was estimated by dividing the UCS of stabilized samples cured for 7 days under controlled conditions and afterwards soaked in water for another 7 days with the UCS of another set of stabilized samples cured for 14 days under controlled conditions in accordance with BS 1924 [33]. The wet-dry and freeze-thaw tests highlighted in ASTM standard were not considered since they are not applicable for tropical climate [34]. All tests were conducted at room temperature. Atterberg limit, UCS, CBR and durability tests were performed on triplicate samples, the average and standard deviation values are presented. Scanning electron microscope (SEM) images of the natural lateritic soil, MES and stabilized sample were obtained.

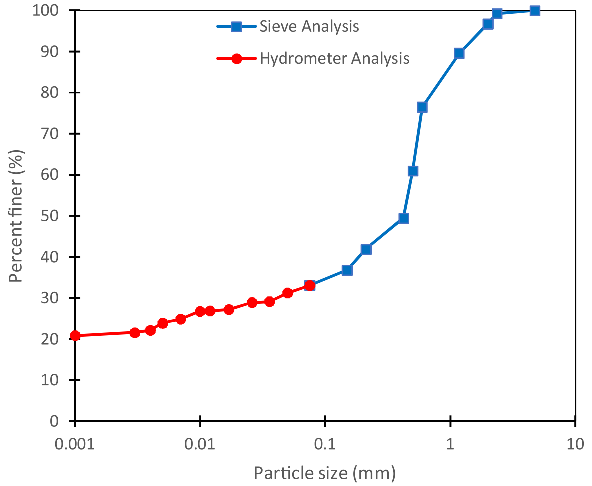

Fig. 1. Particle size distribution curve of natural lateritic soil.

Table 1
Engineering properties of natural lateritic soil.

Properties	Results	Properties		Results
Colour	Reddish brown	AASHTO classification (Group Index)		A-2-7(1)
% passing through BS sieve 75 μm	33.10	USCS classification		SM (Silty sand)
Natural moisture content (%)	10.0 ± 2.0	California bearing ratio (%)	Unsoaked	8.2 ± 2.5
Liquid limit (%)	45.0 ± 3.5		Soaked	7.9 ± 2.4
Plastic limit (%)	30.0 ± 2.5	Unconfined compressive strength (kN/m^2)		227.8 ± 9.8
Plasticity index (%)	15.0 ± 2.9			

3. Results and discussion

3.1. Basic geotechnical test

The particle size distribution curve of the lateritic soil is shown in Fig. 1, while the engineering properties are summarized in Table 1. The results of the basic geotechnical test on the lateritic soil in its natural state showed a liquid limit of 45% and plasticity index of 15%, an indication of medium plasticity and swelling capacity (free swell value is 22%). With about 33.1% passing through sieve 75 μm, the natural soil met the requirements of the Nigerian General Specifications for highways [35] of not more than 35% passing through sieve 75 μm, maximum plasticity index (PI) of 30% and liquid limit (LL) of a maximum of 50% for subgrade material in road construction. The chemical composition of the lateritic soil, MES and OPC are listed in Table 2. As shown, the main oxides present in the lateritic soil were oxides of silicon, aluminium and iron with composition at 52.59%, 30.80% and 7.57% respectively. The laterization degree of 1.37 calculated from the ratio of silica to sesquioxides ($SiO_2/(Fe_2O_3 + Al_2O_3)$) for the natural soil's chemical composition in Table 2 confirmed that it was a lateritic soil. The ternary plot of the three main oxides of the lateritic soil to know the magnitude of laterization in the soil is shown in Fig. 2, the soil was located on the kaolinized profile. MES cannot be classified as a pozzolan because the sum of silica and sesquioxides was less than the minimum 70% recommended by ASTM C618 [36]. The high loss on ignition value for MES (40.78%) could be attributed to high percentage of calcium oxide. Despite the higher percentage composition of calcium oxide in OPC (63.5%) than MES (53.6%), percentage loss on ignition was not high for OPC because it was generated through a heating process, unlike MES.

Table 2
Chemical composition of lateritic soil, OPC and MES.

Oxide composition (%)	Silicon dioxide	Aluminium oxide	Iron oxide	Calcium oxide	Sulfur trioxide	Potassium oxide	Loss on Ignition
Lateritic Soil	52.59	30.80	7.57	0.68	0.01	3.51	2.98
OPC	20.71	7.33	1.11	63.50	3.07	0.58	2.51
MES	0.10	1.55	0.62	53.60	1.57	0.01	40.78

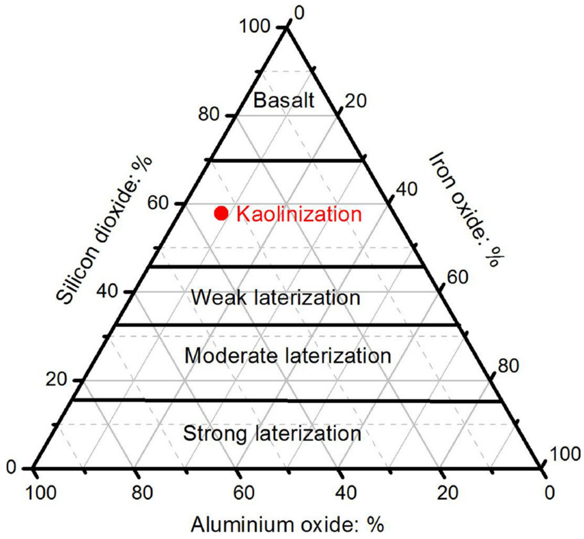

Fig. 2. Ternary plot of natural lateritic soil.

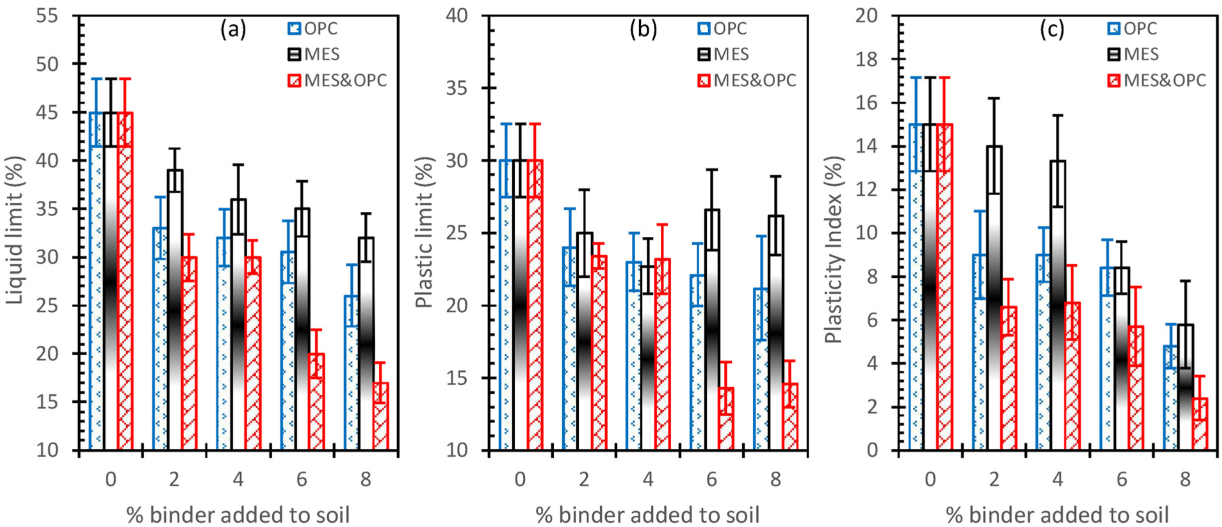

Fig. 3. Variation of Atterberg limits [(a) liquid limit, (b) plastic limit, (c) plasticity index] of lateritic soil with the binder content.

3.2. Atterberg limits

The variation of the Atterberg limit values with the varying quantities of stabilizing binder is shown in Fig. 3. Aside from the plastic limit of samples stabilized with milled eggshell, Atterberg limits (LL, PL, and PI) values decreased with the addition of stabilizing binder to the soil. The Atterberg limit values were in the same range as the values obtained by Olarewaju et al. [25]. The addition of MES&OPC to the soil made it more workable (decreased the Atterberg limits) more than other forms of stabilizing binder. This may be as a result of the efficient process created by the addition of the cement and milled eggshell for optimum dissociation and cation exchange [37]. The addition of the stabilizing binder to lateritic soil causes a colloidal reaction which includes a substitution of cations on the soil surface by calcium cations. This results in flocculation and aggregation of colloidal soil particles, making them less plastic. Some of the stabilized samples recorded plasticity index values less than the 9% maximum recommended for subbase material by the Nigerian General Specifications for highways [35].

The plot of PI against LL to mainly classify the stabilized soil samples (and in turn give first-hand information on the soil sample possible application) according to the American Association of State Highway and Transportation Officials (AASHTO) and Unified Soil Classification system (USCS) is shown in Fig. 4a and b respectively. The AASHTO chart in Fig. 4a showed and confirmed the natural lateritic soil classification as A-2-7. As the quantity of stabilizing binder added to the soil increased, the samples shifted downward left from an area of high compressibility to that of low compressibility, the shift/alteration was

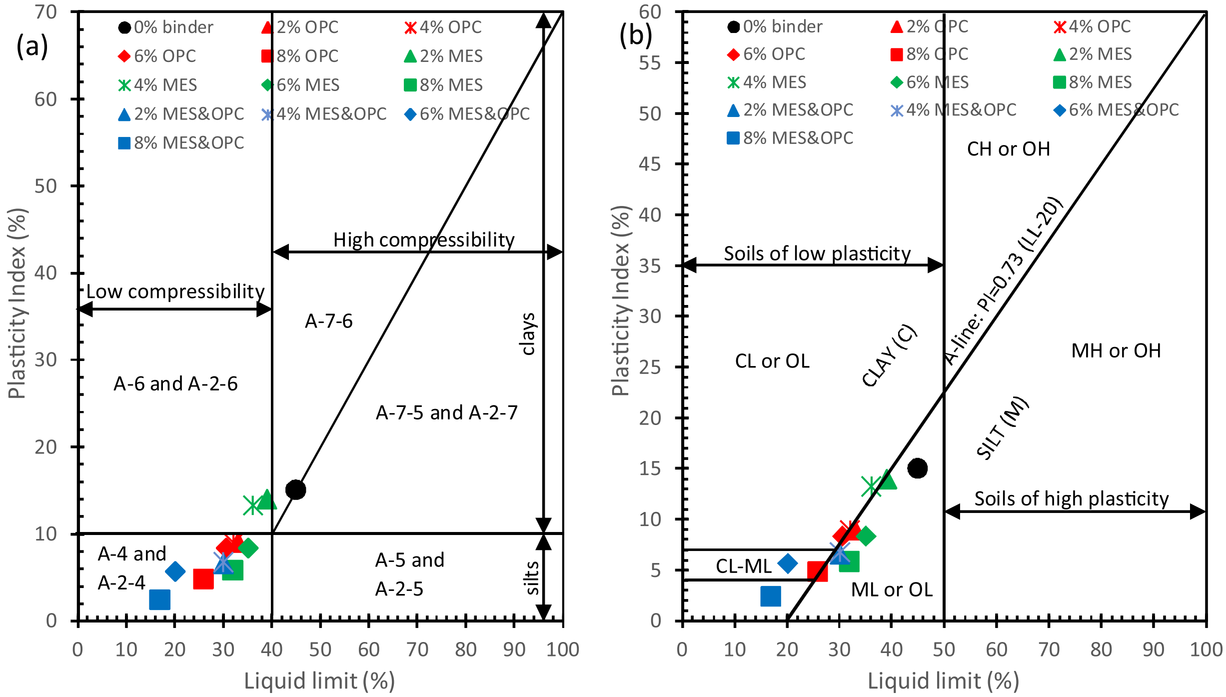

Fig. 4. PI against LL for natural and stabilized samples on (a) AASHTO plasticity chart and (b) USCS plasticity chart.

also from an area of clay to silt soil. The 8% MES&OPC stabilized sample (sample with the lowest PI and LL) alongside some stabilized samples were situated in the A-2-4 portion of the chart. The USCS chart in Fig. 4b showed the classification of the fine particles (particles passing through the sieve with 75 μm aperture) present in the stabilized samples. As the quantity of stabilizing binder added to the soil increased, the samples shifted downward left from a portion of medium plasticity MH (elastic silt) to a portion of low plasticity ML (silt). The 8% MES&OPC stabilized sample (sample with the lowest PI and LL) was situated on the ML (an equivalent of A-2-4 on AASHTO chart) portion of the chart which is a better highway material according to the ratings by Das [38].

3.3. Compaction

The results of the maximum dry density (MDD) and optimum moisture content (OMC) with the addition of the varying quantities of the stabilizing binder are presented in Fig. 5. Fig. 5a shows a decrease in MDD while Fig. 5b shows an increase in OMC as the quantity of stabilizing binder in the soil is increased. As the stabilizing binder increased from 0% to 8%, MDD

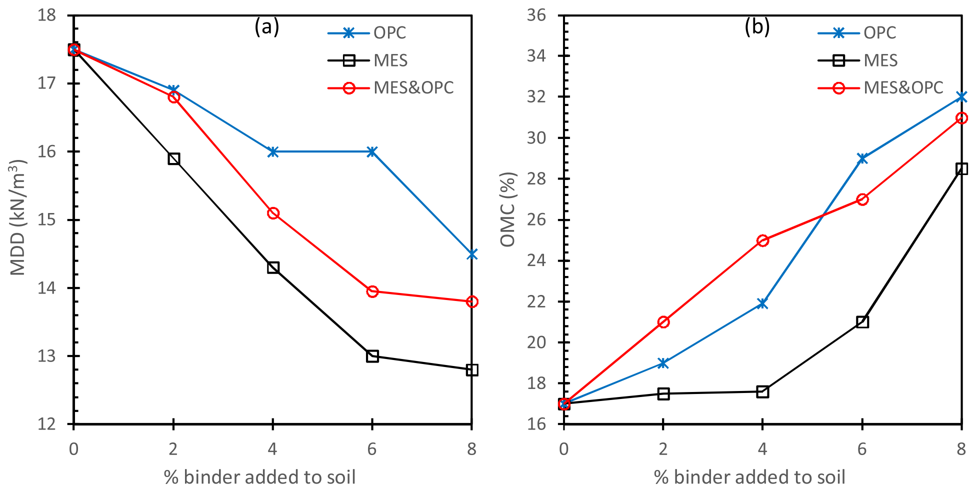

Fig. 5. Variation of compaction parameters [(a) MDD and (b) OMC] with stabilizing binder content.

values decreased from 17.5 kN/m^3 to 14.5 kN/m^3, 12.8 kN/m^3, 13.8 kN/m^3 for OPC, MES and MES&OPC respectively. OMC values increased from 17% to 32%, 28.5%, 31% for OPC, MES and MES&OPC respectively. A similar trend (of a decrease in MDD and increase in OMC) was obtained by Okonkwo et al. [26] who used eggshell ash alongside cement as binder. The decrease in MDD may be attributed to the amalgamation of the stabilizing binder and the lateritic soil intensified by cementitious nature of the binder to form dense aggregates. Osinubi et al. [39] reported that with an increase in volume on the same mass of soil, there is a subsequent decrease in (dry) density of the soil. The specific gravity of the lateritic soil and binder additives may have also contributed to the MDD values obtained in this study. The MES stabilized samples had the lowest MDD (compared to OPC and MES&OPC), lateritic soil particles with a specific gravity of 2.58 in a given volume was substituted by MES content having a comparatively lower specific gravity of 1.11. The OPC stabilized samples had the highest MDD due to the substitution of the 2.58 specific gravity soil particles in a given volume by OPC content having a comparatively higher specific gravity of 3.15. The increase in OMC may be due to stabilizing binder requiring more moisture for the dissociation of the calcium ions and subsequent hydration process.

3.4. California bearing ratio (CBR)

The California Bearing Ratio (CBR) in this study were determined at the standard Proctor energy level, studies had shown that the energy level has a significant effect on the CBR result [40]. The unsoaked and soaked CBR values for the soil samples are presented in Fig. 6a and b respectively. The figures showed an increase in CBR as the quantity of stabilizing binder was increased. The increase in CBR may be attributed to the chemical reaction between the stabilizing binder and the soil particles which is complemented by the compaction process. For the unsoaked samples CBR values increased from a minimum of 8.2% at 0% binder content to 66% at 8% MES content, 73% at 8% OPC content and 86% at 8% MES&OPC content. Soaked CBR values increased from a minimum of 9.98% at 0% binder content to 31% at 8% MES content, 40% at 8% OPC content and 45% at 8% MES&OPC content. The unsoaked CBR values were in the range of the ones obtained by Okonkwo et al. [26] who used a higher OPC content (6 and 8%) alongside eggshell ash, unlike the 4% cement alongside 4% MES used in this study. The CBR value of 8% MES&OPC (which had the highest CBR of all samples tested), met all conditions by the Nigerian General Specifications for highways [35] for use as base, subbase and subgrade materials which are 80% minimum (unsoaked), 30% minimum (soaked) and 10% minimum (soaked) respectively.

3.5. Unconfined compressive strength (UCS) test

Fig. 7 showed the results of the UCS values at different curing periods for the lateritic soil stabilized with MES, OPC and MES&OPC. The UCS values of samples cured for 7 days and soaked for 7days (a factor in determining the durability of sample) were also plotted in Fig. 7. However, this value was not plotted for the lateritic soil with 0% binder because sample deteriorated during soaking and could not be tested. The UCS value of the lateritic soil with 0% binder was 227.8 kN/m^2, by increasing MES, OPC and MES&OPC binder content to 8%, UCS values increased to 345.3 kN/m^2 and 405.8 kN/m^2, 794.8 kN/m^2 and 1011.9 kN/m^2, 839.1 kN/m^2 and 1041.0 kN/m^2 for 7 and 28 curing days, respectively. The increase in the UCS values may be due to the cementitious property of the stabilizing binder which aids in the solidification of the soil matrix thereby increasing the strength. The UCS values were in the range of those obtained by Okonkwo et al. [26] who stabilized an A-6 soil with eggshell ash and cement. The 8% MES&OPC stabilized samples which had the highest UCS value of 839.1 kN/m^2 after 7 days of curing fell short of the UCS value (1710 kN/m^2) specified by TRRL [41] for cement stabilized road base materials.

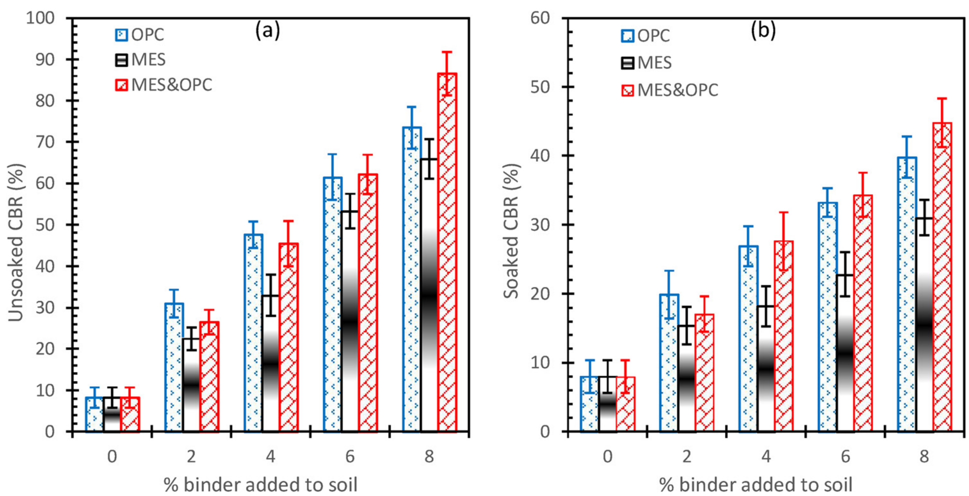

Fig. 6. Variation of [(a) Unsoaked and (b) Soaked] CBR with stabilizing binder content.

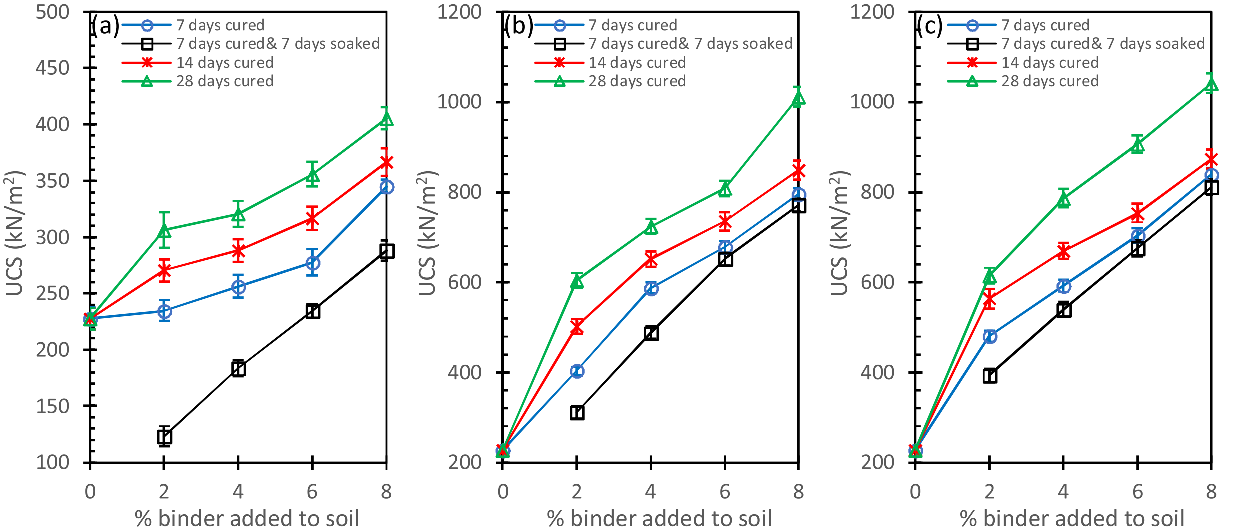

Fig. 7. Variation of UCS with stabilizing binder [(a) MES, (b) OPC, (c) MES&OPC] at different curing periods.

However, this value met the conditions for use as subbase by Ingles and Metcalf [42] of 687–1373 kN/m^2 and by Nigerian General Specifications for highways [35] of 750–1500 kN/m^2.

3.6. Durability

The durability of the lateritic soil with varying stabilizing binder content under tropical conditions was obtained from the sample's resistance to loss in strength. The plot of the percentage resistance to loss in strength against the varying stabilizing binder content is shown in Fig. 8. By increasing the binder content from 2% to 8%, the resistance to loss in strength of stabilized samples increased from 45.6% to 78.7%, 62% to 90.9%, 69.5% to 92.9% for MES, OPC and MES&OPC, respectively. The resistance to loss in strength of the natural lateritic soil (i.e. lateritic soil with 0% binder) was not calculated because its UCS value after 7 days curing and 7 days soaking could not be determined. The durability of some stabilized samples (6% OPC, 8% OPC, 6% MES&OPC and 8% MES&OPC) were however satisfactory because their resistance to loss in strength were higher than the minimum 80% recommended by BS 1924 [33].

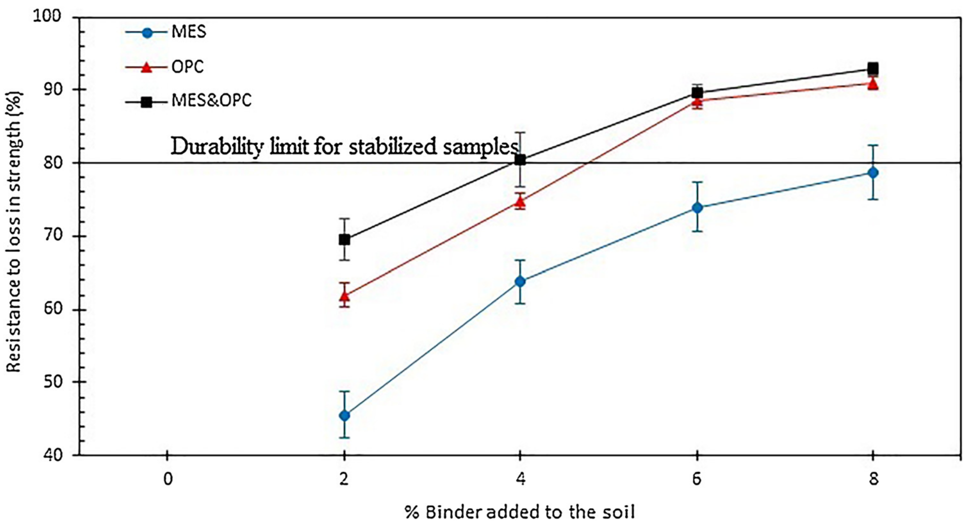

Fig. 8. Variation of resistance to loss in strength of lateritic soil with stabilizing binder content.

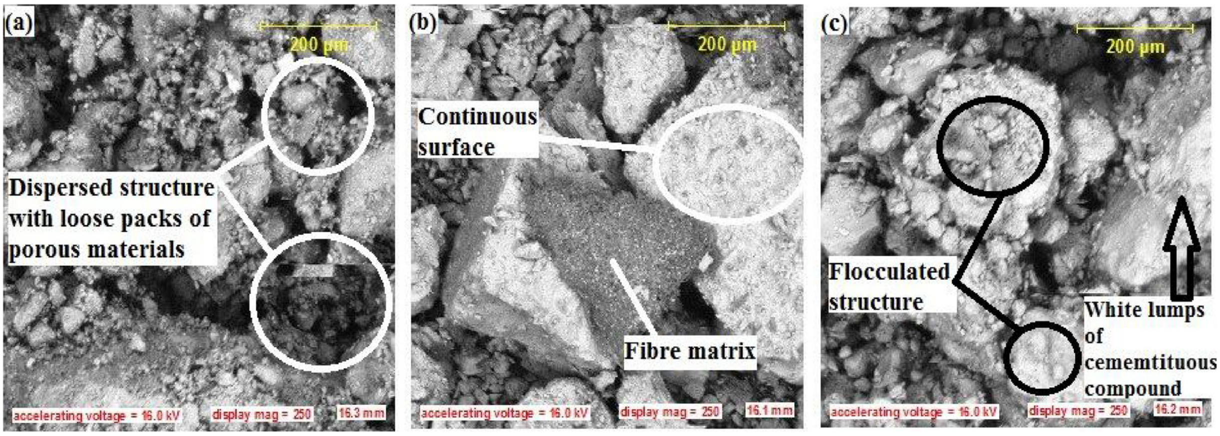

Plate 1. Micrographs of (a) natural lateritic soil (b) milled eggshell {MES} (c) 8% MES stabilized sample.

3.7. Microstructure analysis

The micrographs of the natural lateritic soil, milled eggshell (MES) and 8% MES stabilized sample obtained using the scanning electron microscope were presented in Plate 1 . As shown, the dispersed structure and the presence of loose packs of porous soil materials are evident in the natural lateritic soil (Plate 1 a), while the micrograph of milled eggshell (Plate 1 b) showed a continuous surface with fibre matrices. In Plate 1 c, the image of 8% MES stabilized sample showed a flocculated structure, with the formation of white lumps of calcium ions and cementitious compounds. Calcium ions cation exchange occur between the milled eggshell and lateritic soil when added together resulting in flocs formation; this process is called flocculation. The flocculation of the soil particles gives a denser matrix, making the soil less plastic and decreases the plasticity index. The microstructural characteristics also gave a possible reason for an increase in the mechanical (strength) properties and decrease in the Atterberg limit of the stabilized samples.

4. Conclusion

The lateritic soil was stabilized using various stabilizing binders which include cement, eggshell powder and a mixture of cement and eggshell powder. A series of laboratory tests that included basic geotechnical tests on the collected natural lateritic soil, compaction and strength tests on the stabilized sample was conducted to evaluate the ameliorating effect of the added stabilizing binder. The natural lateritic soil collected was an A-2-7(1) soil according to the American Association of Highway Transportation Officials (AASHTO) and as a SM (Silty sand) soil according to the Unified Soil Classification System (USCS). The Atterberg limits of the stabilized samples all decreased with increase in the stabilizing binder content, a decrease in soil plasticity gave an indication of a more stable soil with marked increased workability. The compaction test results showed that with an increase in the quantity of the stabilizing binder there is a subsequent decrease in the maximum dry density of the soil and increase in the optimum moisture content of the soil. The strength of the stabilized soils gotten from the UCS and (soaked and unsoaked) CBR values of the varying amount of stabilizing binder on the soil showed an increase in strength of samples with an increase in the quantity of stabilizing binder added. The percentage loss in strength showed that the durability of the stabilized soil samples was satisfactory as they did not exceed the recommended maximum of 20%. The microstructural analysis also confirmed the increase in strength and decrease in the Atterberg limits of stabilized samples. The mixture of eggshell powder and cement stabilized lateritic soil could be used as an alternative material for highway construction.

Conflict of interest

The research work is part of a BEng project undertaken by Mr. Temidayo Obayanju. No potential conflict of interest was reported by the Authors.

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