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Original Article

Geotechnical properties of some selected lateritic soils stabilized with cassava peel ash and lime

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ABSTRACT

This study presents the influence of cassava peel ash (CPA) and lime on some geotechnical properties of three lateritic soils. This is with a view to the use of locally available agricultural waste in stabilising lateritic soils. Soil samples (termed A, B, and C) were collected from three different locations in Osun state, South West, Nigeria. Some properties such as particle size distribution, liquid limit (LL), plastic limit (PL), Compaction properties (optimum moisture content, OMC and Maximum dry density, MDD), California bearing ratio (CBR) and unconfined compressive strength (UCS) of the soil samples were determined. Cassava peel collected from a cassava processing factory was calcined at 700^{o}C and CPA produced was sieved through sieve No. 40. Different percentages, 2, 4, 6, 8% (by weight of dry soil) of CPA and a fixed percentage (4%) of lime were mixed with the lateritic soil. Lime was added to supply calcium ion (Ca^{2+}) needed for formation of Calcium Silicate stabilising compounds. The LL, PL, OMC, MDD, CBR and UCS of the stabilised soil samples were determined. There was a general improvement in the geotechnical properties of the soil (especially samples A and B) with about 20% reduction in LL, 38% increase in CBR, 120% increase in UCS. The study revealed that a combination of CPA and lime has the potential of improving the geotechnical properties of fine grained lateritic soil.

1. Introduction

The need for construction of adequate transportation facilities and the maintenance of existing ones are enormously increasing with increase in population. Highway engineers most times are faced with the challenges of providing suitable earth (lateritic) materials for the construction of subbase and sometimes base layers during road construction. Owning to this fact, continuous researches are being carried out by individual, firms and institutions on ways to improve the engineering properties of soils. In some cases the available soils do not have adequate engineering properties to really bear the expected wheel load applied on them, thereby resulting in improvisations to be made so as to make these soils better and more adequate to resist the axle wheel load which will be applied on them after construction. The concept of making the soil better is called soil stabilization. Soil stabilization can be defined as any treatment [including chemical or mechanical) applied to a soil to improve its strength (geotechnical properties) and reduce its vulnerability to water [1]. If the treated soil is able to withstand the stresses imposed on it by traffic load under all weather conditions without deformation, then it is generally regarded as stable [2].

Stabilisation can lead to the alteration of the physical (particle size distribution, arrangement of particles, parking of soil particles, amount of pore fluid) and chemical (soil mineralogy, chemical constitution, chemical bond between particles) properties of soil depending on the method of

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stabilisation used [3]. The alteration of the physical and chemical properties of soil can result in change in some important geotechnical properties of soil such as increased shear strength, stiffness, load bearing capacity, volume stability and reduced lateral earth pressure, compressibility and permeability [3].

Based on the mechanism of altering soil properties for construction work, soil stabilisation can be broadly classified as mechanical and chemical stabilisations. Mechanical stabilization is the process of altering soil properties by changing the gradation through mixing with other soils, densifying the soils using compaction efforts, or undercutting the existing soils and replacing them with granular material. It is achieved by mixing or blending soils of two or more gradations materials to obtain a mixture meeting the required specifications. The soil blending may take place at the construction site, at a central plant, or a borrow area. The blended material is then spread and compacted to required densities by conventional means [4].

Chemical stabilization is the blending of the natural soil with chemical agents with cementitious properties. Stabilisation is achieved when the added chemicals react with the soil and form new and stable chemical compounds that bond or cement the soil particles together [5]. Thus, both the chemical and physical properties of the stabilized soil are changed. Several soil improving additives have been used to obtain different effects. The most commonly used additives are Portland cement, asphalt binders and lime. These chemical stabilizing additives can be mixed with any soil type to achieve stabilisation.

In order to make deficient soils useful and meet geotechnical engineering design requirements, researchers [6–12] have focused more on the use of potentially cost effective materials that are locally available from industrial and agricultural waste in order to improve the properties of deficient soils. The over dependence on industrially manufactured soil improving additives (cement, lime etc) have kept the cost of construction of stabilized road high. Furthermore, the World Bank has been expending substantial amount of money on research aimed at harnessing industrial waste products for further usage [13].

Thus, the possible use of agricultural waste such as Cassava Peel Ash (CPA) will considerably reduce the cost of construction and as well as reduce or eliminate the environmental hazards caused by such waste. Cassava is grown in all ecological zones of Nigeria, but predominantly in the middle belt and the southern parts of the country. Cassava is rich in mineral constituents such as; carbohydrates, starch, protein, fats, and fibre etc., which makes it a very good meal and highly reliable source of energy, sweeteners and industrial raw material. Cassava peel (CP) is a by-product of cassava processing, either for domestic consumption or industrial uses [14]. Adesanya et al. [15] reported that cassava peel constitutes between 20 - 35% of the weight of tuber, especially in the case of hand peeling. Based on 20% estimate, about 6.8 million tonnes of cassava peel is generated annually and 12 million tonnes is expected to be produced in the year 2020. Indiscriminate disposal of cassava peels due to gross underutilization as well as lack of appropriate technology to recycle them is a major challenge, which results in environmental problem. Thus, the need for alternative methods of recycling them (cassava peels) is of paramount importance. Salau et al. [14] studied the pozzolanic potential of cassava peel ash (CPA) and their results showed that cassava peel ash possesses pozzolanic reactivity when it is calcined at 700^oC for 90 minutes. At these conditions, CPA contained more than 70 per cent of combined silica, alumina and ferric oxide.

Laterites are often found and used in tropical regions for the construction of road layers such as the road base and base courses. To ensure the durability of such roads, lateritic soils are often stabilized. In this study, calcium from lime is expected to react in the presence of moisture with silica from CPA and form cementitious calcium silicate hydrate CSH) compounds according to the equation $Ca^{2+} + 2(OH)^- + SiO^2 \rightarrow CSH$. The objectives of this study are to determine the geotechnical properties of the selected lateritic soils, characterize the soil samples and Cassava Peel Ash (CPA), assess the stabilising effect of varying percentages of CPA with a fixed percentage of lime on the geotechnical properties of the soil.

2. Methodology

Lateritic soil samples were collected from three different locations with GPS readings 7º28′46″N, 4º34′45″E (sample A), 7º34′55″N, 4º24′47″E (sample B) and 7º44′54″N, 4º31′10″E (sample C) in Osun state, South West, Nigeria. The locations were borrow pits for ongoing or just concluded road construction. Cassava Peels were collected from a local cassava processing factory. The study areas lie within the basement complex of South Western Nigeria. The parent rocks of soil A is Schists Pegmatised while the parent rock for both soils B and C is Migmatite Gneiss as obtained from the geological map in [16]. Previous study [17] showed that kaolinite is the dominant clay minerals of soils over such rocks in the Southwest Nigeria where the soils are well drained because of high rainfall and elevated temperature.

The cassava peels were washed to remove (dirts and other impurities) and air dried for about two weeks. The dried peels were then calcined at a temperature of 700^oC for 90 minutes (following the recommendation of [18] in an electric furnace. The calcined peels were ground to fine powder and sieved through sieve No. 40 (with 0.425 mm sieve opening). The resulting Cassava Peel Ash (CPA) was kept in an airtight container to prevent moisture gain and any form of contamination. Physicochemical properties such as pH and chemical compositions (i.e. calcium oxide, CaO and silica, SiO_2) of the soil samples and CPA were determined. The pH was determined using a pH meter. The oxide compositions were determined using Particle Induced X-ray Emission (PIXE).

Index properties including specific gravity (G), particle size distribution, Atterberg's limits (Liquid limit, LL and Plastic Limit, PL) of the soil samples were determined according to ASTM D 854, ASTM D 422, and ASTM D 4318, respectively. The index properties results were used to classify the soil according to American Association of State Highway and Transport Officials (AASHTO) and Unified Soil Classification System (USCS) classification systems. Geotechnical properties such as compaction properties (optimum moisture content, OMC and maximum dry density, MDD), California bearing ratio (CBR) and unconfined compressive strength (UCS) of the soil samples were determined. The soil samples were compacted according to the West African compaction method. The West African Compaction Method is a variant of the modified proctor compaction method.

Soil sample was compacted into a CBR mould in five layers, applying 25 blows of a 4.5 kg rammer to each layer. The OMC and MDD of the compacted soil sample were determined. The CBR and UCS of the soil samples were determined according to ASTM-D1883-16 and ASTM D2166, respectively. Samples used to determine the CBR and UCS were remolded using the corresponding OMC and compacted in five layers as explained earlier. A fixed, 4% of lime (based on the optimum obtained by [19] and varying percentages (0, 2, 4, 6, 8%) of CPA by weight of dry soil were added to the soil sample and the aforementioned properties determined. The percentages of CPA were chosen based on similar values used by [12,13,20] who worked on similar agricultural wastes. Lime was added to the soil in order to supply calcium ion (Ca^{2+}) needed for formation of Calcium Silicate stabilising compounds within the soil. Two-way analysis of variance was used to analyse the data in order to determine the statistical significance of the effect of lime and CPA on the geotechnical properties of the soil samples collected at different locations.

3. Results and Discussion

3.1. Physiochemical Properties of the Soil Samples and CPA

The pH and the oxide composition (obtained from the chemical analysis) of the soil samples and CPA obtained from the chemical analysis are presented in Table 1. The pH of the three soil samples shows that they are all acidic which is typical of laterites/lateritic soils [21]. The pH of CPA is basic enough to facilitate the formation of CSH compounds within the soil. This is because it has been shown by [22] that a high pH of about 11 is necessary for the formation of CSH within soil. The addition of lime to the CPA soil mix should also increase the pH of the soil. The percentage of CaO and SiO_2 obtained in CPA agrees relatively with the results obtained by [14] and doubles the amount obtained by [23]. The varying amount of CaO probably suggests that the location of collection of the cassava peel matters. The three soil samples contain reasonable amount of SiO_2 and almost zero amount CaO as presented in Table 1. It is typical of Tropical Laterite/lateritic soils to contain no or very small amount of CaO because of the intense leaching due to high rainfall and elevated temperature the soil has been subjected to [24].

Table 1. Chemical Composition of CPA and Soil Samples

Sample	pH	CaO (%)	SiO_2 (%)
Soil A	4.8	0.003	39.47
Soil B	5.8	0.007	41.56
Soil C	4.2	0.013	38.54
CPA	11.4	11.64	34.67

3.2. Index Properties of the Unstabilised Soil Samples

The results of index properties of the unstabilised soil samples are presented in Table 2. The specific gravity (G) values for the three soil samples are within the range of values for lateritic soils. Particle size distribution results show that sample A and B have fines contents (P_{200}) greater the 35%, making them fine grained soil while sample C has a fines content of less than 35% making it a coarse-grained soil according to the American Association of State and Highway Transport Officials (AASHTO). The soil samples can be said to contain the kaolinite clay material because according to [25], kaolinite soils have liquid limits values ranging from 35 to 100 % and plastic limit values ranging from 20 to 40%. The LL and PL of the soil samples fall within the range. The low pH of the soil samples is also an indication that the soils contain kaolinite because kaolinite usually have low pH (acidic to neutral) according to [26]. Whitlow [27] reported that soil with LL of less than 35% are of low plasticity; between 35 and 50% are of intermediate plasticity; between 50 and 70% are of high plasticity; and between 70 and 100% are of very high plasticity. Based on this, the three soil samples can be said to be intermediate plasticity soils. Combining the results of Atterberg's limits and particle size distribution results, the soil samples were classified according to USCS and AASHTO clay or silt material as presented in Table 2. Based on AASHTO classification, samples A and B were classified as A-4 and A-7-5, respectively. They are considered as Silty-clay materials because more than 35 % of their soil materials were finer than 75 µm, while soil sample C was classified as A-2-6 and considered granular because less than 35 % of its material is finer than 75 µm sieve. Sample A having PI < 10 % is considered silty while sample B having PI > 11 % is clayey according to AASHTO. The USCS confirms the above classification as it classified soil sample A as silt with low plasticity (ML) while samples B and C are clay of low plasticity (CL). According to [28], the requirement for a soil to be used as sub base or base course material for road construction is that P_{200} must be less than or equal to 35%, LL must be less than or equal to 35% and PI must be less than or equal to 12% The P_{200}, LL and PI results presented in Table 2 show that soil C satisfied P_{200} requirement and soil A satisfied PI requirement while soil B does not satisfy any of the requirements. From the foregoing, it is essential that all the soil samples be stabilised since none of them satisfied all the requirements.

Table 2. Index Properties of Unstabilised Soil Samples

Properties	**A**	**B**	**C**
Natural Water Content (%)	20.1	18.0	17.3
Specific Gravity (G)	2.75	2.80	2.55
Percentage Passing Sieve No. 40, P_{40} (%)	71.5	85.3	69.9
Percentage Passing Sieve No. 200, P_{200} (%)	41.1	39.1	32.5
Liquid Limit (LL) %	39.0	46.2	35.8
Plastic Limit (PL) %	35.4	30.1	23.33
Plasticity Index (PI) %	3.6	16.1	12.4
AASHTO Classification	A-4	A-7-5	A-2-6
USCS	ML	CL	CL

3.3. Geotechnical Properties of Unstabilised Soil Samples

The compaction test was carried out on the soil samples in their natural states to determine the optimum moisture content (OMC) and the maximum dry density (MDD). The summary of the results is presented in Table 3. From the result obtained it can be observed that soil sample C has the lowest values for both the OMC and the MDD compared to samples A and B. The unsoaked California bearing ratio (CBR) of the soil samples are presented in Table 3.

Table 3. Geotechnical Properties of Soil Samples in their Natural States

OMC (%)	**24.6**	**16.5**	**13.5**
MDD (kg/m^3)	1558	1850	1110
CBR (%)	18.0	21.0	17.0
UCS (kN/m^2)	180	195	159

Das [29] reported that Asphalt Institute recommended a CBR of 7 to 20 % and 0 to 7% for highway sub base and sub grade materials, respectively. [28] however recommends a soaked CBR of ≥ 30% and ≥ 80% for sub base and base course materials, respectively. It is expected that upon soaking, the soil samples will have lower CBR than the unsoaked values. Thus, all the three soil samples are not good sub base or road base materials unless stabilised. The Unconfined compressive strength (UCS) of the soil samples, presented in Table 3 suggests that the samples are of stiff consistency according to [20] which states that soil with a UCS of between 100 - 200 kN/m^2 is of stiff consistency.

3.4. Atterberg Limits of Stabilized Soil Samples

The Atterberg limits of stabilized soil samples are presented in Figure 1. The first number on the label of the x axis in Figure 1 indicates the percentage of CPA while the second number indicates the percentage of lime. There was a general change in the Atterberg's limits of the soil samples on addition of CPA and lime, although the changes are not the same for all the soil samples. The addition of lime caused about 5% increase, 20% and 7% decrease in the LL of samples A, B and C, respectively. Addition of lime also caused a reduction of about 60% and 80% in the PI of soil samples B and C, respectively. The PI of Soil A was however increased by about 50%. Based on these plasticity results, addition of lime was detrimental to the plasticity characteristics of soil A but beneficial for soil B and C. These variations in the response of the soil samples to lime and CPA stabilization might be due to the fact that soil A is from a different parent material than soils

B and C even though they all contain kaolinite clay mineral.

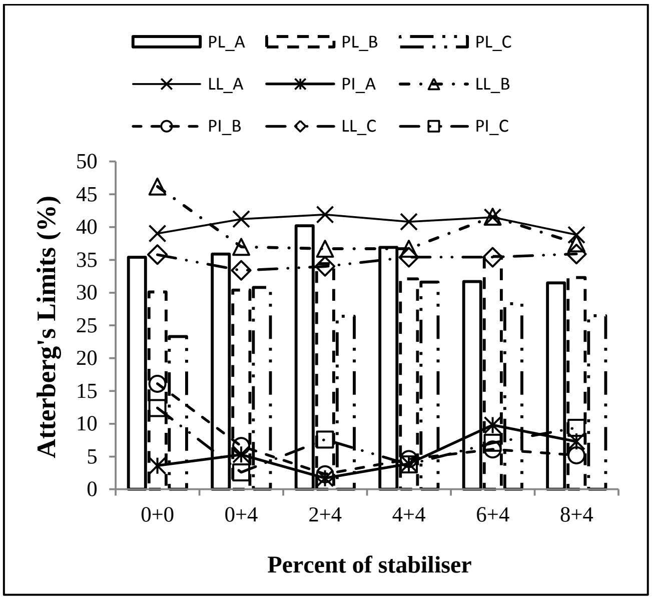

Fig 1. Variation of Atterberg's limits with increasing CPA and lime for sample A

The reduction in Plasticity is in agreement with the findings of [30] who reported that the effect of lime on the plasticity of a clay soil is the reduction in the plasticity index. The reduction in plasticity index is brought about by an increase in the plastic limit and reduction in the liquid limit of the soil [30]. Portelinha [31] reported an initial reduction in the PI of a laterite from Paulo, Brazil on addition of 2% lime. The PI then increased when lime was increased to 4% and remained unchanged afterward as lime content increased up to 12%. The reduction in the plasticity index of the soil samples can be attributed to cation exchange which occurs when Ca^{2+} ions from the lime replace lower valence cations in the soil, thereby causing a reduction in the diffused double layer by the agglomeration of the particles [32]. Although there was a slight increase in the PI of soil A, the increase in LL led to an increase in its PI. The discrepancies in this study are probably due to the mineralogy of the soil samples. It has been shown that lime can either increase or reduce the plasticity of soil depending on the mineralogy of the soil [19,26].

Two way analysis of variance was used to determine the significance of the effect of lime and CPA on the Atterberg's limits of the soil samples. The results show that the $F_{cal} \leq F_{crit}$ with $p > 0.05$. This means that there is no significant effect of the addition of lime and CPA on the Atterberg's limits of the soil samples. Location of collection of the soil sample is, however, a significant factor ($p < 0.05$) affecting the Atterberg's limit of the soil sample.

3.5. Compaction Properties of Stabilized Soils

The results of the compaction properties of the three soil samples on stabilization with lime and cassava peel ash (CPA) are presented in Figure 2. On addition of only 4% lime to the three soil samples, the optimum moisture contents (OMCs) of soil samples B and C increased while the OMC of sample A decreased.

The increase in OMC of soil B and C did not, however lead to decrease in the Maximum Dry Densities (MDDs) of the two soil samples but, rather, increase of more than 12% in B and 74% in C. The MDD of soil A also increased by more than 18%. The increase in the OMC of soils B and C can be attributed to the additional water needed to enable the pozzolanic soil-lime reactions necessary for the stabilization process to take place. Bell [30] reported that, the addition of lime to clayey soils increases the OMC and reduces the MDD for the same compactive effort. [33] also stated that MDD of soil samples treated with lime were lower while the OMC of treated soil samples were higher than that of untreated samples. However, [32] reported that for Laterite soil samples treated with lime, both the OMC and MDD of the treated soil samples increased. The results of this study showed increase in MDD in agreement with [32], this is probably because this study and that of [32] were on lateritic soil. [19] also reported in comparing the effect of soil mineralogy on lime stabilisation that higher MDD are recorded in kaolinitic clays, this further point to the fact that the soil samples probably contain kaolinitic clay.

On addition of 4% lime and varying percentages of CPA to the soil samples, the OMC of soils A and B were consistently higher than that of the unstabilised soils while the OMC of soil A was consistently lower than that of the stabilised soil. For soil samples A and B, the OMC reduced on addition of 2% CPA while the OMC of sample C further increased. When CPA was further increased the changes in OMC of the three soil samples follow the same pattern in varying degrees. On addition of CPA, there was increase in the MDD of the stabilised soil samples when compared to the unstabilised soils. The MDD of soil stabilised with only 4% lime was however higher than the MDD of soil stabilised with both CPA and lime except for soil A where there was a maximum of 9% increase when 8% CPA was added to the soil. The increase in the MDD of soil A can be attributed to the CPA filling up the voids spaces within the compacted soil and densely packing the soil particles together. Thus, CPA and lime can be said to be most beneficial to sample A in which highest increase in MDD was recorded.

Statistical analysis of the results shows that both CPA/lime and sample location have significant effect on the OMC of the soil samples (since $F_{cal} > F_{crit}$ and $p < 0.05$ for both cases). The effect of sample location on the MDD was only significant at 16% confidence level, while the amount of CPA/lime does not have significant effect on the MDD of the soil samples (since $F_{cal} < F_{crit}$ and $p > 0.05$). The non-significance can be attributed to the fact that enough time was not allowed for the soil sample to beneficially react chemically with CPA/lime mixture.

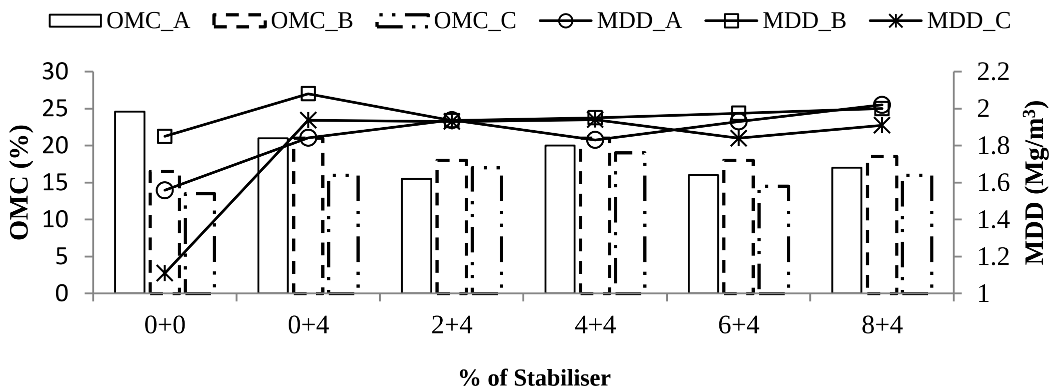

Fig 2. Variation of OMC and MDD with increasing CPA and lime mix for the three soil samples

3.6. California Bearing Ratio of Stabilized Soils

The California bearing ratio (CBR) values of the stabilized soil samples are presented in Figure 3. The addition of 4% lime led to increase in the CBR of soil samples A and B with the higher increase (16%) in soil A. The increase in the CBR of soils A and B can be attributed to the reaction of calcium in lime with the silica in the soil (with high alkaline environment). This is because high alkaline pH condition can induce dissolution of reactive silica and alumina [26].

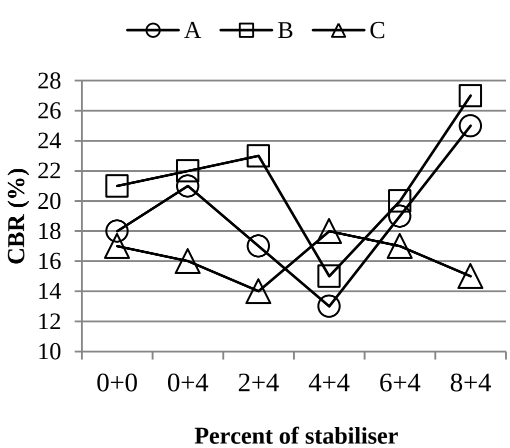

Fig 3. California bearing ratio of the treated soil samples

In paper [19] also reported that lime can attack the minerals in clay. The reduction in the CBR of soil C on addition of lime is an aberration. However, an increase in strength is expected if enough time is given for the lime to react with the soil. There was a further increase in the CBR of soil A when 2% CPA and 4% lime were added to the soil. The CBR of soil B reduced when CPA increase to 4% and increased to the highest CBR at 8% CPA as presented in Figure 3. The CBR of soil A reduced when CPA was added up to 4% CPA, after which it increased up to 8% CPA. The results show that the addition of both lime and CPA led to reduction in the CBR of soil C. There was only about 5% increase in the CBR when lime and 4% CPA was added to soil C.

The CBR of the treated soil samples still did not satisfy the requirement stated in [28] for the soils to be used as subbase material.

3.7. Unconfined Compressive Strength Results of treated soils

The Unconfined compressive strength (UCS) of the treated soil samples are presented in Figure 4. Comparing the values obtained after stabilization with the values obtained when the soil is in their natural states, it was observed that the unconfined compressive strength (UCS) of soil samples A, B, and C reduced with the addition of 4% lime to the soil sample with the decrease more pronounced in soil A (55%).

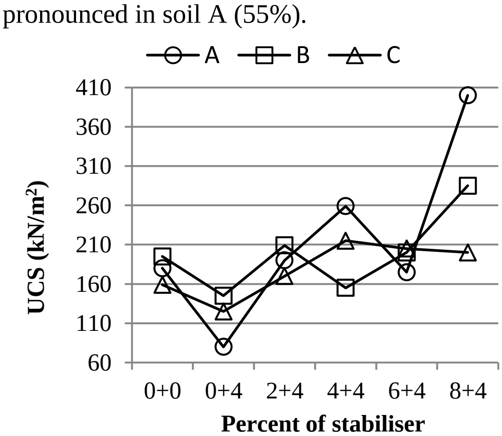

Fig 4. Unconfined compressive strength of stabilised samples

The UCS however increased on addition of 2% CPA for all the soil samples. The UCS of the lime stabilised soil samples show the samples are stiff consistency [29]. The UCS of CPA treated soil samples were higher than the UCS of the untreated soil samples except for sample B at 4% CPA. The results also show no definite patterns for all the soil samples. Statistical analysis of the results show that the varying percentage of CPA has significant effect on the UCS with p = 0.033. The effect of sample location was not statistically significant on the UCS of the treated soil samples.

4. Conclusion

Considering the objectives of the study presented in this paper, several conclusions can be made. Firstly, the index and geotechnical properties of the selected unstabilised soil samples suggest that the soil samples were not suitable as road material and will require stabilisation. Secondly, the effect of the stabilising agents (lime and CPA) varies depending on the soil sample. The effects also vary with no regular patterns. Following the recommendation of [28] in ascertaining the suitability of soil as road material, only the PI requirement was satisfied by the addition of lime and CPA to the soil samples. The LL and CBR requirements were not satisfied. It is therefore recommended that the effect of curing on the soil properties be evaluated. This is because, immediate strength gain might not be obvious as seen in this study.

Conflict of Interest

The authors declare that they have no conflict of interest.

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