International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V71I5P211
Volume 71 Issue 5, 115-124, May 2023

Original Article

A Comparative Investigation on Cement Stabilized Lateritic Soil Admixed with Sugarcane Bagasse Ash and Saw Dust Ash for use in Road Base

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Received: 20 January 2023 Revised: 17 April 2023 Accepted: 09 May 2023 Published: 25 May 2023

Abstract *- The study dealt with the effects of adding sugar cane bagasse ash (SCBA) and saw dust ash (SDA) in cement-stabilized lateritic soil on index properties, compaction characteristics and strength development. Unlike previous studies which focused on the effects of adding these materials without a comparative analysis, this investigation compares the behavior of lateritic soil cement when SCBA and SDA are added separately. Untreated lateritic soil, cement-treated lateritic soil, cement sugarcane bagasse ash and cement saw dust ash-treated lateritic soil(LS) for low-volume road suitability were studied based on Kenyan Pavement Design Guideline for low-volume sealed roads. A number of unconfined compressive strength (UCS) tests were performed initially as follows (0%, 3%, 5%, 7% and 9%) for different curing periods of 7, 14 and 28 days. According to Pavement Design Guideline for low-volume sealed roads, the study suggested 7% cement as the optimum cement content based on their 1.999 MPa UCS values which satisfied the requirement of 1.5MPa for UCS for road base for low-volume sealed roads in Kenya. The next study involved partially replacing the optimum cement content with sugar cane bagasse ash (SCBA) in the following proportions 0%, 2%, 4%, 6% and 7% to obtain the optimum cement & SCBA content required for optimum stabilization of lateritic soil for use in road base for low volume sealed roads. The final segment of this investigation involved partially replacing the optimum cement content with saw dust ash (SDA) in the following proportions 0%, 2%, 4%, 6% and 7% to obtain the optimum cement-SDA content required for optimum stabilization of lateritic soil for use in road base for low volume sealed roads. A number of tests were conducted, which included the Atterberg limits, compaction properties, California bearing ratio and unconfined compressive strength. According to the Kenya Pavement Design Guideline for Low Volume Sealed Roads, 5% cement and 2% SCBA was found sufficient to obtain a UCS of more than 1.5MPa for low volume sealed roads construction, and 5% cement and 2% saw dust ash was found adequate to obtain a UCS of more than 1.5MPa for low volume sealed roads construction, therefore sugar cane bagasse ash and saw dust ash acting singly as an auxiliary additive in cement can be used in the construction of lateritic soil road base for low volume sealed roads in Kenya.*

Keywords *- Sugarcane bagasse ash, Saw dust ash, Unconfined compressive strength, Lateritic soil, Low volume sealed roads.*

1. Introduction

The rapid increase in the world's population, more so in developing countries, has prompted an increased desire for road facilities. Road pavement design guidelines make an assumption that aggregates are an integral ingredient of the road pavement structure, but the depletion of these aggregates has made most nations' initiatives at providing basic roadway facilities for their citizens costlier due to the high cost of aggregates as highway construction material [20]. Consequently, it is necessary for governments to provide policies that encourage the reuse of domestic, industrial, and agricultural wastes that are produced and deposited in large quantities in landfills with associated environmental problems. The safe disposal of these wastes is increasingly becoming a greater concern to the world [16,54,25,12,23]. Most researchers all over the world today are focusing on the utilization of either industrial or agricultural wastes as an alternative material for improving the engineering performance of soil along with other additives. The utilization of these waste products from the industry is economical and also aids in preventing the utility of land as a dumping place [37].

Construction of roads over expansive soils is one of the important civil engineering running issues worldwide due to the fact that expansive soils shrink and swell with changes in moisture content [56]. Failure in the highway pavement structure is mostly caused by environmental factors, overloading and substandard construction materials. The need to improve the engineering properties of highway construction materials for the overall performance of the pavement structure is very important. Soil stabilization is the alteration of one or more soil properties by mechanical or chemical means to create an improved soil material possessing the desired engineering properties. Soils may be stabilized to increase strength and durability or to prevent erosion and dust generation. Stabilization is the process of blending and mixing materials with soil to improve certain soil properties [51]. The increasing population have resulted in the vast construction of the transportation infrastructure. Although urbanization has improved and the majority of people live in urban areas, rural roads still play a crucial role in supporting rural communities to move and transport their goods conveniently [33].

Lateritic soil, predominant in most tropical countries, could replace gravel in low-volume roads. Low-volume roads have average daily traffic (ADT) of below 250 vehicles per day [5]. Fine-grained, tropical lateritic soils are very vulnerable when exposed to the atmosphere. That is, tropical soils alter their properties with interaction with the atmosphere. In dry conditions, the hardened laterite soil can be compacted to produce the hardened layer, but in wet or rainy conditions, the hardened laterite soil becomes a loose layer due to the vehicle load; as such, it is not suitable for the construction of road pavements. Improving the mechanical properties of poor soils is important due to the limited existence of conventional good quality materials such as sand, stone and gravel [53]. Most lateritic gravels are unsuitable for road bases due to poor nodule hardness (incomplete laterization) and high plasticity [32]. Lateritic soil modification is the addition of a modifier (cement, lime, among others) to the laterite to change its index properties. At the same time, stabilization is the treatment of soil to enable its strength and durability to be improved such that they become totally suitable for construction beyond its original classification [47]. [49], observed through his study on the geotechnical properties of saw dust ash stabilized Southwestern Nigeria lateritic soils that the linear shrinkage, natural moisture content, optimum moisture content, maximum dry density, plasticity index, non-soaked California bearing ratio, specific gravity and unconfined compressive strength were optimally improved by the addition of saw dust ash at 6%, he concluded that saw dust ash satisfactorily acts as a cheap stabilizing agent for sub grade and sub base in lateritic soil. [55], in their study on the lime and saw dust ash stabilization of clayey soil, they observed that the maximum compressive strength of stabilized soil was obtained when 5% lime and 8% saw dust ash was used and concluded that saw dust ash is a satisfactory stabilizing agent for clayey soils. This can reduce the construction cost of low-volume roads in the rural areas of the developing world.

[39], researched on the effect of saw dust ash and lime on expansive soil (black cotton soil) and observed that the liquid limit decreased as the saw dust ash and lime content increased up to 2%, thereafter the liquid limit increased as the saw dust ash and lime content increased, plastic limit gradually increased up to 2% and then gradually decreased with increase in saw dust ash and lime content, the maximum dry density increased as the saw dust ash and lime content increased up to 2%, and thereafter decreased with increase in saw dust ash and lime content, the optimum moisture content decreased as the saw dust ash and lime content increased up to 1%, and then it suddenly increased at 2% and decreased with increase in saw dust ash and lime content, the unconfined compressive strength increased as the saw dust ash and lime content increased up to 2% then it decreased gradually with increase in saw dust ash and lime content, the California bearing ratio value increased as the saw dust ash and lime content increased up to 2% followed by a slight decrease with increase in saw dust ash and lime content. [15], researched the stabilization of soft clayey soils with sawdust ash and noted that the optimum percentage of the sawdust ash for improvement in the soil samples was 4 to 6%. They concluded that saw dust ash can be considered a cheap and acceptable stabilizing agent in road construction.

[18], carried out research on the effect of bagasse ash on lime-stabilized lateritic soil and noted that the lateritic soil was classified as an A-6-9 soil using the American Association of State Highway and Transportation Officials (AASHTO) classification system and CL using the Unified Soil Classification System (USCS). They noted that the Peak unconfined compressive strength and California bearing ratio values of 698 KN/m^2 and 43% were recorded for soil treated with 8% lime and 6% bagasse ash. Although the properties of the natural soil improved, the peak unconfined compressive strength value did not reach the 1710 KN/m^2 value specified by Transport and Road Research Laboratory (TRRL) as a criterion for adequate stabilization using Ordinary Portland Cement. [2], when studying the effect of bagasse ash on the properties of cement-stabilized black cotton soil observed that the maximum dry density and optimum moisture content of the soil were affected by cement and bagasse ash treatment. The soaked 7 days California bearing ratio value was achieved with 8% cement and 5% bagasse ash stabilization, which was 73%, slightly below the recommended 80% value for base material. In addition, the blend with 8% Cement and 5% bagasse ash at 7 days achieved an unconfined compressive strength value of 851 KN/m^{2,} which did not meet the base course requirement of the Nigerian Federal Ministry of Works specifications but fell within the range (750 - 1500 KN/m^2) of the 7 days unconfined compressive strength recommended for sub base. Their study recommended the application of 5% bagasse ash and 8% ordinary Portland cement as the optimum blend for the stabilization of black cotton soil for use as a sub-base in flexible pavement.

[3], conducted research on the stabilization of expansive soil using sugarcane straw ash and observed that the

unconfined compressive strength value increased with the increase in the curing period. The increase in the unconfined compressive strength value was more significant for the 10 % addition of sugar cane straw ash. The California bearing ratio value also increased with the increase in the curing period. The peak California bearing ratio value was obtained for a 10 % addition of sugarcane straw ash and decreased with a further increase in the percentage of sugarcane straw ash. The swelling property was reduced with the increase in the sugar cane straw ash percentage and the increase in the curing period. [28], focused their study on the use of bagasse ash for the stabilization of lateritic soil and reported that the maximum dry density and optimum moisture content of the treated soil showed trends of decrease and increase, respectively, with higher bagasse ash content. They noted that the trend could be of advantage in construction involving wet soils since there is less need for the soil to be dry prior to compaction. The unconfined compressive strength increased from 366 KN/m^2 for the natural soil to 836, 842 and 973 KN/m^2 for specimens treated with 2% bagasse ash content and cured for 7, 14 and 28 days, respectively. The soil samples stabilized with bagasse ash, though they recorded some gain in unconfined compressive strength that did not satisfy the 7-day 1,700 KN/m^2 strength criterion recommended by TRRL (1977) for base course materials. They noted that the material could be used for low-cost roads with light traffic. The maximum California bearing ratio value of 16% was recorded for soil treated with 2% bagasse ash. This value does not meet the requirement of the Nigerian General Specifications (1997) of 180% for laboratory tests of the cement-stabilized material mix-in-place method. The resistance to loss in strength achieved at 2% bagasse content is 9%, which implies that bagasse ash cannot be used as a lone stabilizer in road pavement.

[30], conducted their research with a focus on enhancing the engineering properties of expansive soil using bagasse ash and hydrated lime, they observed that increasing the amount of bagasse ash and hydrated lime bagasse ash admixture from 0% to 25% (based on dry soil mass) resulted in a significant decrease in linear shrinkage and there was a significant improvement in California bearing ratio values with increase in bagasse ash and hydrated lime-bagasse ash combinations from 0% to 25%. They concluded that the hydrated lime-bagasse ash admixture stabilized expansive soil satisfied the requirements for most specifications for either subgrade or subbase materials for road and highway construction purposes based on California bearing ratio. [21], studied the bagasse ash as an auxiliary additive to lime stabilization of expansive soil, strength and microstructural investigation and concluded that the maximum strength gain on the addition of bagasse ash was achieved not at optimum lime content but at initial consumption of lime, the pattern of percentage strength gain was similar for pure lime stabilization and bagasse ash amended lime stabilization of expansive soil.

The previous studies dealt with the saw dust ash, sugar cane bagasse ash used separately with cement or lime without comparing their effects on cement-stabilized lateritic soils, but this research has focused on the comparative investigation of the effects of sugar cane ash and saw dust ash on cement stabilized lateritic soil for possible use in road base for low volume sealed roads.

2. Materials and Methods

The materials used in this research were; lateritic soil(LS), Ordinary Portland Cement(OPC), Sugar cane bagasse ash (SCBA) and Saw dust ash (SDA). The lateritic soil used for this study was obtained from the Kamiti area, County of Kiambu, Kenya. The soil sampled was first dried in the sun for two days to become fully dry. The color of the sampled and dried soil was reddish brown, showing that it had high iron oxides. Ordinary Portland Cement (42.5N), one of the common agents for stabilization purposes in road engineering, was selected as the main binder [44]. Ordinary Portland cement applied in this investigation was CEM I 42.5N, produced by the Bamburi Cement Company in Kenya and obtained from Thika Town in the County of Kiambu, Kenya. The saw dust ash used for this study was obtained from a Timber Processing Factory in Kiambu Town, County of Kiambu, Kenya. After collection, clean sawdust was air-dried and burnt in a furnace at a temperature of 800^0 C. This burning which is typically different from that done by sawmills was done in a closed furnace so that the ash produced did not escape into the atmosphere and, by implication, yielded larger quantities of the ash with minimized environmental pollution [17]. The saw dust ash (SDA) was then sieved through 600-micron sieves to remove the lumps, gravels, unburnt particles and other materials deleterious to the soil. The saw dust ash passing through 600 microns sieve was used for the laboratory investigation. The pH and specific gravity of the saw dust ash used in this study were 12.8 and 1.74, respectively. The sugar cane bagasse used in this research was collected from South Nyanza Sugar Company (SONY) in Awendo town, County of Migori, Kenya. The bagasse ash used had a pH of 9.60 and specific gravity of 2.22. The air-dried bagasse was burnt in a locally constructed incinerator at a controlled temperature range between 600°C and 700°C to get the bagasse ash [2]. The bagasse ash obtained was passed through BS No. 200 sieve.

The Engineering properties of the lateritic soil were investigated in the laboratory in accordance with BIS specifications which included liquid limit, plastic limit, shrinkage limit, specific gravity, grain size distribution, compaction characteristics, California bearing ratio (CBR), unconfined compressive strength (UCS), pH followed by classification of the soil. The chemical and elemental analysis of lateritic soil, cement, saw dust ash and sugar cane bagasse ash was done through X-ray fluorescence (XRF).

Table 1. Properties of lateritic soil

Property	Value
Liquid limit	47.7%
Plastic limit	25.0%
Plastic index	22.7%
Shrinkage limit	11.8%
Maximum Dry Density	1.72g/cm^3
Optimum Moisture Content	18.0%
Unconfined Compressive Strength	0.226MPa
California Bearing Ratio	30.9%
AASHTO Classification	A-2-7

Table 2. Experimental design for cement and SCBA

Optimum Cement Content		Optimum Cement, SCBA Content			
LS	**CEM**		**LS**	**CEM**	**SCBA**
100	0	**C1**	100-n-0	n	0
97	3	**C2**	100-n-2	n-2	2
95	5	**C3**	100-n-4	n-4	4
93	7	**C4**	100-n-6	n-6	6
91	9	**C5**	100-n-7	n-7	7

Table 3. Experimental design for cement and SDA

Optimum Cement Content			Optimum Cement, SDA Content		
LS	**CEM**		**LS**	**CEM**	**SDA**
100	0	**A1**	100-n-0	n	0
97	3	**A2**	100-n-2	n-2	2
95	5	**A3**	100-n-4	n-4	4
93	7	**A4**	100-n-6	n-6	6
91	9	**A5**	100-n-7	n-7	7

The soil was stabilized with cement through the addition of varying proportions of cement from 0%, 3%, 5%, 7% and 9% by weight of the soil as the initial segment of this investigation. Previous studies used the same proportion for soil stabilization in road construction [42,6,45]. A number of tests were conducted on the soil-cement samples to find out the optimum cement content (n%). The tests conducted included the: Atterberg limits, which were done in accordance with BS1377: Part 2: 1990, Moisture content, maximum dry density (MDD) and California bearing ratio, which were done in accordance with BS 1377: Part 4: 1990, pH which was done in accordance to BS 1377: Part 3: 1990 and unconfined compressive strength which was done into accordance to BS1924: Part 2: 1990.

The UCS tests were carried out on the samples compacted at their optimum moisture content in the standard Proctor mold with an internal diameter of 100 mm and an internal height of 115 mm [9,60,61]. The samples were subjected to curing for 7, 14, and 28 days under controlled conditions in a curing cabinet with a relative humidity condition of 100%. The samples were then subjected to a uniaxial compression test at a rate of 0.2 m/s using a compression machine. At the point of failure, the maximum load was recorded, and the maximum compressive strength, the UCS value, was calculated [61,60,9]. The next investigation involved partially replacing the optimum cement content with sugar cane bagasse ash (SCBA) in the following proportions 0%, 2%, 4%, 6% and 7% in order to obtain the optimum cement-SCBA content required for optimum stabilization of lateritic soil for use in road base for low volume sealed roads as shown in Table 2. This agrees with research undertaken by [29,57,58]. The following tests were conducted to achieve this objective: Atterberg limits, OMC, MDD, CBR and UCS in accordance with BIS standards.

The final investigation involved partially replacing the optimum cement content with saw dust ash (SDA) in the following proportions 0%, 2%, 4%, 6% and 7% to obtain the optimum cement-SDA content required for optimum stabilization of lateritic soil for use in road base for low volume sealed roads as shown in Table 3. The range adopted is within those used by [11,48]. The following tests were conducted: Atterberg limits, OMC, MDD, CBR and UCS in accordance with BIS standards.

3. Results and Discussion

3.1. Characterization of Laterite Soil, Saw Dust Ash and Sugar Cane Bagasse

3.1.1 Grain Size Distribution of Lateritic Soil

Fig. 1 illustrates the grain size distribution curve of lateritic soil as follows: silt 4.9%; clay 17.8%; and 24.7%; and gravel 52.6%. The soil falls in the classification of A-2-7: silty, clay gravel sand in accordance with the American Association of State Highway and Transportation Officials (AASHTO) classification. According to the (AASHTO) classification system, the overall engineering properties of the soil were classified as A-2-7. This shows that the soil is unsuitable as a road base construction material; therefore, the need for stabilization for use in road base construction.

3.1.2. Chemical Composition of Lateritic Soil, Saw Dust Ash and Sugar Cane Bagasse Ash

The main oxides found in the laterite soil were iron oxides 28.47 %, silica oxides 42.94 % and aluminum oxides 18.29 %, as shown in Table 4**.** The silica to sesquioxides ratio [(SiO_2)/(Al_2O_3+Fe_2O_3)] was adopted as an indication of the degree of laterization. This ratio was found to be 0.92, which is less than 1.33, implying that the soil is true laterite [59]. The sum of the silica and sesquioxides contents in the sugar cane bagasse ash (SCBA) is 78.59, as shown in Table 4. which is greater than 70%, the minimum required by ASTM C 618-05 (2005), indicating that the ash is pozzolanic, this is consistent with the findings of other researchers [37,40].

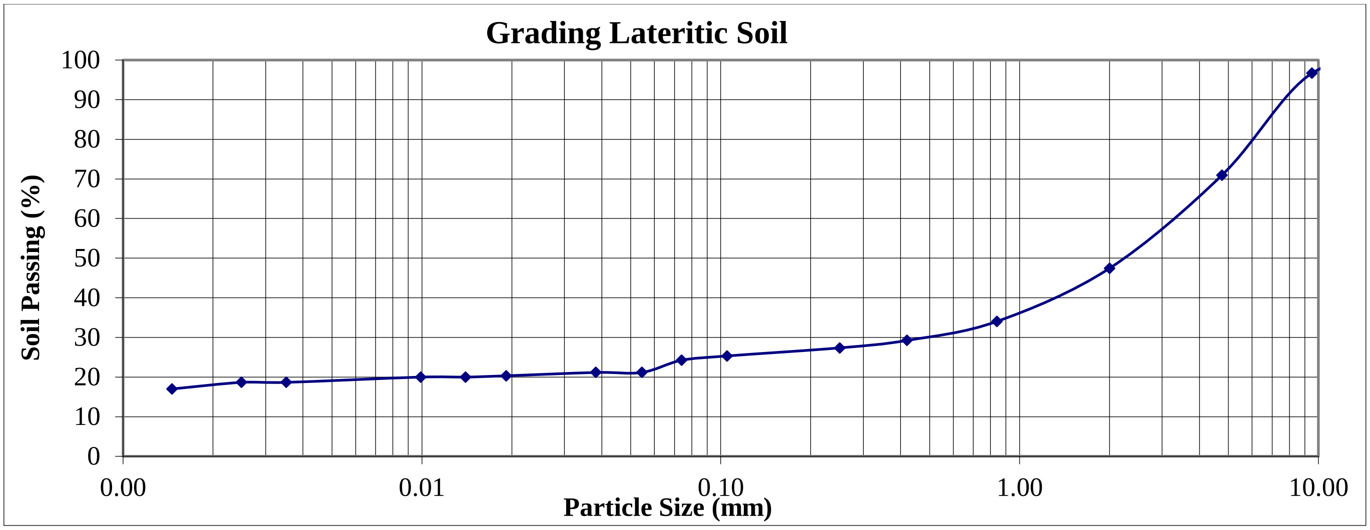

Fig. 1 Particle size distribution curve of the lateritic soil

Table 4. Chemical characteristics of LS, SCBA, SDA

Components	LS	CEM 42.5	SCBA	SDA
Fe %	28.47	4.08	11.58	2.58
MgO %	-	0.49	-	4.03
Al_2O_3, %	18.29	6.02	7.09	0.96
SiO_2, %	42.94	25.30	59.92	-
K_2O, %	1.28	-	5.13	15.71
CaO, %	0.46	59.50	10.39	66.07
TiO_2, %	2.36	-	1.93	0.41
P_2O_5, %	0.21	-	1.50	3.69
S, %	0.14	2.63	1.11	3.75
Cl, %	0.04	0.001	0.21	1.15
Residue, %	-	4.41	-	-
L.O.I@750^{0}C	-	4.39	-	-

Table 5. Variation of atterberg limits with cement

Properties	0%	3%	5%	7%	9%
LL	47.7	52.0	53.1	50.1	42.4
PL	25.0	33.0	36.4	37.8	35.5
PI	22.7	19.0	16.7	12.3	6.9
SL	11.8	10.7	8.57	7.14	5.71

The saw dust ash (SDA) does not exhibit pozzolanic characteristics given the sum of silica and sesquioxides contents is less than 70%, as indicated in Table 4. [17], noted that the SDA contain a high quantity of quicklime, CaO which could be necessary for both short term and long term (pozzolanic) reactions, this finding is consistent with this research which also found that CaO was 66.07%. The results obtained for lateritic soils show that they are within the ranges found for lateritic soil by other researchers [13,7,35].

3.2. Stabilization of Laterite Soil with Cement

3.2.1. Effects on Index Properties and Compaction Characteristics

Results in Table 5 show that the plasticity index decreased from 22.7 to 6.9, indicating that the soil plasticity improved. The higher the plasticity index, the more clayey the soil is [46]. The influence of cement on the compaction properties of lateritic soil is clearly demonstrated in Table 6. The MDD and OMC for untreated soil were obtained equal to 1.72 g/cm^3 and 18.0%, respectively. After mixing, the MDD increased to 1.76 g/cm^3 at 3%, 1.76 g/cm^3 at 5%, 1.77 g/cm^3 at 7% and 1.79 g/cm^3 at 9%. Again, the OMC increased to 21.5% at 3%, 21.5% at 5%, 24.5% at 7% and 24.7% at 9%. This is consistent with the research undertaken by [9].

3.2.2. Effects on California Bearing Ratio

The results in Table 6 show the summary of the soaked CBR values for the varying cement content. The CBR values increased from 30.9% at 0%, 67.5% at 3%, 119.7% at 5% and 175.7% at 9%, increasing cement content to an optimum value of 175.7% at 7% addition of cement. Thereafter the CBR values decreased to 102.6% with a 9% addition of cement. The increase in values of CBR is consistent with the research done by [36,3]. The increase in values of California Bearing Ratio (CBR) upon the addition of cement may be attributed to the presence of adequate amounts of calcium required for the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which are the major compounds responsible for strength gain [18]. The reduction in CBR value at 9% may be due to excess cement that was not mobilized in the reaction, therefore, reducing the bond in the cement and soil matrix [9,51,64]

3.2.3 Effects on Unconfined Compressive Strength

Table 6 shows the results for unconfined compressive strength at 7 days. The unconfined compressive strength increased with increasing cement content. At 7 days of curing time, the untreated UCS of 0.226 MPa improved to 0.483 MPa, 0.775MPa, 1.999MPa and 2.769MPa for 3%, 5%, 7% and 9% cement. The strength improvement is due to the decreased soil porosity when adding cement, compaction and hydration of cement [43,34,9,62]. Cement stabilization involves three processes: cement hydration, cation ion exchange reaction and pozzolanic reaction carbonation [38]. Calcium hydroxide in the soil water reacts with the silicates and aluminates (pozzolans) in the soil to form cementing materials or binders consisting of calcium silicates and/or aluminate hydrates. The UCS at 7 days of curing is the most important strength criterion used for cement-stabilized materials for road purposes. [52], stated that the UCS test should be used to determine the strength of cement stabilized soil base. Since the UCS values at 7 days of curing increased with cement content and all the soil-cement mixes from 7% cement content satisfy the specification 1.5MPa of the Kenya Pavement Design Guideline for Low Volume Sealed Roads, which recommends a minimum of 1.5MPa for road bases, the 7% cement content was taken as the Optimum Cement Content. This is nearly consistent with the research of [41], in which between 2% and 6% cement was suggested for the stabilization of Colombian lateritic soil to be applied to construct low to medium-volume roads. [6], proposed the usage of 9.23% Ordinary Portland Cement value to fulfil the requirement where 80% CBR can achieve 1428.09 KPa strength.

3.3. Stabilization of Lateritic Soil with Cement, Sugar Cane Bagasse and Cement Saw Dust Ash

3.3.1. Comparative variations of Atterberg limits of Cement-Sugar Cane Bagasse Stabilized Lateritic Soil, and Cement-Saw Dust Ash Stabilized Lateritic Soil

Tables 7 & 8 show the Atterberg limits of lateritic soil cement stabilized with SCBA and lateritic soil cement stabilized with SDA. In both cases, the liquid limit, plastic limit, plastic index and shrinkage limit show an increasing and decreasing trend. The possible reason for these results is the complete chemical hydration of cement in the mixes and the aggregation and cementation of particles into larger clusters due to pozzolanic reactions between the LS and SDA, LS and SCBA [19]. It also shows that the additives were able to stabilize the soil to some extent, though the effects of the additives were not so felt due to the high content of clayey in the soil [4].

Table 6. Variation of OMC, MDD, CBR & UCS with Cement

Properties	0%	3%	5%	7%	9%
OMC %	18.0	21.5	21.5	24.5	24.7
MDD (g/cc)	1.72	1.76	1.76	1.77	1.79
Soaked CBR (%)	30.9	67.5	119.5	175.7	102.6
UCS at 7 days (MPa)	0.226	0.483	0.775	1.999	2.769

Table 7. Variation of atterberg limits with cement & SCBA Content

Property	C1	C2	C3	C4	C5
LL	50.1	51.0	55.0	52.5	51.5
PL	37.8	29.8	40.4	37.9	28.4
PI	12.3	21.4	14.6	14.6	23.1
SL	7.14	9.23	9.06	8.57	8.95

Table 8. Variation of atterberg limits with cement & SDA Content

Property	A1	A2	A3	A4	A5
LL	50.1	48.3	50.0	51.4	53.5
PL	37.8	26.7	32.3	29.4	34.0
PI	12.3	21.6	17.6	21.9	19.4
SL	7.14	9.09	9.29	8.95	9.3

Table 9. Variation of OMC, MDD with Cement SCBA-SDA content

SCBA Content	OMC	MDD	SDA Content	OMC	MDD
C1	24.5	1.77	A1	24.5	1.77
C2	18.2	1.77	A2	21.0	1.76
C3	17.5	1.75	A3	23.2	1.74
C4	16.5	1.72	A4	20.0	1.69
C5	16.0	1.71	A5	22.2	1.65

3.3.2 Comparative Variations of Optimum Moisture Content of Cement-Sugar Cane Bagasse Ash and Cement-Saw Dust Ash

Table 9 shows that when SCBA is added to lateritic soil cement, the optimum moisture content decreases, this agrees with past researches [14,8]. Table 9 presents the results of lateritic soil cement stabilized with SDA. The OMC shows an initial increase, then decreases, and then increases again. The initial increase might be due to increased water demand by the cations (supplied by the cement and SDA) and the lateritic soil clay mineral particles to undergo hydration. Whereas the decrease in OMC, on the other hand, could have been due to cations exchange causing flocculation of the clay particles [14]. Again, the OMC trend for SDA-stabilized lateritic soil cement can be attributed to the higher SDA content of the mixes that increased the surface area of the particles, thus requiring more water to lubricate the entire matrix of the mixes [26].

3.3.3. Comparative variations of Maximum Dry Density of cement-sugar cane bagasse ash and cement-saw dust ash

Table 9 above presents the MDD of lateritic soil cement stabilized with SCBA. With the addition of SCBA, the MDD decreased from 1.77g/cm^3 to 1.71g/cm^3. A similar trend was noticed in lateritic soil cement stabilized with SDA, as shown in the same Table 9, which depicts a decreasing trend from

1.77g/cm^3 to 1.65g/cm^3. Similar results were also found by [60,61]. The observed MDD trend of the mixes was probably due to the agglomeration of the SCBA and SDA and the fine fraction of lateritic soil accentuated by the pozzolanic action of the SCBA and SDA. The lateritic soil aggregates occupied larger spaces, thus increasing their volume and consequently decreasing their dry densities [25].

3.3.4. Comparative Variations of Unconfined Compressive Strength of Cement-Sugar Cane Bagasse Ash Stabilized Lateritic Soil, and Cement-Saw Dust Ash Stabilized Lateritic Soil

The results in Table 10 show the UCS values of lateritic soil cement stabilized with SCBA at 7 days. The values depicted a decreasing trend from 1.999MPa at 7% cement, 1.633MPa at 5% cement & 2% SCBA, 1.033MPa at 3% cement & 4% SCBA, 0.742MPa at 1% cement & 6% SCBA and 0.342 MPa at 0% cement & 7% SCBA. Table 10 presents the UCS values of lateritic soil cement stabilized with SDA at 7 days. The values show a declining UCS values from 1.999MPa at 7% cement, 1.517MPa at 5% cement & 2% SDA, 0.946 MPa at 3% cement & 4% SDA, 0.571MPa at 1% cement & 6% SDA and 0.368 MPa at 0% cement &7% SDA**.** The same results were also found by [60,61]. The decreasing UCS is due to soil-bagasse ash reactions and soil-saw dust ash reactions, which result in the formation of cementitious compounds that bind soil aggregates [28]. This is also attributed to the availability of sufficient water that enhances the hydration reaction of cement, which reacts with silica and alumina in the laterite soil to produce secondary cementation compounds [24,63] and calcium ions that combine reactive silica and aluminium or both to form insoluble calcium silicates or aluminates and other pozzolanic products and the agglomeration of the heterogenous materials of the SDA-stabilized LS and SCBA stabilized LS [19,9]. The optimum values of UCS at 7 days of curing for lateritic soil cement stabilized with SCBA were found to be 5% Cement & 2% SCBA with a UCS value of 1.633MPa, whereas the lateritic soil cement stabilized with SDA was established to be 5% cement & 2% SDA with a UCS value of 1.517MPa which satisfy the Kenya Pavement guideline for Low Volume Sealed Roads requirement of 1.5MPa for road base for Low Volume Sealed Roads. [32] states that stabilized materials are rigid or semi-rigid, and the CBR is meaningless. The most convenient strength criterion for such materials is Unconfined Compressive Strength (UCS).

Table 10. Variation of CBR, UCS with cement SCBA-SDA content

SCBA Content	CBR%	UCS at 7 days MPa	SDA Content	CBR%	UCS At 7 days
C1	175.7	1.999	A1	175.7	1.999
C2	135.0	1.633	A2	102.9	1.517
C3	53.4	1.033	A3	81.5	0.946
C4	33.7	0.742	A4	59.0	0.571
C5	18.4	0.342	A5	30.7	0.368

3.3.5. Comparative Variations of California Bearing Ratio of Cement-Sugar Cane Bagasse Ash and Cement-Saw Dust Ash

The results in Table 10 above show the CBR of lateritic soil cement stabilized with SCBA. The CBR values decreased from 175.7% at C1, 135% at C2, 53.4% at C3 , 33.7% at C4 and 18.4% at C5. Similarly, Table 10 depicts a declining trend for lateritic soil cement stabilized with SDA, which shows the CBR values as 175.7% at A1, 102.9% at A2, 81.5% at A3, 59.0% at A4 and 38.7% at A5. Similar findings were also found by [60,61,62]. The gradual decrease in the CBR may be due to excess SDA-SCBA that was not mobilized in the reaction, which consequently occupies spaces within the sample and therefore reduces the bond in the soil-cement-SCBA and soil-cement-SDA mixtures [1]. The unconfined compressive strength is an important soil testing method used to establish the quality of stabilized materials. [52], stressed that the UCS test should be used to establish the strength of cement-stabilized materials. As stabilized materials are rigid or semi-rigid, the CBR is meaningless. The most convenient strength criterion for such materials is unconfined compressive strength [32].

4. Conclusion

Considering the Kenya pavement design guidelines for low-volume sealed roads, the obtained results indicated that the untreated lateritic soil could not be utilized as road base material for low-volume sealed roads unless stabilized with cement-sugar cane bagasse ash or cement-saw dust ash. According to the obtained results, the following conclusions can be drawn;

- In both cases, the liquid limit, plastic limit, plastic index, and shrinkage limit show an increasing and decreasing trend for both cement & SCBA and cement & SDA.
- The OMC for the lateritic soil stabilized cement & SCBA showed a decreasing trend, whereas lateritic soil stabilized cement & SDA depicted an increasing and decreasing trend.
- The MDD for both cement & SCBA-stabilized lateritic soil and cement & SDA stabilized lateritic soil showed a declining trend.
- The UCS stabilised lateritic soil for both cement & SCBA, stabilized lateritic soil, and the cement & SCBA stabilized lateritic soil showed a declining trend.
- The CBR for both cement & SCBA-stabilized lateritic soil and cement & SDA stabilized lateritic soil showed a decreasing trend.
- Based on the Kenya Pavement Design Guideline for Low-Volume Sealed Roads, 5% Cement and 2% SCBA was

found sufficient to obtain a UCS of more than 1.5MPa for low-volume sealed road construction.

- Considering the Kenya Pavement Design Guideline for Low-Volume Sealed Roads, 5% cement and 2% SDA was found sufficient to obtain a UCS of more than 1.5MPa for low-volume sealed road construction.
- Sugar cane bagasse ash and Saw dust ash acting singly as auxiliary additives in cement can be used in constructing lateritic soil road bases for low-volume sealed roads in Kenya.

Funding Statement

The research is funded by the Jomo Kenyatta University of Agriculture and Technology, The African Development Bank and The National Construction Authority, Kenya.

Acknowledgement

The Authors are grateful to the Jomo Kenyatta University of Agriculture and Technology, Materials Testing & Research Centre in the Ministry of Transport & Infrastructure, National Construction Authority and the African Development Bank for providing support to complete this study.

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