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Enhancing Geotechnical Properties of Lateritic Clay with Sawdust Ash-Lime Stabilizer

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ABSTRACT

One important means of refining the geotechnical characteristics of soils is stabilization. This research sought to improve the geotechnical properties of lateritic clayey soil using sawdust ash-lime (SDAL) stabilizer. Soil-SDAL mixtures were made, after collecting lateritic clay samples and preparing mixtures of lime and sawdust ash in a ratio of 1:2. SDAL mixtures were added to the lateritic clay in increasing percentages from 0 to 10%. The materials' index properties were determined, and compaction of the Soil-SDAL mixtures was done using four compactive efforts namely Reduced British Standard Light (RBSL), Standard Proctor (SP), West African Standard (WAS), and Modified Proctor (MP). Unconfined compressive strength (UCS) tests were performed on the Soil-SDAL mixtures as well. Results of the tests showed that the soil could be classified as an A-7-5(7) soil with a 13.7% plasticity index. The plasticity index increased with the addition of SDAL mixtures up to 6% after which there was a gradual decline. Meanwhile, maximum dry density (MDD) decreased while optimum moisture content (OMC) increased with SDAL addition. Unconfined compressive strength (UCS) of the soil increased from 38.58kN/m^2 at 0% SDAL to a maximum of 129.63kN/m^2 at 6% SDAL, after which there was a gradual decrease. Similar trends were noticed at all compactive efforts, indicating consistency in the performance of the stabilizer. Optimum results were achieved at 6% SDAL content, with Modified Proctor compactive effort giving the maximum value of 1,860kg/m^3 MDD. The results prove that sawdust ash-lime mixture offers tremendous abilities in improving lateritic clay soil properties.

Keywords: Lateritic Clay, Sawdust Ash-Lime, Stabilization, Geotechnical Properties, Compactive effort.

1 Introduction

Soils play an integral role in almost every aspect of civil engineering practice, ranging from road construction to buildings, dams, bridges, etc. Lateritic soils particularly are commonly utilized for various earthwork projects and the construction of road pavement in most tropical nations, including Nigeria, due to their accessibility and inexpensive cost [1]. However, it has been noted that the poor geotechnical characteristics of lateritic soils, which usually act as the major components of sub-grade and base materials, are principal reasons for roadway failure [2]. As a result, it is crucial to apply a variety of stabilizers to enhance the engineering qualities of lateritic soils. In recent times, using waste materials for the purpose of soil stabilization has been gaining popularity. A variety of waste materials have been adapted by researchers for soil stabilization, including waste plastic, ceramic waste, waste fibre, ashes of bio-waste, and others [3]–[5]. Sawdust, a type of wood waste generated from sawmills, constitutes a menace to the environment due to improper disposal. However, when burnt to ashes, the material possesses properties that make it suitable as a potential stabilizer or additive thereby improving the engineering characteristics when combined with lateritic soils. Lime, also, has been noted as a very effective material in soil modification due to its reaction with pozzolanic materials to form cementitious compounds [5]. There are, however, demerits in using lime alone for soil stabilization such as sulphate attack, effects of carbonation, and the negative environmental impact. It is therefore desirable to have a partial substitute material for lime that can aid in mitigating its negative environmental impact while concurrently contributing positively to the strength gain of the soil. This research therefore sought to examine the potential of sawdust ash combined with lime in improving the geotechnical characteristics of lateritic clay.

Lateritic clay soils are a byproduct of weathering from rock or soil components with low concentrations of iron and aluminum oxides or hydroxides [2]. These soils are typically found beneath ferruginous earth crust or hardpan, and mostly have red, reddish-brown, or dark brown color [6]. A warm climate having variations in wet and dry seasons, found commonly in tropical regions, favors laterization [7]. When wet, there is usually no significant swelling or loss of resistance in lateritic clays. However, there is considerable shrinkage when they lose water [8]. In their natural conditions, a number of lateritic clay soils have poor engineering qualities, occasionally exhibiting severe swelling, low strength, excessive plasticity, and a large drop in strength when exposed to water [1].

Sawdust, on the other hand, is wood chippings or waste wood particles gotten from hardwood that has been processed in sawmills. When the sawdust is calcinated, they produce sawdust ashes. If the initial moisture content of this ash is kept within reasonable limits (less than 50%), it can be a viable lightweight fill material with minimal issues during compaction [9]. Typically, sawdust ash has a high concentration of alumina and silica with little lime, as well as a good pozzolanic performance especially when clean sawdust is used [10]. It is a very cheap and widely available material for use since sawdust can be gotten from any local sawmill at very little or no cost. Using sawdust ash also makes possible a better and more economical means of managing waste from the wood industry. This prompted the choice of sawdust ash for use in this study.

Lime (or Calcium oxide), generally referred to as quicklime, is a caustic alkaline solid crystal with a white color at room temperature [9]. When lime reacts with medium-, moderately-,

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or fine-grained soils, it improves strength and workability while reducing plasticity [11]. It also reduces the apparent amount of soil fines, by promoting the coalescence and aggregation of clay particles [12]. Generally, when lime interacts chemically with moist clay minerals, the pH rises, increasing the solubility of siliceous and aluminous compounds [13]. It has also been noted that specific soil properties can affect the chemical reaction of lime with soils to produce cementitious materials, some of which include: pH, clay mineralogy, natural drainage, and organic content.

This study aimed at the characterization of lateritic clay, sawdust ash, and lime, and the determination of the compaction and strength characteristics of lateritic clay combined with sawdust ash lime (SDAL) mixtures.

2 MATERIALS AND METHODS

2.1 Study Soil

The lateritic soil sample chosen for this study was taken at a depth of 0.8m from a site located at the Federal University of Technology, Akure (latitude 7˚18`18.48" and longitude 5˚8`20.65"), Ondo State, Nigeria.

2.2 Sawdust Ash

This is an agricultural by-product obtained from the calcination of sawdust gotten from local sawmills in the state. The sawdust used in this study was obtained from a local sawmill at Roadblock, Orita Obele, Akure, Ondo State, Nigeria, and calcinated using a locally made furnace.

2.3 Lime

For the purpose of this study, hydrated lime, $Ca(OH)_2$, was purchased from Pascal Scientific, Akure, Ondo State. The mechanism of action of lime reaction with soil is explained briefly as follows. As soon as the soil is mixed with lime, there are instantaneous changes in the soil's strength, workability, and plasticity index, due to flocculation-agglomeration reaction and cation exchange. After then, cementation produced by carbonation—a reaction between lime and carbon dioxide in cavities in the soil or the open air—occurs, leading to an immediate strength gain. In the long term, the pozzolanic reactions between lime and the clay mineral's silica and alumina result in the development of cementitious products including calcium-silicate-hydrates (C-S-H), calcium-aluminate-hydrates (C-A-H), and calcium-aluminum-silicate-hydrates (C-A-S-H) [14]. These reactions are represented in equations Eq. (1) to Eq. (3):

$$Ca(OH)_2 \rightarrow Ca^{2+} + 2(OH)^- \quad (1)$$

$$Ca^{2+} + OH^- + SiO_2 \text{ (silica from clay)} \rightarrow CSH \quad (2)$$

$$Ca^{2+} + OH^- + Al_2O_3 \text{ (alumina from clay)} \rightarrow CAH \quad (3)$$

2.4 Mix Proportion

In choosing the right chemicals to stabilize soil, certain requirements were prescribed by [11]. Lime was considered appropriate for soils having a plasticity index higher than 10 (PI>10). With soils having their plasticity index falling between a range of 5 – 20, lime fly-ash blends are advised, with the lime addition in a range of 4 – 7% and fly ash (class C type) between limits of 4% and 7%. While combining both lime and fly ash, a range of 1:1 to 1:9 respectively is advised. It is important to note, however, that lime addition to soil depends on the application. For stabilization, 5% to 10% lime is considered appropriate, while 2% to 3% lime by dry weight of soil is acceptable for modification [15]. According to Beeghly [16], for cases of lime and Class F fly ash combination, lime can be added to the Class F fly ash in ratios from 1:2 to 1:4 respectively with satisfactory results. He noted that this combination of lime and fly ash will produce greater strengths than using lime singly.

The combination of sawdust ash with lime is hence expected to produce a more efficient result. Thus, considering the above recommendations, one part of lime was added to two parts of sawdust ash (referred to as SDAL), and then the mixture was added to the lateritic soil in percentages ensuring an even mix. The appropriate amount of soil was combined with SDAL mixes in percentages of 0, 2, 4, 6, 8, and 10% to create the test specimens. Table 1 shows the mixture proportion of the soil-SDAL mixture. The samples of the sawdust ash, lime, sawdust ash lime mixture, and combination of the SDAL with dry lateritic clay are shown in Fig. 1.

Plate 1: Sawdust Ash

Plate 2: Hydrated Lime

Plate 3: Sawdust Ash Lime Mixture (SDAL)

Plate 4: Mixture of SDAL with dry lateritic

Fig. 1 Sawdust Ash, Hydrated Lime, SDAL, and SDAL with dry lateritic clay

Table 1 Mixture percentages of Soil-SDAL

Sample ID	Percentage of SDAL added (%)
LCA	0
SDAL-2	2
SDAL-4	4
SDAL-6	6
SDAL-8	8
SDAL-10	10

2.5 Index Properties

The distribution of the soil's particle size, specific gravities of the soils and sawdust ash, as well as the soil's plasticity characteristics, were determined in accordance with BS1377:Part 2 [17].

2.6 Compaction Test

Four compactive energy levels were employed including Standard Proctor (SP), Modified Proctor (MP), West African Standard (WAS), and Reduced British Standard Light (RBSL). The soil was first dried in an oven and properly ground to pass through the 4.75mm sieve. The Standard Proctor (also known as British Standard Light) and the Modified Proctor (also known as British Standard Heavy), and the Reduced British Standard Light (RBSL) compaction tests were conducted in consonance with BS1377:Part 4 [18]. The reduced British Standard Light (RBSL) is the force produced by a 2.5 kg rammer striking three layers at a distance of 300 mm apart with 13 uniformly distributed blows on each layer [18]. The WAS compaction, which is frequently used in West Africa, involves applying ten (10) blows to each of five layers in a British Standard mold using the force generated by a 4.5 kg rammer falling through a distance of 450 mm [19].

2.7 Unconfined Compressive Strength Test

In accordance with BS1377:Part 7 [20], unconfined compressive strength (UCS) test was conducted on cylinder-shaped specimens of soil-SDAL mixtures 40 mm in diameter and 81 mm in depth. The specimens were placed in a UCS machine and tested under a 1%/min strain rate.

3 Results and Discussions

3.1 Soil-SDA Index Characteristics

Physical characteristics of the soil and sawdust ash are presented in Table 2 while Fig. 2 shows the particle size distribution curve for the lateritic soil. Fig. 3 shows the description of Atterberg limits based on the plasticity characteristics of the soil.

Table 2 Physical Characteristics of Lateritic Soil and Sawdust Ash

S/N	Property	Sieve Mesh Diameter (mm)	LCA
1.	Grain Size Distribution (percent finer than)	4.760	91.35
		2.360	72.92
		1.700	69.86
		1.180	59.27
		0.600	56.14
		0.500	48.38
		0.425	48.34
		0.212	41.73
		0.150	38.93
		0.075	36.91
		0	0
2	Specific Gravity	2.75	1.98

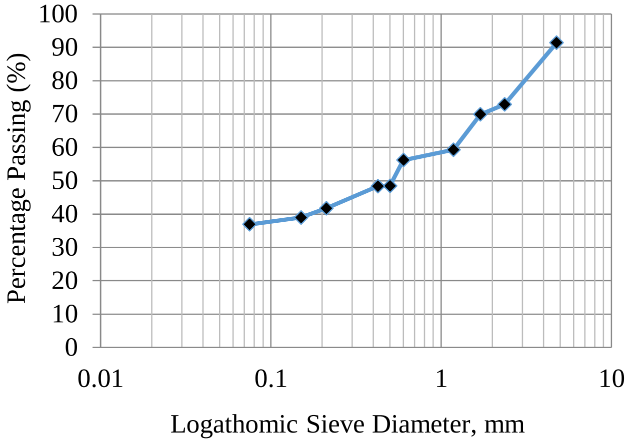

Fig. 2 Particle size distribution for the lateritic soil

Furthermore, Atterberg limit results, including plastic limit (PL), liquid limit (LL), linear shrinkage (LS), and plasticity index (PI) for the specimens of soil-SDAL mixtures are shown in Fig. 3.

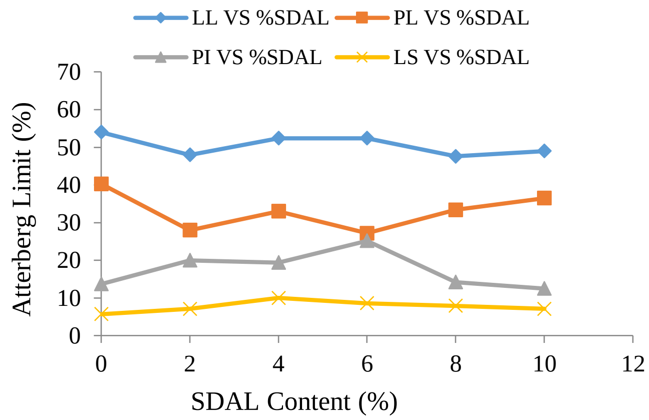

Fig. 3 Comparison of Atterberg limits based on SDAL content

Results from the particle size analysis (Table 1 and Fig. 2) show that the soil contains about 36.78% fines (silt and clay size fraction). The soil has a specific gravity of 2.75, falling within the suitable standard range of 2.60 to 2.80 specified by Wright [21]. Meanwhile, the sawdust ash was found to have a low specific weight with a specific gravity of 1.98. The soil had a plasticity index of 13.7%, with a 54% liquid limit and a 40.3% plastic limit. The soil can thus be classified as an A-7-5(7) soil based on the AASHTO classification system since its plasticity index (PI) ≤ (LL-30).

When the sawdust ash lime mixtures were combined with the soil, a general reduction in the liquid limits (LL) and plasticity indices (PI) was noticed although with slightly inconsistent variations, between a range of 54 and 47.6% for LL, and 20 and 12.5% for PL, for SDAL content from 0 to 10%. This is seen in Fig. 3. There was also a sudden increase of PI at 6% SDAL after which there was a reduction. The PL gradually increased with 6 to 10% SDAL content. This demonstrates how the lateritic clay soil lost its plasticity after being treated with a sawdust ash lime mixture. This occurrence could be a result of the changing soil texture due to the flocculation and aggregation of clay particles induced by the sawdust ash-lime combinations [22]. The values of linear shrinkage were initially 5.7 and 7.1% at 0 and 2% SDAL content, but later showed a marked reduction with an increase in

SDAL content from 4 to 10% SDAL content, with linear shrinkage values of 10.0, 8.6, 7.9 and 7.1% respectively.

In a research conducted by Raheem and Suleiman [23], results for the chemical composition of sawdust ash showed an average percentage composition of $SiO_2 + Al_2O_3 + Fe_2O_3$ to be 74.89% and CaO to be 4.21%. Hence, sawdust ash can be classified as Class F fly ash, having satisfied the 70% minimum condition for pozzolans in accordance with ASTM C618 [24] and Jerath and Hanson [25]. With CaO content lower than 10% and a low potential for pozzolanic reaction, Reimer [26] noted that Class F fly ash is not effective as a stabilizing agent by itself. However, in the presence of lime or cement, fly ash turns will be very efficient for stabilization. As a result, it can be argued that the sawdust ash in this case serves both as a filler and a major contributor to the pozzolanic reaction that is brought about by the mixture of soil and lime.

3.2 Compaction Characteristics

Fig. 4 and Fig. 5 shows the variations of MDD and OMC with SDAL content added to the soil.

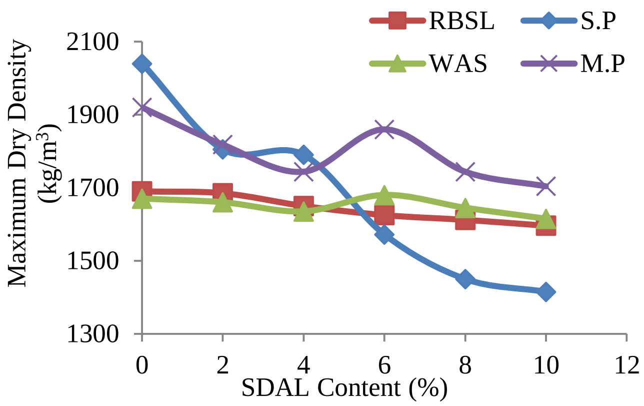

Fig. 4 Comparison of maximum dry Density based on SDAL content

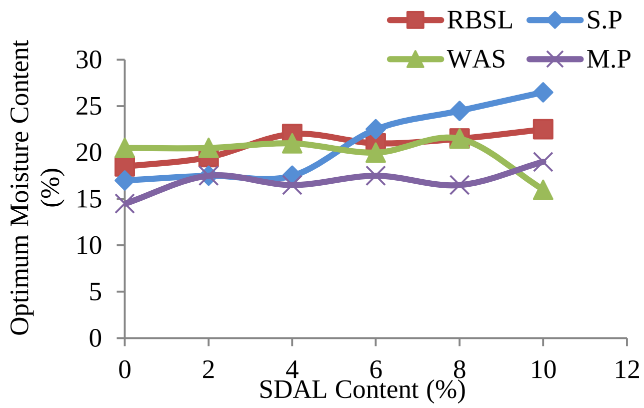

Fig. 5 Comparison of optimum moisture content based on SDAL addition

As shown in Fig. 4, a decreasing trend was noticed with the MDD values of the compacted soil-SDAL mixtures within the ranges of 1,690kg/m^3 to 1,596kg/m^3 for Reduced British Standard Light compactive effort, 2,040kg/m^3 to 1,415kg/m^3 for Standard Proctor, 1,670kg/m^3 to 1615kg/m^3 for West African Standard, and 1,920 kg/m^3 to 1,704kg/m^3 for Modified Proctor compactive effort. While there was an overall reduction in MDD for all compactive efforts, it was specifically observed that there was a sharp sudden increase at 6% SDAL content for Modified Proctor and West African Standard efforts, before a later reduction.

At 6% SDAL content, the highest MDD values were obtained for the four compactive efforts, with values of 1,625 kg/m^3, 1,572 kg/m^3, 1,680 kg/m^3 and 1,860 kg/m^3 for Reduced British Standard Light, Standard Proctor, West African Standard, and Modified Proctor compactive efforts respectively (Fig. 4). The sawdust ash's lower specific gravity, the flocculation and aggregation of clay particles brought on by cation exchange, which increased volume and generated a commensurate decline in dry densities, are possible causes of the fall in the dry unit weight. The rise in the OMC, on the other hand, could be explained by the sawdust ash lime's larger surface area and the additional water required for hydration [19], [22], [27]–[30]. Several studies have noticed a similar pattern [9], [22], [29].

On the other hand, the OMC showed an increasing trend with an increasing percentage of SDAL content (from 0% to 10%), with values between 17.0 and 26.5% for the Standard Proctor (S.P) compactive effort, 16.5 and 21.5% for the West African Standard (WAS) compactive effort, and 14.5 and 19.0% for Modified Proctor (M.P) compactive effort as shown in Fig. 5. However, while there was an initial increase in OMC for the Reduced British Standard Light (RBSL) compactive effort, there was a sudden drop at 6% SDAL content to 21% and latter increase to 22.5% at 10% SDAL content.

3.3 Unconfined Compressive Strength

Fig. 6 shows the effect of SDAL content on the unconfined compressive strength, while Fig. 7 represents the stress-strain curve of the lateritic soil based on SDAL content.

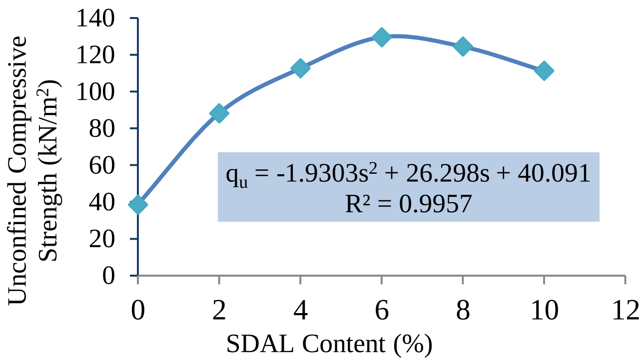

Fig. 6 Effect of SDAL content on unconfined compressive strength

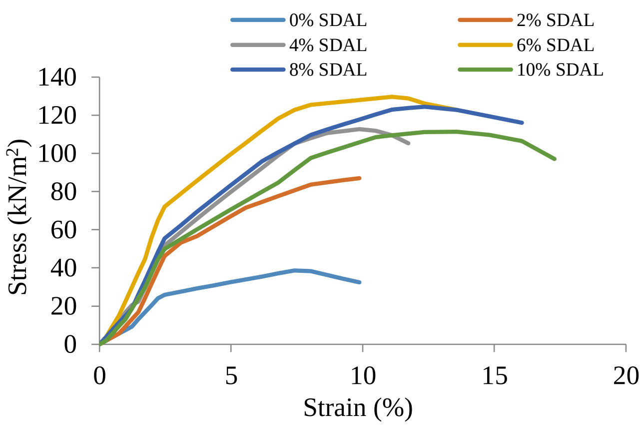

Fig. 7 Soil stress-strain curve relationship based on SDAL content

As seen in Fig. 6, the unconfined compressive strength of the natural lateritic soil sample was 38.58kN/m^2. When SDAL was added, UCS values increased with SDAL content to a maximum value of 129.63kN/m^2 at 6% SDAL content, after which there was a gradual decrease in the UCS value till 10% SDAL content. The stress-strain curve in Fig. 7 also shows that the addition of sawdust ah lime mixtures to the soil improves the elastic properties as well as the strength of the soil. The natural lateritic soil was able to withstand low stress and strain. However, with the addition of SDAL, the treated soil showed higher strength and strain at failure compared to that of the untreated soil. A similar pattern was observed by [31], and the strength improvement can be attributed to the pozzolanic reaction between the sawdust ash lime and the soil constituents. The variation of the unconfined compressive strength of the soil-SDAL mixtures, as described in Fig. 6, can be represented by the polynomial Eq. (4), with a coefficient of determination value of 0.9957.

$$q_u = -1.9303s^2 - 26.298s + 40.091 \quad (4)$$

Where q_u represents unconfined compressive strength, and s represents the percentage of SDAL added.

3.4 Comparison of Compaction Characteristics of Soil-SDAL Mixtures at 6% SDAL

At the optimum value of 6% SDAL, a comparison of the values of maximum dry densities for all four compactive efforts is presented in Fig. 8.

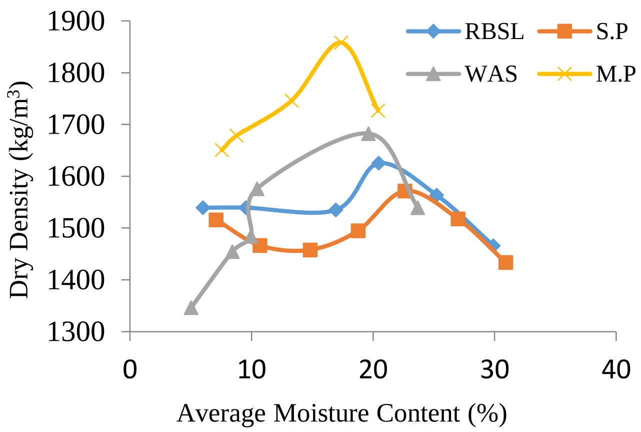

Fig. 8 Compaction test results for SDAL-6

Optimum strength values were achieved at 6% SDAL content, using Modified Proctor compactive effort with the maximum value of 1,860kg/m^3 MDD. The maximum unconfined compressive strength value obtained was 129.63kN/m^2, indicating an increase in strength over 200 percent (236 percent) compared to that of the natural lateritic soil sample (LCA). This result amply demonstrates the efficiency of the sawdust-ash lime combinations when applied at this optimum value.

4 Conclusion

This study was carried out as an initial evaluation with the goal of improving the geotechnical properties of lateritic clay with sawdust ash-lime mixtures for engineering applications. Test specimens were made by combining lime and sawdust ash in a 1:2 ratio, after which the mixtures were combined with the soil at increasing percentages of 2% from 0 to 10% SDAL. Following SDAL treatment, index characteristics of the lateritic clay improved with a decrease in plasticity index and a rise in linear shrinkage. It was also observed that there was a reduction in MDD decreased while OMC increased with higher SDAL content. The maximum value of MDD and least OMC was obtained with the Modified Proctor Effort, making it the most preferred method of compaction for promising results. A Peak UCS value of 129.63kN/m^2 was obtained at 6% SDAL addition, after which there was a falling trend. With over 200% increase in the soil's UCS value, 6% optimum SDAL content is advised. With compaction, higher UCS values can yet be achieved. This study demonstrates that using this agro-industrial/chemical mixture significantly improves the engineering qualities of lateritic clay soil and offers an efficient approach to handling agro-industrial by-products rather than disposal, which could cause environmental issues.

Further investigation using increased lime content in the SDAL ratio, and the suitability of other additives is proposed. Moreover, this mixture can also be investigated for its suitability in landfill liners.

Declaration of Interest

The authors declare no conflict of interest.

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