GEOTECHNICAL CHARACTERISTICS OF LATERITIC SOIL STABILIZED WITH SAWDUST ASH-LIME MIXTURES

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ABSTRACT

This study assesses the geotechnical characteristics of lateritic soil and sawdust ash lime (SDAL) mixtures. Preliminary tests were carried out on the natural soil sample for identification and classification purposes. The sawdust was mixed with lime for stabilization in the ratio 2:1. This mixture was thereafter added to the lateritic soil in varying proportions of 2, 4, 6, 8 and 10% by weight of soil. Addition of SDAL increased values of Optimum Moisture Content (OMC) from 17.0% at 0% SDAL to 26.5% at 10% SDAL by weight of soil, also, values of Maximum Dry Density (MDD) decreased from 2040 kg/m^3 at 0% SDAL to 1415 kg/m^3 at 10% SDAL. Values of Unconfined Compressive Strength (UCS) increased from 38.58 kN/m^2 at 0% SDAL to highest value of 129.63 kN/m^2 at 6% SDAL. The values of liquid limits and plasticity index of the soil were effectively reduced with the addition of the SDAL, from 54.0% at 0% SDAL to 49.0% at 10% SDAL and from 13.7% at 0% SDAL to 12.5% at 10% SDAL respectively. It was therefore concluded that the sawdust ash lime (SDAL) mixture can serve as a cheap soil stabilizing agent for poor lateritic soil.

KEYWORDS

Atterberg limits, geotechnical properties, lime, sawdust ash, stabilization

INTRODUCTION

Soil improvement in a broad sense incorporates the various methods employed for modifying the properties of a soil to enhance its engineering performance. Soil improvement as a term is being used for a variety of engineering projects; prominent among such are: road pavement construction and airfield pavements where the main objective is to increase the stability of soil and reduce the construction cost by making the optimal use of locally available materials [1]. Soil improvement could either be in form of soil modification or soil stabilization [2]. Modification refers to soil improvement that occurs in the short term, during or shortly after mixing (within hours). This modification reduces the plasticity of the soil (improves the consistency) to the desired level and improves the short-term strength to the desired level (short term could be defined as strength derived immediately and within about 7 days after compaction). Even if no remarkable pozzolanic or cementitious reaction occurs, the textural changes that accompany consistency improvements normally result in the measurable strength improvement. Stabilization occurs when a significant longer-term reaction takes place. This longer-term reaction can be due to hydration of calcium silicates and calcium aluminates in Portland cement or class C fly ash or due to pozzolanic reactivity between the free lime and the soil pozzolan or added pozzolan. A strength increase of 350 kPa or greater (of the stabilized soil strength compared to the untreated soil strength under the same conditions of compaction and cure) is a reasonable basis for stabilization [3]. According to Attoh-Okine [4], soil stabilization is the process of altering of the geotechnical properties to satisfy the engineering requirements, this has been used in land fill mines, building of roads, aircraft runways, earth drain and embankments, in erosion control and in the reduction of the cost having the possibility of employing stabilized soil for building houses at low cost in undeveloped region of the world [5].

The concept of the soil stabilization is of utmost necessity in civil engineering projects, such as roadways, building foundation, dams among others, in the sense that most lateritic soils in their natural states commonly have low bearing capacity and low strength due to high content of clay. When lateritic soil consists of high plastic clay, the plasticity of the soil may cause cracks and damage on the civil engineering projects, thus, the improvement in the strength and durability of lateritic soil in recent time has become imperative and has consequently encouraged researchers towards using stabilizing materials that can be sourced locally at very low cost. These local materials can be classified as either agricultural or industrial wastes [6].

Research into new and innovative use of waste material is continually advancing and particularly concerning the feasibility, environmental suitability and performance of the beneficial reuse of industrial and agro industrial waste products [7].

Koteswara *et al.* [8], performed geotechnical tests to investigate the effect of sawdust and lime on the marine clay. In the study, the soil was mixed with a variation of 5%, 10%, 15%, 20%, 25%. The maximum dry density was obtained at the addition of 15% sawdust to the marine clay. This led to combination of the marine clay with the sawdust at varying percentages of lime from 3% to 7% lime. The maximum dry density (MDD) for these variations was obtained at addition of 4% lime. It was also observed that on addition of 15% sawdust and 4% lime, the liquid limit (LL), plasticity, optimum moisture content (OMC) of the marine clay decreased while the Plastic Limit (PL), Maximum Dry Density (MDD), and California Bearing Ratio (CBR) value increased. He therefore concluded that sawdust can potentially stabilize an expansive soil solely or mixed with lime.

In order to evaluate the effects of Sawdust Ash on the geotechnical properties of lateritic soils, Ogunribido [9] performed tests on three samples of lateritic soils A, B and C, where he dealt with Consistency Limits, Specific Gravity, Compaction, Unconfined Compressive Strength, Shear Strength and California Bearing Ratio (CBR). These tests were conducted at non-stabilized and stabilized states by adding 2%, 4%, 6%, 8% and 10% sawdust ash (SDA). He obtained optimum results from a combination of 6% sawdust ash (SDA) and concluded that sawdust ash was an effective stabilizer for lateritic soils. However, he did not consider the addition of lime.

Ayininuola and Oyedemi [10] performed a study on the impact of hardwood and softwood ashes on soil and the geotechnical properties of the soil.

Two soil samples were collected from two different locations and mixed separately with hardwood ash and softwood ash in varying percentage replacements of 0%, 2%, 4%, 6%, 8%, 10% and 15% by sample weight. Geotechnical tests such as Particle size distribution, Specific gravity, Atterberg limit, Compaction test and California Bearing Ratio (CBR) were carried out on the samples. It was observed that the MDD values reduced with increase in ash content similar to the pattern obtained for soil specific gravity, while CBR for both samples increased from 0% to 8% for softwood and hardwood ashes with optimum result achieved at 8% ash replacement. Also, wood ash led to increase in soil liquid and plastic limits of the soil. It was therefore concluded that hardwood and softwood ashes are suitable for improving California Bearing Ratio (CBR) of soil.

Adrian *et al.,* [7] carried out laboratory study on compacted tropical clay treated with up to 16% rice husk ash (RHA), an agro-industrial waste, to evaluate its hydraulic properties and hence its suitability in waste containment system. Compacted samples were permeated and the hydraulic behavior of the material was examined considering the effects of molding water content, water content relative to optimum, dry density and RHA contents. Results revealed decreasing hydraulic conductivity with increasing molding water content and compactive efforts; it also varied greatly between the dry and wet side of optimum decreasing towards the wet side. Hydraulic Conductivity generally decreased with increased dry density for all efforts, but they were within recommended values of $1X10^{-7}$ cm/s for up to 8% rice husk ash treatment irrespective of the compactive effort used. They concluded that the material was suitable as a hydraulic barrier in waste containment systems for up to 8% rice husk ash treatment.

Lime Stabilization

Lime is one of the oldest and still popular additives used to improve fine-grained soils. The following are the four major lime-based additives used in geotechnical construction; hydrated high calcium lime $Ca(OH)_2$, calcific quick lime CaO, monohydrated dolomitic lime $Ca(OH)_2$ MgO and dolomitic quick lime CaO MgO. Lime treatment of soil facilitates the construction activity in three ways. First, a decrease in the liquid limit and an increase in the plastic limit results in a significant reduction in plasticity index. Reduction in plasticity index facilitates higher workability of the treated soil. Second, as a result of a chemical reaction between soil and lime, a reduction in water content occurs. This facilitates compaction of very wet soils. Further, lime addition increases the optimum water content but decreases the maximum dry density and finally immediate increase in strength and modulus results in a stable platform that facilitates the mobility of equipment.

When lime is mixed with clayey material in the presence of water, several chemical reactions take place. They include cation exchange, flocculation-agglomeration, pozzolanic reaction and carbonation. Cation exchange and flocculation-agglomeration are the primary reactions, which take place immediately after mixing. During these reactions, the monovalent cations that are associated with the clay minerals are replaced by the divalent calcium ions. These reactions contribute to the immediate changes in plasticity index, workability and strength gain. Pozzolanic reaction occurs between the lime and the silica and alumina hydrates. Carbonation occurs when lime reacts with carbondioxide to produce calcium carbonate instead of calcium-silicate-hydrates, such carbonate is an undesirable reaction from the point of soil improvement [11].

MATERIALS AND METHODS

Materials

The raw materials used for this study were lateritic clay soil, Sawdust Ash (SDA), hydrated lime and water.

Lateritic clay soil

Lateritic soil was collected at a depth not less than 1.2m from an existing burrow pit in the Federal University of Technology, Akure (FUTA), Nigeria.

Sawdust Ash (SDA)

According to Adetoro and Adam [12], sawdust is a by-product of cutting, grinding, drilling, sanding or otherwise pulverizing wood with a saw or other tool. The dust is commonly used as domestic fuel. The resulting ash is a form of pozzolana known as sawdust ash (SDA). Sawdust without a large amount of bark has proved to be satisfactory, this does not introduce a high content of organic material that may upset the reactions of hydration. Sawdust was collected from the sawmill factory in Akure town. It was later burnt to ashes and sieved through BS Sieve of 0.212mm to get a powdered ash.

Tab. 1 - Chemical Properties of Sawdust Ash, source [13]

Elemental Oxides	Weight (%)
SiO_2	86
Al_2O_3	2.6
Fe_2O_3	1.8
CaO	3.6
MgO	0.27
LOI	4.2

Tab. 2 - Physical Properties of Sawdust Ash, source [13]

Serial No	Property	Sieve Openning No	Value
1	Grain size distribution (mm)	4.75	100
		2.0	96
		0.6	80
		0.425	50
		0.21	29
		0.075	8
2	Specific gravity		2.01

Lime

The hydrated lime ($Ca (OH)_2$) was obtained from an accredited chemical store.

Water

Water was obtained from the water taps in the laboratory.

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Methods

Preliminary tests, such as Atterberg limit test, particle size distribution, specific gravity and natural moisture content were carried out for the purpose of classification and identification of the lateritic soil sample.

Natural Moisture Content test

The test is expressed as this:

Moisture Content= $a/_b \times 100$

Where a= (weight of empty can+ wet sample) – (weight of empty can+dry sample)

And b= (weight of empty can+dry sample) – (weight of empty can)

Specific gravity test

The test is expressed hereby:

$$\frac{x}{y-z}$$

Where *x*=(weight of density bottle +soil)- (weight of empty density bottle)

y= (weight of empty density bottle+water, when full) – (weight of empty density bottle)

z= (weight of density bottle+soil+water)-(weight of density bottle+soil)

Particle size distribution (sieve analysis)

The sieve analysis was done to determine the grain sizes of the soil collected so as to classify the soil to their known engineering properties. This involved sieving a quantity of soil through a stack of sieves of progressively smaller mesh opens from top to bottom of the stack.

Atterberg limits

There are three limits in the determination of the soil Atterberg limits and they are liquid limit, plastic limit and plasticity index.

Liquid Limit Determination

Soil Sample passing through 425 µm sieve, weighing 200g was mixed with water to form a thick homogeneous paste. The paste was collected inside the Casagrande's apparatus cup with a groove created and the number of blows to close it was recorded. The corresponding moisture content was used to indicate the liquid limit.

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Plastic Limit Determination

Soil Sample weighing 200g was taken from the material passing the 425µm test sieve and then mixed with water till it became homogenous and plastic and was able to be shaped into a ball. The ball of soil was rolled on a glass plate until the thread cracked at approximately 3 mm diameter. The corresponding moisture content was used to indicate the plastic limit.

Plasticity Index Determination

This is simply gotten from subtracting Plastic limit from the corresponding Liquid limit.

Mathematically expressed as: Liquid limit (%) – Plastic limit (%) = Plasticity Index (%).

Preparation of Soil-SDAL Mixtures

Sawdust was burnt to ashes first and then sieved through a BS Sieve of 0.212mm to get very fine ash. It was thereafter stored in an air-tight container to prevent moisture loss and any form of contamination. Design procedures for soil modification or stabilization [14] advocated the criteria for chemical stabilization of soil. It was suggested that lime could be used for soil with plasticity index greater than 10 (PI> 10) or lime flyash blends for plasticity index between 5 and 20 (5$< PI < 20$). It was also advised that lime to be added should fall within the range of 4% and 7%, while flyash class c should fall within the range 10% and 16%. A combination of both lime and flyash was advised to be in the range of 1:1 to 1:9 respectively. Beeghly [15] noted that a higher strength will be obtained from a combination of lime and flyash more than lime alone due to the pozzolanic reaction of lime and flyash. For the purpose of this experiment, sawdust ash was mixed with lime for stabilization in the ratio 2:1. For the purpose of this work, the mixture with the lateritic clay will be denoted by LAT-An, where n= percentage of SDAL mixture added. The symbol 'LAT' stands for lateritic clay while sawdust ash lime (SDAL) mixtures is denoted by An. The lateritic clay soil was thereafter treated with sawdust-lime mixtures (SDAL) at varying proportions of 2%, 4%, 6%, 8% and 10%. At each stage of the mixture, the stabilized lateritic clay soil had the following tests performed on them; Compaction; Atterberg limits and Unconfined Compressive Strength tests.

Engineering Tests

Compaction Characteristics

The compaction test was performed on the soil in its natural state and with addition of varying percentages of the sawdust ash lime mixtures. The method adopted for this test was the British Standard Light (BSL) energy method.

Unconfined Compressive Strength (UCS) tests

This test is applicable in virtually all geotechnical engineering design (e.g. design and stability analysis of foundations, retaining walls, slopes and embankments) to obtain a rough estimate of the soil strength and viable construction techniques. It is about the most popular method of soil shear testing because it is one of the fastest and cheapest methods of measuring shear strength. This method is mostly used for saturated, cohesive soils recovered from thin-walled sampling tubes.

Atterberg limits tests

With the increasing addition of SDAL to the soil sample in proportions of 0%, 2%, 4%, 6%, 8% and 10%, the mixes at each stage were subjected to Atterberg limits tests.

RESULTS

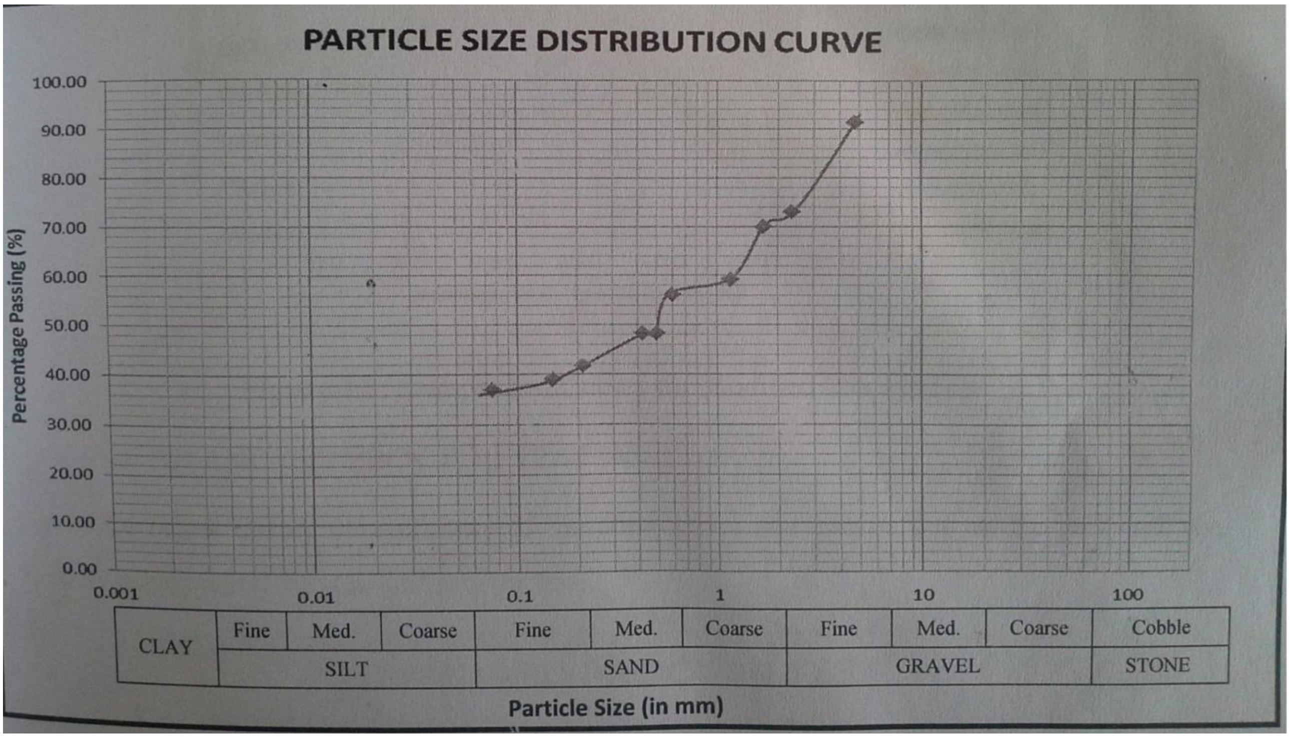

Fig. 1 - Particle size distribution curve for soil sample.

From Figure 1; the percentage of material passing through Number 200 sieve is 36.78% can be classified as a silt-clay material, it has significance constituent material of clayey soils and has its general subgrade rating as fair to poor therefore, it is not suitable for subgrade, sub base and base materials as the percentage by weight finer than the No 200 BS sieve is greater than 35% in accordance with AASHTO soil classification [16].

Tab. 3 - Preliminary test results of the lateritic clay soil

Property	Values
Percentage of material passing through No 200 BS Sieve	36.78
Natural Moisture Content (%)	16.10
Specific gravity	2.75
Liquid limit (LL) (%)	54.0

Plastic limit (PL) (%)	40.3
Plasticity Index (PI) (%)	13.7
Maximum Dry Density (kg/m^3)	2040
Optimum Moisture Content (%)	17
Unconfined Compressive Strength (kN/m^2)	38.58
AASHTO Classification	A-7-5
USCS Classification	Silt-clay

The specific gravity of the lateritic soil is 2.75, which is within the range of 2.6 and 3.4 as reported for lateritic soil [17]. The specific gravity of the sawdust is 1.98, which is relatively lesser than that of the lateritic soil. From Table 3, the lateritic soil has liquid limit (LL) value of 54%, while its Plastic Limit (PL) was 40.3%.This gave the Plasticity Index (PI) to be 13.7%.With these results obtained in combination with the result of sieve analysis, the soil can be classified using AASHTO system as an A-7-5 soil, subgroup A-7-5, has Plasticity Index (PI) 13.7 <LL(54.0)-30=24, and it is of silt-clay material. This, indicates that it is a fair to poor sub-grade material [18].

Tab. 4 - Compaction test results

Sample ID	**Percent SDAL (%)**	**OMC (%)**	**MDD (kg/m^3)**
LAT-A0	0	17.0	2040
LAT-A2	2	17.5	1805
LAT-A4	4	17.5	1790
LAT-A6	6	22.5	1572
LAT-A8	8	24.5	1450
LAT-A10	10	26.5	1415

From Table 4, with the increasing addition in percentage of SDAL, the OMC values increased from 17.0% at 0% SDAL to 26.5% at 10% SDAL. While proportion of added SDAL increased in percentage, the values of the Maximum Dry Density decreased from 2040 kg/m^{3}at 0% SDAL to 1415 kg/m^{3}at 10% SDAL. The decrease in the maximum dry unit weight can be attributed to coating of the soil by the SDAL which results to large particles with larger void, hence less density. The decrease in the maximum dry unit weight may also be explained by considering the SDAL as filler (with lower specific gravity) in the soils, while increase in value of OMC with increase in SDAL content is due to the decrease of the quantity of free silt and clay fraction and coarser materials with larger surface areas formed (these processes need water to take place). This implies also that more water is needed in order to compact the soil – SDAL mixtures [19].

Tab. 5 - Unconfined Compressive Strength tests

Sample ID	**Percent SDAL (%)**	**Unconfined Compressive Strength (kN/m^2)**
LAT-A0	0	38.58
LAT-A2	2	88.15
LAT-A4	4	112.65
LAT-A6	6	129.63
LAT-A8	8	124.51
LAT-A10	10	111.30

Table 5 shows that unconfined Compressive Strength of the soil without the SDAL (that is, at 0% SDAL) is 38.58 kN/m^2. This showed that the soil is soft and the strength low, but the addition of SDAL mixture at 6% gives the highest strength value of 129.63 kN/m^2. The increase in the UCS is attributed to the formation of cementitious compounds between $Ca(OH)_2$ present in the soil and SDAL and the pozzolans present in the SDAL [20]

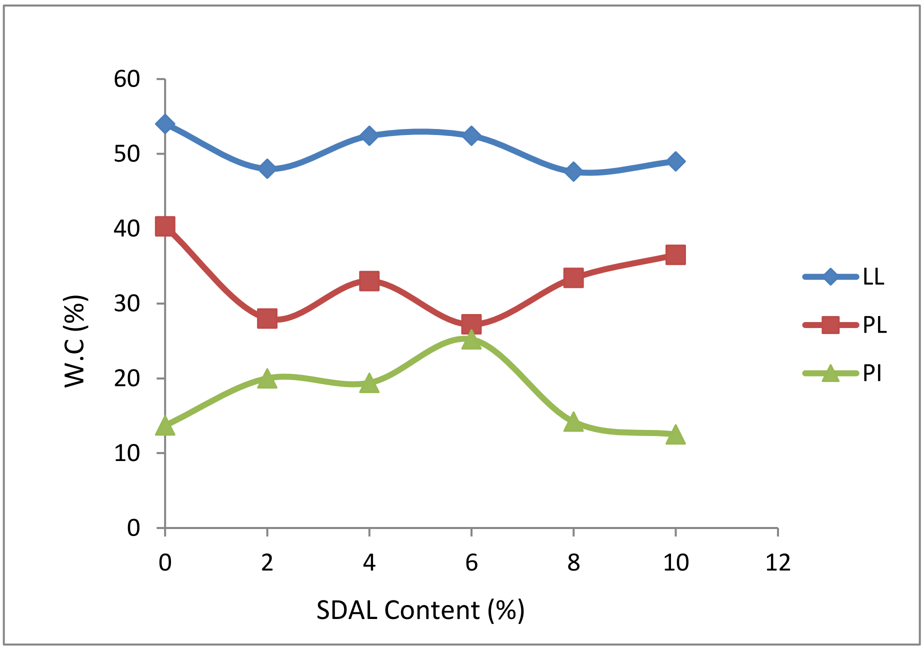

Fig. 2 - Showing effects of SDAL on Atterberg limits

From Figure 2,with the addition of Sawdust ash lime to the soil from 2% to 10%, the LL and PI were observed to decrease and later increase, but ultimately, both reduced in values, suggesting improvement of soil properties [21]. LL decreased from 54% at 0% SDAL to least value at of 47.6% at 8% SDAL and PI decreased from 13.7% at 0% SDAL to 12.5% at 10% SDAL. This can be considered to be a result of the addition of sawdust lime, which has less affinity for water and yields a decrease limit of liquid. There was an increase in PI at 6% SDAL content. The Plastic limit was found to increase gradually with higher SDAL content between 6% to 10% SDAL addition. This shows that the addition of sawdust ash lime to the lateritic soil resulted in the soil losing its plasticity, thereby enhancing the engineering properties. This may be due to alterations in the texture of the soil essentially by flocculation and agglomeration of the clay particles in the presence of sawdust ash lime mixes [19].

CONCLUSION

The laboratory tests were carried out according to BS 1377 [23] and BS 1924 [24].

The addition of sawdust ash lime increases the optimum moisture content of the soil and decreases the maximum dry density of the soil which makes it good for engineering purposes.

The Unconfined Compressive Strength of the studied soil is optimally improved by adding sawdust ash lime mixture.

The sawdust ash lime mixture satisfactory acts as a cheap stabilizing agent for poor lateritic soil.

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