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Effect of Sawdust on the Geotechnical Properties of a Lateritic Soil

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Abstract
In this work, laboratory investigation on the stabilization of residual lateritic soil with up 15 % sawdust by dry weight of the soil was carried out with the aim of determining its potential effects on the properties of the soil. The index properties, swelling properties, unconfined compressive strength, permeability characteristics, CBR and moisture-density relationship of the stabilized soil were studied. X-ray diffraction analysis showed that the lateritic soil consists of kaolinite, quartz, mica, hematite, and K-feldspar. The lateritic soil classified as ML in the USCS and in group A-7-5 of the AASTHO classification. The liquid limit, plasticity index and maximum dry unit of the soil decreased with increasing sawdust content while the linear shrinkage and optimum moisture content increased with increasing sawdust content. CBR, cohesion and unconfined compressive strength increases with addition of sawdust up to an optimum value of about 7.5%, beyond which these parameters begin to decrease. On the other hand, permeability and compression index decreases to lowest values at about 7.5 %, beyond which they begin to increase. This study reveal that the stabilized soil may not be suitable for road construction as the UCS and soaked CBR of the stabilized soil failed to meet the requirements for embankment, sub-base and base course materials.

Keywords: *Soil stabilization, Laterites, plasticity, permeability, Sawdust.*

Introduction

In most developing countries like Nigeria, rapid increase in human population and urban settlements have increased the demand for good access highways and roads to guarantee connectivity among the different urban settlements. This, in addition to scarcity of quality aggregates, has compelled government and road authorities to make use of naturally occurring geomaterials or construction materials in constructing roads (Netterberg 2014). Laterite or lateritic soil – a kind of residual soil that is restricted to the humid and tropical parts of the world - is an example of naturally occurring geomaterial which is widely used in the construction of engineering structures such as roads, compacted landfill liners, embankments as well as foundation materials (Gidigasu 1976, Adeyemi *et al.* 2014, 2015).

However, laterite/lateritic soil, in their natural state, rarely have properties appropriate for the desired engineering applications such as road and highway construction. Residual soil such as laterite/lateritic soil often occur in a loose, structured state and can collapse due to loading or wetting, resulting to sudden settlements (Toll 2012). Similarly, lateritic soil can experience strength deterioration because of their varying silt and clay contents which often make them sensitive to changes in moisture content (Nicholson and Kasyap 1993). In addition, when subjected to stresses, the soil particles are often less stable and crushable due to the aggregation of finer particles into coarse-grained size fractions (held together by cementing agent or clay matrix) and this may lead to volumetric compression (Lee and Coop 1995). Another factor that makes this soil problematic and play a critical role in the failure of structures (such as pavements) constructed on or with this type of soil is the alternating periods of dry and raining seasons in terrain (mostly basement complex) characterized by shallow groundwater table. Hence, the strength of this soil will be influenced by prevailing moisture contents and soil above the water table will undergo swelling and shrinkage, respectively on wetting and drying (Abiddin Erguler and Ulusay 2003, Mohamedzein and Al-Rawas 2011, Mir and Sridharan 2013).

For this soil to be suitable for highway and pavement design, ground/soil improvement method is usually used to address the numerous ground condition problems and improve its undesirable engineering properties. Ground improvement is defined as the alteration or process of improving the physical and mechanical properties of a soil to improve its performance or attain a predetermined value (Nicholson 2015, Latifi *et al.* 2018). This improvement can be achieved in several ways, including soil densification (such as compaction or preloading), hydraulic modification (such dewatering or electro-osmosis), admixture stabilization (mechanical, chemical, and biological stabilization), geosynthetic reinforcement and structural inclusions (Nicholson 2015).

Chemical stabilization has been shown to be an effective method of improving and modifying the index and engineering properties of residual soil such as lateritic soil (Millogo *et al.* 2008, Eberemu 2011, Joel and

Agbede 2011, Mengue *et al.* 2017). Cement, lime, limestone, rice husk ash, wood ash, and fly ash are few examples of admixtures available to stabilize lateritic soils and these admixtures are classified by (Reddy *et al.* 2015) into cementitious, non-cementitious and chemical additives. Literature have shown that cementitious additives such as lime and cement are widely used in the stabilization of lateritic soils. Studies such as (Osinubi 1998, de Brito Galvão *et al.* 2004, Li *et al.* 2012, Oyediran and Okosun 2013, Mengue *et al.* 2017, Oyediran and Ayeni 2020) reported that addition of lime and cement improved the CBR, unconfined compressive strength, plasticity and compressibility of the lateritic soil. Despite the widespread usage of cement and lime in chemical stabilization of problematic soils, the followings are problems associated with their usage: (1) high cost of production and procurement; (2) adverse environment impact such as release of greenhouse gasses during production (Chang *et al.* 2015); (3) formation of hazardous compounds which could contaminate soil and groundwater (Goodarzi *et al.* 2015); (4) modification of the soil pH which could lead to an alkaline attack on concrete (Mitchell and Soga 2005). Consequently, these shortcomings have compelled researchers to source for alternative materials that are both economic and environmentally friendly in place of lime and cement.

Researchers have also used non-cementitious agricultural and industrial wastes to stabilize and improve the properties of lateritic soils. These non-cementitious materials are made attractive because they are cheaply available and have high cementation reaction. The results of using fly ash (Osinubi *et al.* 2006, Amadi 2010), bagasse ash (Eberemu 2013), steel slag (Akinwumi *et al.* 2012, Athulya *et al.* 2017a), rice husk ash (Alhassan and Mustapha 2007, Oyediran and Ayeni 2020), groundnut shell ash (Abdu *et al.* 2017), and oil palm fiber ash (Edeh *et al.* 2020) to chemically stabilized and improve the properties of lateritic soils have shown desired effect or improvement when these alternative stabilizers are used alone or with cement/lime. Although majority of these non-cementitious stabilizers are cheap but they are mostly obtained through burning (mostly in open air) of their respective wastes and this could result to air pollution. In addition, the quantity may not be sufficient enough to stabilize the required amount of soils needed for desired construction. Hence, the need to source for more cheaper and readily available material or waste material that can serve as stabilizer.

Sawdust is one of the byproducts of the wood processing factories. In year 2010, according to (Ogunwusi 2014), the wood processing factories produced over 1,000,000 m^3 of sawdust, planner shaving, split wood and sander dust in Nigeria. Of these byproducts, saw dust constitutes environmental nuisance and health hazards if not properly managed (Wihersaari 2005). The wood processing factories normally dumped the sawdust at different locations and allowed to decay or resorts into incineration in the open atmosphere. These adopted methods of disposal constitute serious danger to water bodies and the atmosphere but also prevents the sawdust from being used.

Recently, however, in order to find an environmentally friendly disposal method and creative use of this organic residue, sawdust have been used to patch potholes on highways and as fillings in some parts of Nigeria. Literature have however shown that little or no research have been conducted to examine the effects the sawdust might have on lateritic soils. This study, therefore, examines the performance of lateritic soil when its properties is improved or stabilized sawdust and its suitability for use as different pavement components. As remarked by Sun *et al.* (2018): "*Due to its rough surface texture, sawdust can produce large friction that can effectively improve the strength of the soil. The main chemical components of sawdust are lignin and cellulose, which do not cause any negative environment impact*".

Materials and Test Methods

Materials

Soil

The lateritic soil samples used for this research were collected from an abandoned burrow pit as disturbed samples located at Ogbomosho, Southwestern Nigeria. Lateritic soils have been previously excavated from this burrow pit for construction purposes. The sampling location is located on latitude 8^0 17 '10" N and longitude $4^0$25'23" E. The soil samples were collected from the laterite horizon, being the preferred soil for construction purposes. The previous work showed that the lateritic soil was derived from migmatite gneiss; the most abundant rock type in the basement complex rock of SW, Nigeria (Rahaman 1988). Table 1 shows the chemical and mineralogical compositions of the lateritic soil. The table shows that the soil samples are made up of kaolinite, quartz, mica, K-feldspar (rutile) and hematite. The soil consists mainly of silica (SiO_2), alumina (Al_2O_3), iron III oxide Fe_2O_3. The percentage composition of oxides such as MgO, MnO, CaO, Na_2O, K_2O, and P_2O_5 are negligible. The Sesquioxide Ratio (SR) of the studied soil was computed using the Equation below:

$$SR = \frac{\%\ SiO_2}{\%\ Al_2O_3 + \%\ Fe_2O_3}$$

The computed SR of the soil is 2.2 indicating that the soil is lateritic (Bell 2007).

Physical and engineering properties of lateritic soil including grain size distribution, liquid and plastic limits, linear shrinkage, specific gravity, permeability, unconfined compression, shear strength and compressibility were determined in accordance with the recommendations of British Standard 1377 (1990). All tests were carried out on air dried soil samples. The particle size distribution analysis shows 44.5 % of the soil sample passes through sieve number 200 (< 0.075 mm). In addition, the soil is generally well graded. The values of the index and engineering properties of the soil sample are shown in Table 2.

Table 1: Mineralogical and Chemical Composition of the Lateritic Soil

		Values
Chemical Composition (%)	SiO_2	59.35
	TiO_2	0.56
	Al_2O_3	23.76
	Fe_2O_3	6.06
	MgO	0.73
	MnO	0.02
	CaO	0.62
	Na_2O	0.03
	K_2O	1.89
	P_2O_5	0.02
	LOI	7.76
Sesquioxide ratio	$\frac{\%\ SiO_2}{\%\ Al_2O_3 + \%\ Fe_2O_3}$	1.99
Mineralogical Composition (%)	Kaolinite	60
	Quartz	21
	Mica	13
	Rutile	4
	Hematite	2

Casagrande plasticity chart classifies the lateritic soil as inorganic silt of plasticity. According to American association for state highway transportation officials (AASHTO) soil classification system, the soil is rated fair to poor subgrade soil (A-7-5) with group index of 12. Hence, the lateritic soils can be deduced as not suitable for sub-grade and base materials as the percentage of particles finer than sieve No.200, the plasticity index and liquid limit of the lateritic soils are more than 35 %, 12 %, and 30 % respectively recommended for sub-base/base soils by the Federal ministry of works and housing (FMWH) specification (1997).

Sawdust

The sawdust used in this study was taken from the saw mill located at Sobi road, Ilorin. Prior to use, the sawdust was washed with clean water to remove impurities such as dust and foreign objects. Thereafter it was sun-dried for two weeks. The sun-dried sawdust used for soil stabilization was then sieved with sieve number 40 and only saw dust particles smaller than this sieve size was used. Then the sieved saw dust was added into the lateritic soil in different percentages up to 15 % of the dry weight of the lateritic soil.

Table 2: Index and Engineering Properties of the Lateritic Soil

Property	Value[n]
Liquid limit (%)	48
Plastic limit (%)	36
Plasticity index (%)	12 (intermediate plasticity)
Linear shrinkage	7.5
Specific gravity	2.57
Natural moisture content (%)	14
Maximum Dry Density (kg/m^3)	1907
Optimum moisture content (%)	15.59
California Bearing Ratio (%)	31
California Bearing Ratio (%) (Soaked)	9
Permeability (cm/s)	4.05E-03
Unconfined compressive strength (kPa)	329.6
Cohesion (kN/m^2)	5
Angle of internal friction (φ)	14°
Particle size distribution	
Sand (%)	55.5
Silt (%)	34.5
Clay (%)	10
Activity	1.23
Unified Soil Classification	ML
AASHTO Classification	A-7-5 (12) (fair to poor subgrade)

n = average of 6 samples

Test Methods

Lateritic soil samples collected were air-dried in the laboratory until constant mass was attained. Series of laboratory tests were carried out to study the properties and behavior of the untreated and sawdust stabilized lateritic soil. The laboratory tests were done in two stages. The first set of experiment were carried out to determine the index and engineering properties of the untreated lateritic soil. Subsequently, sawdust considered as stabilizer, was added to the lateritic soil in varying proportions (0, 2.5, 5.0, 7.5, 10.0, and 12.5 %) by dry weight of the soil. Properties such as consistency limits, compaction characteristics, soaked and unsoaked CBR, permeability, compressibility characteristics and shear strength of the stabilized soil were determined. The stabilized lateritic soil samples used for the engineering tests were all prepared using the Optimum Moisture Content (OMC) of the soil. The results from the second phase of the experiment was used to determine the optimum amount of sawdust that could be utilized to stabilized the lateritic soil.

Particle size analysis of the soil samples was carried out following the standards specified by British Standard (BS) 1377 – 2 (1990) with some minor modifications. Sieve and hydrometer analysis were only conducted on the untreated soil. Before sieving, the soil samples were soaked in a weak Calgon solution for 24 hours for proper segregation of grains of the soil. During this period of soaking, the solution was regularly agitated. The consistency limits tests were carried out to determine index properties such as liquid limit (W_L), plastic limit (W_P), plasticity index and linear shrinkage of the soil. These tests were determined in accordance to the specification of British Standard 1377 – 2 (1990) for both the untreated and treated soil samples using soil fractions that pass-through sieve size 0.045 mm. The W_L and W_P were determined using Casagrande method and the thread-rolling test, respectively. Linear shrinkage was determined using a half-cylindrical brass mold of about 14 cm long and 1.25 cm in radius.

The moisture content – dry density relationship (compaction) test was conducted using the standard Proctor level of compaction. This test was carried out on both the natural and sawdust stabilized soil samples according British Standard 1377 – 4 (1990) specification. This compactive effort is the energy obtained from a 2.5 kg rammer falling from a height of about 0.3 m on to three layers of soil in a cylindrical mold of about 945 ml in volume with each layer receiving 25 blows that are uniformly distributed. The California bearing ratio (CBR) tests were carried out on both set of compacted soil as per British Standard 1377 – 4 (1990). Soaked and unsoaked CBR tests were carried out on the compacted samples. The specimen used for the CBR tests were all compacted to their respective maximum dry density (MDD) and optimum moisture content (OMC). For soaked CBR, the compacted specimens were soaked in water for 2 days before the determination of the CBR. The compacted specimens were continuously sheared at a constant rate of 1.25 mm/min. the unsoaked and soaked CBR of the compacted specimens were obtained at penetrations of 2.5 and 5.0 mm.

The permeability of the natural and treated lateritic soil was determined using falling head permeameter in accordance to the specification of British Standard 1377 – 5 (1990). Samples compacted at standard Proctor level was soaked in water until they were fully saturated. The saturated samples were then connected to the falling head permeameter. Readings were taking at regular interval to record the head losses across the samples. The test was continued until at least three constant permeability values were recorded. The natural and treated lateritic soil samples used for the consolidation tests were compacted at OMC using the standard proctor effort in the oedometer ring (British Standard 1377 – 5, 1990). The height and diameter of the sample is about 20 mm and 60 mm, respectively. The samples were sufficiently saturated; hence the sample were tested at water content near saturation. The stress applied were: 0.02, 0.04, 0.08, 0.16, 0.32, 0.48, 0.64 and 1.28 MPa. For each stress increment, the readings on the dial gauge was used to record the changes in the height of the compacted soil samples. Each loading was maintained for about 24 hours to ensure that the compacted samples attained full compressibility. The Casagrande's and Taylor's methods were used to determine the consolidation's parameters such as compression index (C_c), coefficient of consolidation (C_v), and coefficient of volume compressibility (m_v).

Shear strength parameters, determined by direct shear test, of the natural and sawdust stabilized lateritic soil samples was conducted according to British Standard 1377 – 7 (1990). The samples used for this test were compacted at OMC using the standard Proctor compaction effort. The sample dimension is about 60 mm (length) × 60 mm (width) × 20 mm (height). The specimens were sheared at a shearing rate 0.03 mm/min until maximum horizontal displacement or failure is reached. The applied normal stresses of 2, 4, and 6 kPa were applied during the shearing of the specimens. Samples of sawdust stabilized and natural lateritic soil were mixed with the required water so as to achieve the OMC and then compacted in a cylindrical mold of dimension 76 mm × 38 mm using a tamping rod. The compacted samples were subjected to unconfined compression test immediately after compaction at a loading rate of 0.6 mm/min according to British Standard 1377 – 7 (1990) specification. The stress (applied load divided by cross-sectional area of the sample) and strain (change in length divide by the original length of the sample) were plotted against each other to determine the unconfined compressive strength of the samples

Statistical Analysis

To examine the effects of the additive (sawdust) on the lateritic soil with respect to the response of investigated index and geotechnical properties, one-way ANOVA statistical test was carried out. This was done because sawdust was used as the only source of variation on the investigated index and geotechnical properties. At any degree of freedom, there is a specific value of "F" in the table at a known confidence level. When the calculated "F" is greater than the "F" in the table, the difference is declared statistical significance and the null hypothesis is rejected. In such situation, P value is usually < 0.05.

Results and Discussion

Effect of Sawdust on the Consistency Limits of the Soil

Fig. **1** shows the results of consistency limits tests for the untreated soil and sawdust-stabilized soils. From the consistency limits tests, soils mixed with 10 %, 12.5 % and 15 % sawdust were found to be non-plastic. The remaining soil mixes were, however, plastic.

Table **3** shows the plasticity characteristics of the sawdust treated lateritic soils. Fig. **1** and Table **3** show that W_L and W_P decreased with increase in sawdust content. This result is consistent with the work of (Sun *et al.* 2018). This may be attributed to the fact that sawdust particles are less hydrophilic than soil particles especially clay and silt. Invariably, this led to reduction in plasticity when it blends with the lateritic soil.

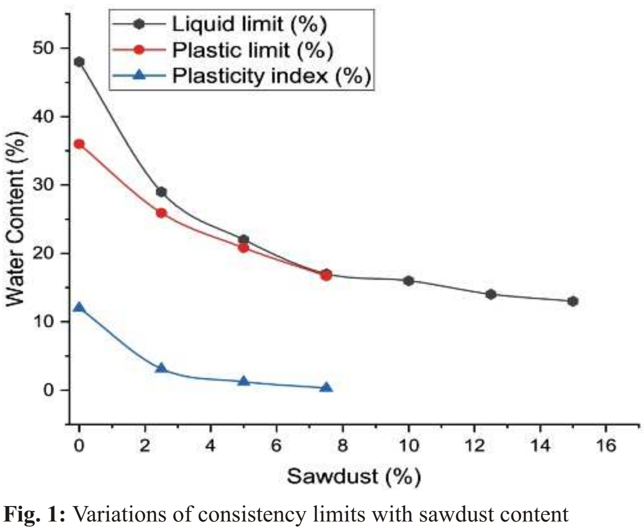

Fig. 1: Variations of consistency limits with sawdust content

In addition, the bonds that exist between the clay particles are reduced as the sawdust – clay particle bond increased. The sawdust treated soils being non – plastic (at 10 – 15 % sawdust) may be attributed to the fact that sawdust being lightweight was added in percentages related to soil weight and the plasticity of the treated soil is mainly influenced by large volume of sawdust in the soil mix when 10 %, 12.5 % and 15 % sawdust was added as stabilizer to the lateritic soil.

Table 3: Plasticity characteristics and linear shrinkage of treated and untreated lateritic soil

Sawdust (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Linear Shrinkage (%)
0	48	36.0	12.0	7.5
2.5	29	25.9	3.1	8.4
5.0	22	20.8	1.2	8.7
7.5	17	16.7	0.3	9.4
10.0	16.0	Non - plastic	Non - plastic	9.7
12.5	14	Non - plastic	Non - plastic	10.0
15.0	13	Non - plastic	Non - plastic	10.2

The decrease in plasticity characteristics due to addition of sawdust shows that the index properties of the soils were enhanced (Eberemu 2011, Mengue *et al.* 2017). The result of one-way ANOVA test conducted on the consistency limits of the soils is summarized in Table 4. Results showed that $F_{Cal} = 8.819$ and $F_{Crit} = 4.747$ for liquid limit. This indicates that $F_{Cal} > F_{Crit}$, and therefore, addition of sawdust had significant effect on the liquid limit of the treated and was statistically significant. In addition, the $F_{Cal} = 0.016$ and $F_{Crit} = 5.987$ (i.e. $F_{Cal} < F_{Crit}$) for plasticity index shows that the addition of sawdust to the soils had no significant effect on this property of the soil.

Casagrande plasticity classification chart shows that the untreated lateritic soil was of intermediate plasticity but on treatment with sawdust the plasticity of the treated soils changed to low plasticity (Fig. **2**). Sample treated with 7.5 % sawdust however changed from silty soil to clayey soil of low plasticity. Similarly, the untreated sample belongs to group A-7-5 of AASTHO classification which is regarded as poor subgrade material while the sawdust treated samples falls into either group A-4 or A-2-4 of the classification system.

Table 4: One-way ANOVA tests for consistency limits and shrinkage limits at varying sawdust content

Property	SoV	DF	F_{Cal}	P-Value	F_{Crit}	Remark
Liquid Limit	Sawdust	1 12	8.819	0.012	4.747	$F_{Cal} > F_{Crit}$ Significant
Plastic limit	Sawdust	1 6	22.307	0.003	5.987	$F_{Cal} > F_{Crit}$ Significant
Plasticity index	Sawdust	1 6	0.016	0.902	5.987	$F_{Cal} < F_{Crit}$ Not Significant
Linear shrinkage	Sawdust	1 12	0.617	0.448	4.747	$F_{Cal} < F_{Crit}$ Not Significant

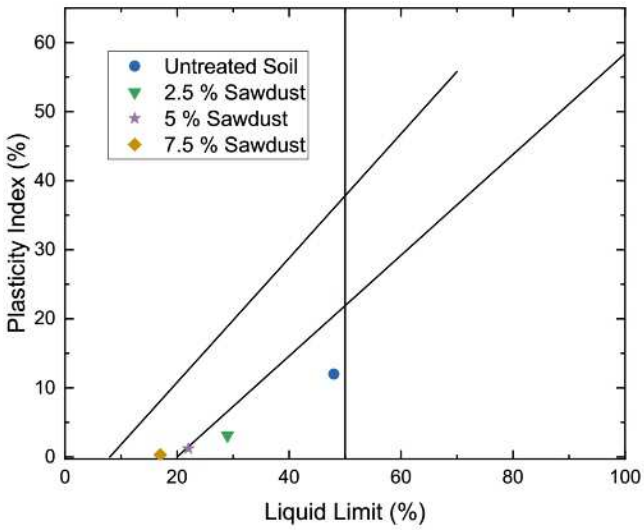

Fig. 2: Casagrande plasticity chart of the soil

According to Moghal *et al.(* 2018) linear shrinkage is one of the important tests in road construction as it is used to evaluate the shrinkage property of soils. Fig. 3 shows the variation of linear shrinkage of natural and soil treated with sawdust. The figure shows that the linear shrinkage increased with an increase in sawdust percent. This observation is in contrast to previous works (that used lime, cement and palm fiber ash as stabilizers) which reported that linear shrinkage decreased with increase in percent stabilizer (Moghal *et al.* 2018, Dhar and Hussain 2019, Edeh *et al.* 2020). This increase may be attributed to the fact that sawdust were occurring in the soil matrix in dispersed form and parallel oriented flaky particle or grain have greater shrinkage capacity (Keramatikerman *et al.* 2016). The one-way ANOVA test (F_{Cal} = 0.617 and F_{Crit} = 4.747 (i.e. FCal < FCrit)) for shrinkage limit however shows that the addition of sawdust to the soils had no significant effect on this property of the soil.

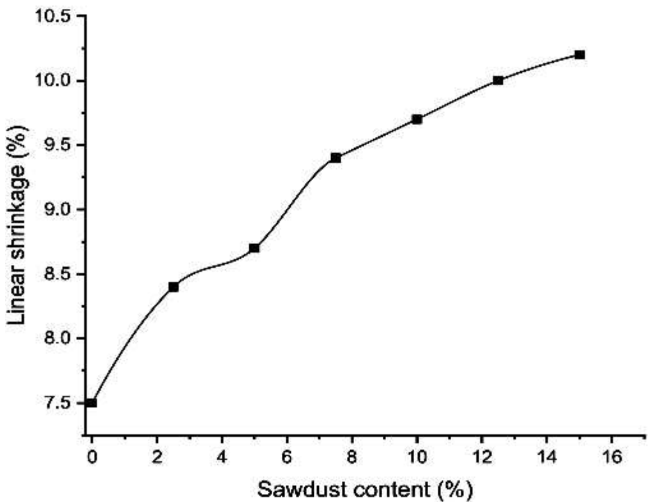

Fig. 3: Variations of linear shrinkage with sawdust content

Effect of Sawdust on the Moisture – Dry Density Relationship

Fig. **4** illustrates compaction curves for the sawdust stabilized soil specimens with various additive contents. It is obvious from the compaction curves that the sawdust stabilized soils show higher MDD and lower OMC than the untreated soil. In addition, Fig. **4** also revealed that the compaction curves of the stabilized soil become less steep as the amount of sawdust increases.

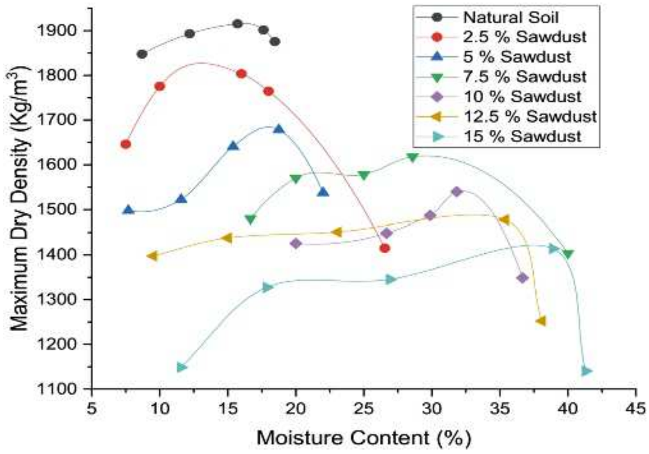

Fig. 4: Compaction curves for the natural and stabilized soils with various sawdust contents

The relationship between the compaction parameters (MDD and OMC) and sawdust content is shown in Fig. 5. The figure revealed that the MDD of the stabilized soil decreased as the percentage sawdust increased. Similar results were obtained Edeh *et al.* (2014) and Zhang *et al.* (2018) when sawdust ash and lime, respectively were used to stabilized problematic soils. The decrease in MDD may be attributed to the fact that sawdust has lower specific gravity compared with the soil and as result produced a soil that is lighter than in its natural state. In addition, the sawdust particles will tend to occupy the spaces between the soil particles and increase the volume of the soil mix; hence reducing the MDD (Osinubi *et al.* 2012). On the other hand, the OMC of the stabilized soils increased as the percentage of sawdust added increased. This may be attributed to fact that sawdust reduced the number of clay particles that can clumped together creating a change in the specific surface area and make these clay particles to absorb more water. Hence, the soils treated with sawdust required more water to attain optimum moisture content.

The result of one-way ANOVA test conducted on the compacted parameters of the soils is summarized in Table 5. Results showed that F_{Cal} = 20.75 and F_{Crit} = 4.75

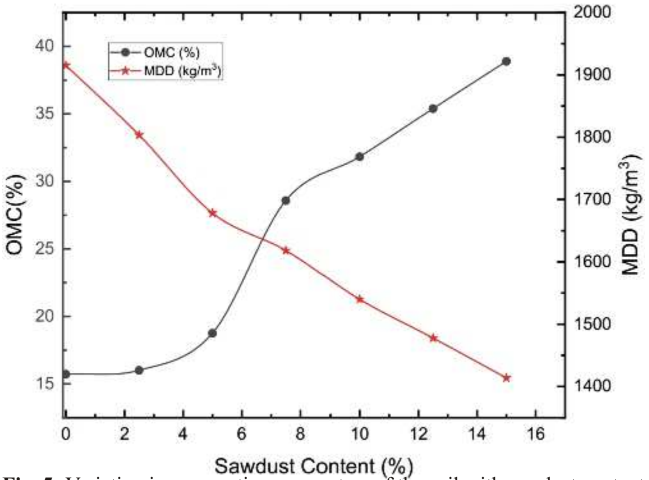

Fig. 5: Variation in compaction parameters of the soil with sawdust content

for OMC. This indicates that $F_{Cal} > F_{Crit}$, and therefore, addition of sawdust had significant effect on the OMC of the treated soils and was statistically significant. In addition, the $F_{Cal} = 579.70$ and $F_{Crit} = 4.75$ (i.e. $F_{Cal} > F_{Crit}$) for MDD shows that the addition of sawdust to the soils had a significant effect on this property of the soil.

Table 5: One-way ANOVA tests for compaction parameters at varying sawdust content

Property	SoV	DF	F_{Cal}	P-Value	F_{Crit}	Remark
OMC	Sawdust	1	20.75	0.00066	4.75	$F_{Cal} > F_{Crit}$
		12				Significant
MDD	Sawdust	1	579.70	1.58E-11	4.75	$F_{Cal} > F_{Crit}$
		12				Significant

Effect of Sawdust on the Strength Behavior of the Soil

CBR of the Soil

The CBR is one of the practical means of determining the strength of the sub-grade soil and the required thickness of pavement for a given loading condition. The variation of soaked and unsoaked CBR values of sawdust treated lateritic soils are shown in Fig. **6**. The figure shows that CBR values increased with increase in sawdust content to peak values of about 43 and 15 %, for the unsoaked and soaked conditions, respectively at 7.5 % sawdust content. Beyond 7.5% sawdust, a decrease in soaked and unsoaked CBR were observed. The initial increase may be as result of the rough texture of the sawdust which produce large friction that can help improved the strength of compacted sawdust treated soil (Sun *et al.* 2018). The decrease in CBR, with further increase in sawdust content from 7.5 to 15%, may be due to lack of proper or poor bonding between soil particles as a result of high sawdust content.

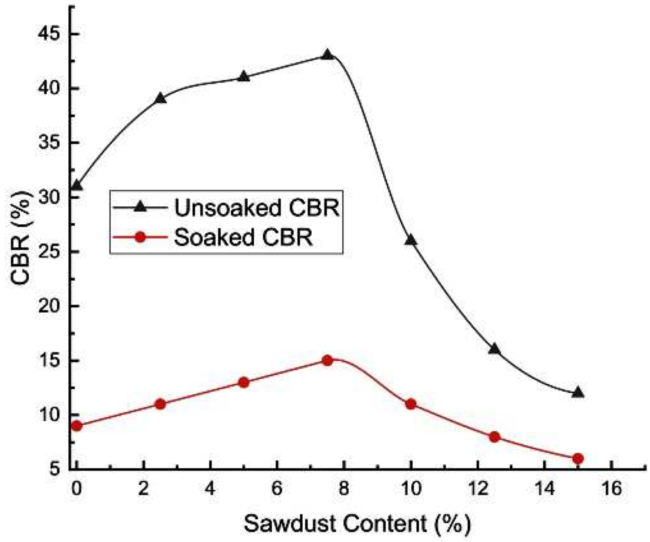

Fig. 6: Variation of soaked and unsaoked CBR with sawdust content

The results (Fig. **6**) also revealed that after soaking the samples for 48 h, the CBR of the soil reduced greatly. This trend was consistent with the results of Edeh *et al.* (2014) and Athulya *et al.* (2016). This indicates that the soil-sawdust mix have high water retention capacity and the treated soils were sensitive to changes in moisture. The reduction in strength or CBR as a result of soaking may be due to the non-formation of cementitious compounds during the hydration process which are known to enhance strength (Athulya *et al.* 2017a). The result of one-way ANOVA test conducted on the soaked and unsaoked CBR of the soils is summarized in Table **6**. The results showed that addition of sawdust had significant effect on the unsoaked CBR of the treated soils (i.e. $F_{Cal} > F_{Crit}$) and was statistically significant. However, the $F_{Cal} = 1.56$ and $F_{Crit} = 4.75$ (i.e. $F_{Cal} < F_{Crit}$) for soaked CBR shows that the addition of sawdust to the soils had no significant effect on this property of the soil.

Table 6: One-way ANOVA tests for strength parameters and permeability at varying sawdust content

Property	SoV	DF	F_{Cal}	P-Value	F_{Crit}	Remark
Unsoaked CBR	Sawdust	1	19.15	0.000903	4.75	$F_{Cal} > F_{Crit}$ Significant
		12				
Soaked CBR	Sawdust	1	1.56	0.2353	4.75	$F_{Cal} < F_{Crit}$ Non-
		12				Significant
UCS	Sawdust	1	290.22	8.99E-10	4.75	$F_{Cal} > F_{Crit}$
		12				Significant
Φ	Sawdust	1	9.05	0.0108	4.75	$F_{Cal} > F_{Crit}$
		12				Significant
Cohesion	Sawdust	1	13.49	0.00318	4.75	$F_{Cal} > F_{Crit}$
		12				Significant
	Sawdust	1	13.49	0.0032	4.75	$F_{Cal}l > F_{Crit}$
Permeability		12				Significant

Uncured Unconfined Compressive Strength (UCS) of the Soil

The results of uncured UCS for natural soil and stabilized soil specimens with different percentages of sawdust are shown in Fig. **7**. The figure shows an increase in the uncured UCS of the sawdust treated soil as the stabilizer content was increased from 2.5 – 7.5 %. However, a decrease in uncured UCS occurred on increasing the sawdust content to 10 % (and beyond) by weight. Edeh et al. (2014) and Sun *et al.*(2018) also observed similar trend. The initial increase in uncured UCS may be attributed to the rough texture of the sawdust which produce large friction between the soil particles. The sawdust particles might serve as filler in this case and fill the void spaces between the particles. However, as the sawdust content increases above 7.5 % the sawdust particles start replacing the clay particles in such a way that it reduced the cohesion between the clay particles, which will eventually affect the uncured UCS of the sawdust treated soils. In addition, as the sawdust content increases beyond 7.5 % and start replacing the clay particles, the behavior of sawdust-soil matrix may be influenced by the large volume of sawdust in the soil mix (sawdust-sawdust interaction); therefore, the uncured UCS of the treated soil reduces. The result of one-way ANOVA test conducted on uncured UCS of the soils is summarized in Table **6**. The results showed that addition of sawdust had significant effect on the uncured UCS of the treated soils (i.e. $F_{Cal} > F_{Crit}$) and was statistically significant.

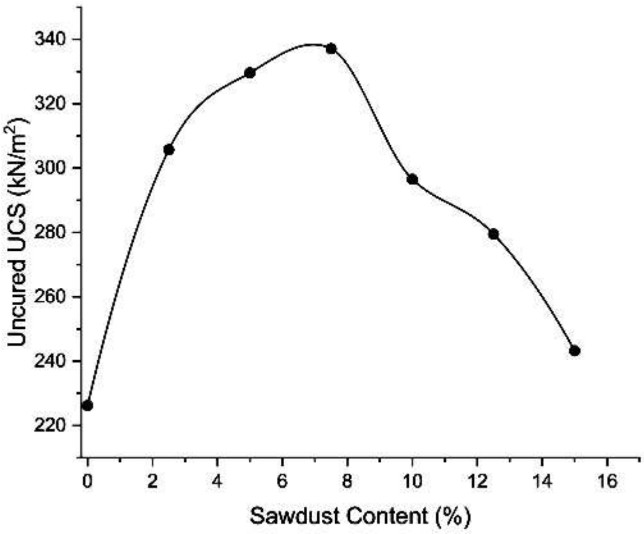

Fig. 7: Variation of uncured UCS with sawdust content

Shear Strength Parameters of the Soil

Fig. **8** illustrates the relationship between the shear strength and sawdust content under different applied normal stress. Generally, the shear strength of the treated soil increased as the both the normal stress and sawdust content increase. However, a reduction in the shear strength occurred on increasing the sawdust content beyond 7.5 % by weight. The increase in the shear strength may be attributed to the interwoven structure of soil and sawdust particles as described by Sun *et al.* (2018). The results of the shear strength parameters (Cohesion; C and Angle of internal friction; φ) of the different soil mixes compacted at their respective OMC are shown in Fig. **9**.

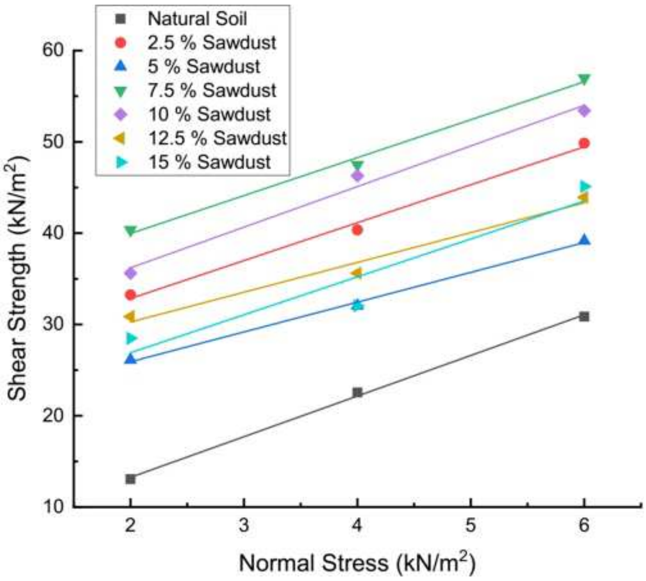

Fig. 8: Relationship between the sawdust content and shear strength under different normal stress

Figure 9 shows that the C of the stabilized soil increased for 2.5 - 7.5 % addition by weight of the sawdust to the soil and decreased afterwards with increasing stabilizer content. However, there is a slight decrease in C of the treated when sawdust content increased from 2.5 – 5 %.

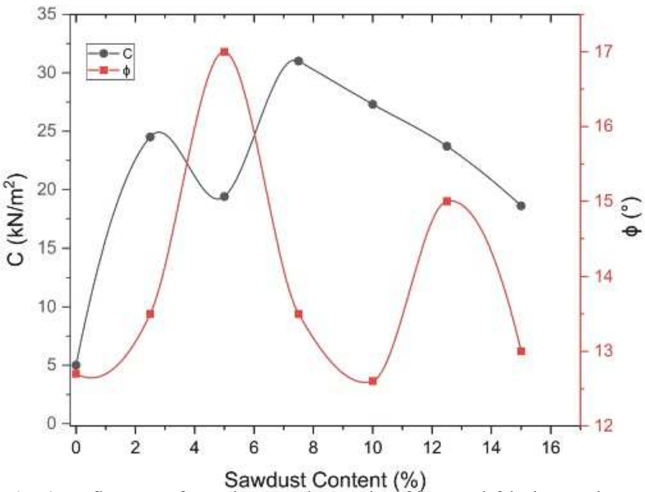

Fig. 9: Influence of sawdust on the angle of internal friction and cohesion of the treated soils

The increase in the C may be attributed to the bond between the soil and sawdust particles when the amount of sawdust is small (Sun *et al.* 2018). With further increase in sawdust content, the volume of sawdust increased and formed weak surfaces that not only destroyed the original soil structure but also the cohesion that exist between the soil particles. An increase in φ was observed as the sawdust content was increased from 2.5 – 5 % (Fig. **9**). Further addition of sawdust (7.5 – 10%) decreased the φ before it increased further on addition of 12.5 % sawdust. Addition of 15% sawdust decreased the φ further. The decrease in the friction angle when the sawdust content is large might be attributed to the possible increase in the porosity of the treated soil which provide path for the movement of the soil particles.

The result of one-way ANOVA test conducted on the strength parameters of the stabilized soils is summarized in Table **6**. Results showed that $F_{Cal} = 13.49$ and $F_{Crit} = 4.75$ for C. This indicates that $F_{Cal} > F_{Crit}$, and therefore, addition of sawdust had significant effect on the C of the treated soils and was statistically significant. In addition, the $F_{Cal} = 9.05$ and $F_{Crit} = 4.75$ (i.e. FCal > FCrit) for φ also shows that the addition of sawdust to the soils had a significant effect on this property of the soil.

Influence of Sawdust on the Permeability of the Soil

The variation in the permeability of the treated lateritic soil with different sawdust content is illustrated in Fig. **10**.

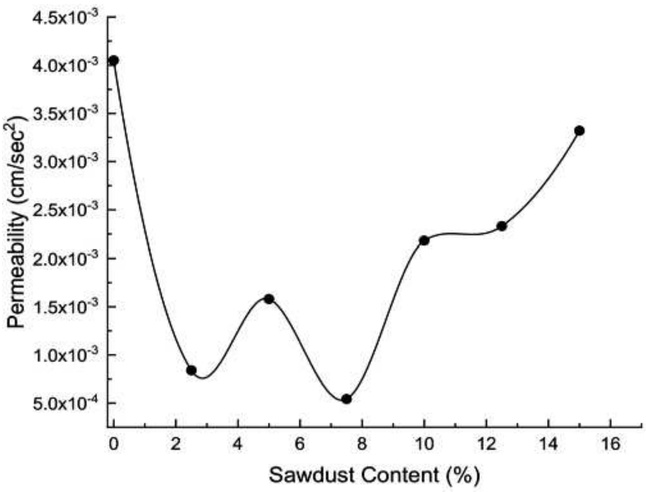

Fig. 10: Variation in the permeability of the treated soil with amount of sawdust

The figure reveals that the permeability of the sawdust-treated soil decreased to lowest value at 7.5 % sawdust content. The decrease in the permeability may be as a result of sawdust particles filling the pore spaces or air voids present in the soil and this improved the bond among the soil particles. Beyond 7.5% sawdust, an increase in permeability values were observed. This implies that as the sawdust content in the soil increased, the bond between the soil particles reduced or weakened as result of their interaction with the sawdust or the increase in the volume of sawdust in the mixes. This might produce a substantial number of interconnected pores in the sawdust treated soil. This may be the reason for the gradual increase in the permeability of the soil as the percentage of sawdust increased beyond 7.5 %. However, despite this increase, the permeability of the untreated soil sample remains the highest. Similar trend was also observed by previous workers (Mengue *et al.* 2017, Oyediran and Ayeni 2020). The result of one-way ANOVA test conducted on the permeability of the soils summarized in Table 6 shows that addition of sawdust had significant effect on the permeability of the treated soils (i.e. $F_{Cal} > F_{Crit}$) and was statistically significant.

Influence of Sawdust on the Compressibility Behavior of the Soil

The compression curves (one dimensional) for both the natural and the sawdust-stabilized lateritic soil specimens are shown in Fig. **11**.

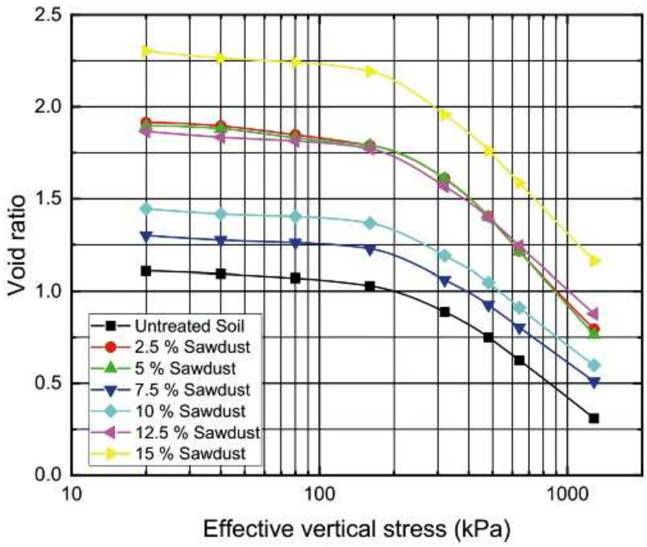

Fig. 11: Compressibility curves of the treated soils

An increase in void ratio occurred for sawdust contents of 2.5 - 15% compared to the untreated laterite. However, there is a slight decrease in void ratio when the sawdust content increased from 5 – 7.5 % after which the void ratio increased again. This phenomenon may be attributed to the arrangement of the particles of the soil-sawdust mixture. Relationship between the sawdust content and consolidation's parameters such as compression index (C_c), coefficient of consolidation (C_v), and coefficient of volume compressibility (m_v) are shown Figures 12 and 13. The curves however show the relationship between the C_v, M_v and sawdust content at pressure range of 320 – 480 kPa.

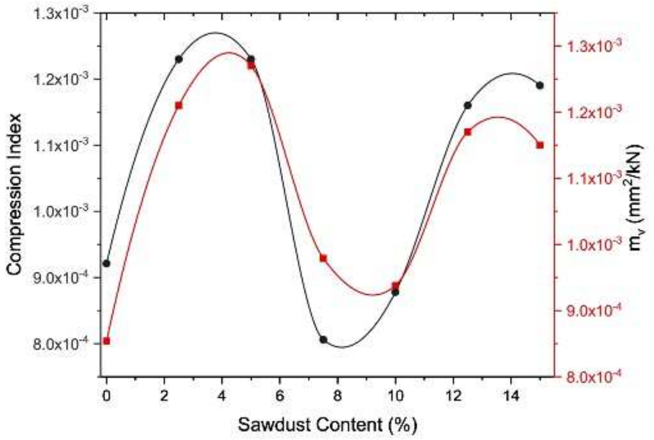

Fig. 12: Variation in the Cc and Mv of the treated soil with amount of sawdust

C_c represent the amount of anticipated settlement that a soil layer will undergo when subjected to pressure increment. C_c is normally obtained from the slope of the linear portion of the e-log p curve. An increase in C_c was observed as the sawdust content was increased from 2.5 – 5 % (Fig. **12**). Further addition of sawdust (7.5 % by weight) decreased the C_c to the minimum before it increased further on addition of 10 - 15 % sawdust. This increase in the Cc may be as result of increase in number of voids as the amount of sawdust increased. In addition, flaky particles have greater shrinkage capacity. M_v, regarded as the volume change per unit increase in effective stress for a unit volume of soil, displayed a trend similar to Cc. However, the minimum occurred when the sawdust content was 10 % (Fig. **12**). C_v relates to the time it will take an amount of consolidation to occur. C_v is affected by factors such as; the quantity of water squeezed out, and the rate at which that water can flow out. The lower its value, the lower the permeability. Fig. **13** shows that C_v decreased to minimum 7.5 % sawdust addition after which there is increase with further sawdust addition.

The result of one-way ANOVA test conducted on the consolidation parameters of the soils summarized in Table 7 shows that addition of sawdust had significant effect on the consolidation parameters of the treated soils (i.e. $F_{Cal} > F_{Crit}$) and was statistically significant.

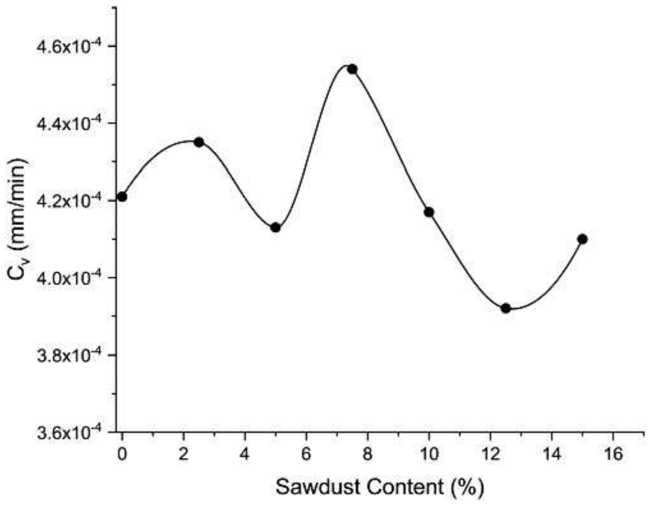

Fig. 13: Variation in the Cv of the treated soil with amount of sawdust

Table 7: One-way ANOVA tests for consolidation parameters and at varying sawdust content

Property	SoV	DF	F_{Cal}	P-Value	F_{Crit}	Remark
C_V	Sawdust	1	13.4961	0.003185	4.75	$F_{Cal} > F_{Crit}$
		12				Significant
C_c	Sawdust	1	13.4985	0.003183	4.75	$F_{Cal} > F_{Crit}$
		12				Significant
M_V	Sawdust	1	13.4963	0.003185	4.75	$F_{Cal} > F_{Crit}$
		12				Significant

Suitability of Sawdust Treated Lateritic Soil for Road Construction

The index and geotechnical properties of the sawdust treated and natural lateritic soil were compared to the Nigerian standard and other related standards (Table 8).

Despite the fact that addition of sawdust improved some properties of the soil, the results of index and geotechnical tests on sawdust treated soil show that the stabilized soil may not be entirely suitable for road construction as some of the results of these test are lower than the acceptable limits for the different pavement component (Table 8). Generally, liquid limit and plasticity index of the treated soils with up to 15 % of the sawdust measured up to the standards for materials that can be used for embankment, base, and sub-base. Similarly, the MDD of the sawdust stabilized soil only satisfied the criteria for embankment and subgrade materials at sawdust content in the range of 2.5 – 7.5 %. However, the UCS and soaked CBR of the stabilized soil failed to meet the requirements for embankment, sub-base and base course materials as stipulated by the different standards. CBR is one of the strength characteristics of pavement component and it is a key parameter used in designing and determining the required thickness of pavements. The inability of the

Table 8: Typical acceptance values for soils used in road construction

Properties	Natural Soil	2.5% Sawdust	5% Sawdust	7.5% Sawdust	10% Sawdust	12.5% Sawdust	15% Sawdust	Accepted Value	Reference
Liquid Limit (%)	48	29	22	17	16	14	13	< 40[a] < 35[b] ≤ 30[c] ≤ 40[c]	(FMW&H 1997) (FMW&H 1997) (FMW&H 1997) (DNIT 098/2007)
Plasticity Index (%)	12	3.1	1.2	0.3	NP	NP	NP	< 20[a] < 16[b] ≤ 13[c] ≤ 15[c]	(FMW&H 1997) (FMW&H 1997) (FMW&H 1997) (DNIT 098 2007)
MDD (kg/m3)	1915.22	1803.57	1678.31	1618.045	1539.91	1477.71	1413.86	1600[a] 1750[d]	MORTH (2001) MORTH (2001)
Soaked CBR (%)	9	11	13	15	11	8	6	> 20 ≥ 30[b] > 80[c] 5-11[d] ≥ 60[c]	(FMW&H 1997) (FMW&H 1997) (FMW&H 1997) (FMW&H 1997) (DNIT 098 2007)
UCS (kN/m^2)	226.2	305.7	329.6	337.1	296.5	279.5	243.2	700[b] 1717[c]	MORTH (2001) MORTH (2001)

CBR and UCS of the soil to meet the required standard for the different pavement component (except for subgrade) may be as result of the fact that the compacted samples were not cured before soaking and unconfined compression test was carried out.

Conclusion

This study investigates the effect sawdust (up to 15 % by dry weight of the soil) on the index and geotechnical properties of lateritic soil. The natural lateritic soil used in the study classifies as ML and A-7-5 (12) in USCS and AASHTO classification systems, respectively. Plasticity characteristics of the treated soil vary between ML – CL. The treated soil however becomes non plastic when the sawdust content is greater than 7.5 %. With increase in sawdust content a general reduction in MDD was observed. The OMC and linear shrinkage increase with increase in sawdust content. The CBR, uncured UCS and C increase with addition of sawdust, and reach the peak at 7.5 % sawdust. Permeability, C_c and C_v reduced to the minimum at 7.5 % sawdust content, then subsequently increased. The one-way ANOVA test shows that the addition of sawdust to the soil had significant effect on the liquid limit, plastic limit, OMC, MDD, unsoaked CBR, UCS, cohesion, permeability and compressibility characteristics of the treated soil. It, however, had no significant effect on properties such as soaked CBR, plasticity index and linear shrinkage of the treated soil. The results of index and geotechnical tests of sawdust treated soil show that the stabilized soil may not be entirely suitable for road construction as some of the results of these test are lower than the acceptable limits for the different pavement component. Additional work may be encouraged to assess the influence of curing on the strength properties of the treated soil.

References

Abdu, A.A., Musa, K.A. and Arafat, Y.S. (2017). Compaction Behaviour of Lateritic Soils Stabilized with Blends of Groundnut Shell Ash and Metakaolin. *Journal of Environment and Earth Science*, 7 (10), 28–39.

Abiddin Erguler, Z. and Ulusay, R. (2003). A simple test and predictive models for assessing swell potential of Ankara (Turkey) Clay. *Engineering Geology*, 67 (3–4), 331–352.

Adeyemi, G.O., Afolagboye, L.O. and Chukwuemeka, C.A. (2015). Geotechnical properties of non-crystalline coastal plain sand derived lateritic soils from Ogua, Niger Delta, Nigeria. *African Journal of Science, Technology, Innovation and Development*, 7 (4), 230–235.

Adeyemi, G.O., Afolagboye, L.O., and Ezenwafor, C.O. (2014). Engineering Geological Evaluation of some Soils from Ozubulu, Near Onitsha, SE Nigeria for use as a Liners in Waste Disposal Landfill. *Journal of Mining and Geology*, 50, 109 – 117.

Akinwumi, I.I., Adeyeri, J.B. and Ejohwomu, O.A. (2012). Effects of Steel Slag Addition on the Plasticity, Strength, and Permeability of Lateritic Soil. *In*: W.K.O. Chong, J. Gong, J. Chang, and M.K. Siddiqui, eds. *ICSDEC 2012*. Reston, VA: American Society of Civil Engineers, 457–464.

Alhassan, M. and Mustapha, A., 2007. Effect of rice husk ash on cement stabilized laterite. *Leonardo Electronic Journal of of Practices and Technologies*, 11 (11), 47–58.

Amadi, A.A. (2010). Pozzolanic Influence of Fly Ash in Mobilizing the Compressive Strength of Lateritic Soil. *AU Journal of Technology*, 14 (2), 139–146.

Athulya, G.K., Dutta, S. and Mandal, J.N. (2017). Performance evaluation of stabilised soil–slag mixes as highway construction material. *International Journal of Geotechnical Engineering*, 11 (1), 51–61.

Bell, F.G. (2007). *Engineering geology*. 2nd ed. Elsevier: Oxford.

British Standard 1377, 1990. *Methods of test for soils for civil engineering purposes*. London: British Standards Institution.

de Brito Galvão, T.C., Elsharief, A. and Simões, G.F. (2004). Effects of Lime on Permeability and Compressibility of Two Tropical Residual Soils. *Journal of Environmental Engineering*, 130 (8), 881–885.

Chang, I., Im, J., Prasidhi, A.K. and Cho, G.-C. (2015). Effects of Xanthan gum biopolymer on soil strengthening. *Construction and Building Materials*, 74, 65–72.

Dhar, S. and Hussain, M. (2019). The strength and microstructural behavior of lime stabilized subgrade soil in road construction. *International Journal of Geotechnical Engineering*.

Eberemu, A.O. (2011). Consolidation Properties of Compacted Lateritic Soil Treated with Rice Husk Ash. *Geomaterials*, 01 (03), 70–78.

Eberemu, A.O. (2013). Evaluation of bagasse ash treated lateritic soil as a potential barrier material in waste containment application. *Acta Geotechnica*, 8 (4), 407–421.

Edeh, J.E., Joel, M. and Ogbodo, V.O. (2020). Effects of oil palm fibre ash on cement stabilised lateritic soil used for highway construction. *International Journal of Pavement Engineering*, 1–7.

Federal Ministry of Works and Housings, [FMW&H] (1997). *General Specifications (Roads and Bridges)*. Government of the Federal Republic of Nigeria.

Gidigasu, M.D. (1976). *Laterite Soil Engineering: Pedogenesis and Engineering Principles*. New York: Amsterdam Elsevier Scientific.

Goodarzi, A.R., Goodarzi, S. and Akbari, H.R. (2015). Assessing geo-mechanical and micro-structural performance of modified expansive clayey soil by silica fume as industrial waste. *Iranian Journal of Science and Technology - Transactions of Civil Engineering*, 39 (C2), 333–350.

Joel, M. and Agbede, I.O. (2011). Mechanical-cement stabilization of laterite for use as flexible pavement material. *Journal of Materials in Civil Engineering*, 23 (2), 146–152.

Keramatikerman, M., Chegenizadeh, A. and Nikraz, H. (2016). Effect of GGBFS and lime binders on the engineering properties of clay. *Applied Clay Science*, 132–133, 722–730.

Latifi, N., Vahedifard, F., Ghazanfari, E., Horpibulsuk, S., Marto, A. and Williams, J. (2018). Sustainable Improvement of Clays Using Low-Carbon Nontraditional Additive. *International Journal of Geomechanics*, 18 (3), 04017162.

Lee, I.K. and Coop, M.R. (1995). The intrinsic behaviour of a decomposed granite soil. *Géotechnique*, 45 (1), 117–130.

Li, Y., Tan, Y.Z., Jiang, J. and Xia, C.F. (2012). Experimental Study on the Compressibility of Cement Improved Laterite Soil. *Applied Mechanics and Materials*, 170–173, 371–374.

Mengue, E., Mroueh, H., Lancelot, L. and Medjo Eko, R. (2017). Physicochemical and consolidation properties of compacted lateritic soil treated with cement. *Soils and Foundations*, 57 (1), 60–79.

Millogo, Y., Hajjaji, M., Ouedraogo, R. and Gomina, M. (2008). Cement-lateritic gravels mixtures: Microstructure and strength characteristics. *Construction and Building Materials*, 22 (10), 2078–2086.

Ministry of Works and Housings [MORTH] (2001). Ministry of Road Transport & Highways, Government of India.

Mir, B.A. and Sridharan, A. (2013). Physical and Compaction Behaviour of Clay Soil-Fly Ash Mixtures. *Geotechnical and Geological Engineering*, 31 (4), 1059–1072.

Mitchell, J.K. and Soga, K. (2005). *Fundamentals of soil behavior*. 3rd ed. New York: John Wiley & Sons.

Moghal, A.A.B., Chittoori, B.C.S., Basha, B.M., and Al-Mahbashi, A.M. (2018). Effect of polypropylene fibre reinforcement on the consolidation, swell and shrinkage behaviour of lime-blended expansive soil. *International Journal of Geotechnical Engineering*, 12 (5), 462–471.

Mohamedzein, Y.E.A. and Al-Rawas, A.A. (2011). Cement-Stabilization of Sabkha Soils from Al-Auzayba, Sultanate of Oman. *Geotechnical and Geological Engineering*, 29 (6), 999–1008.

Netterberg, F. (2014). Review of specification for the use of laterite in road pavements. 1–60.

Nicholson, P.G. (2015). *Soil improvement and ground modification methods soil improvement modification*. Waltham: Butterworth Heinemann.

Nicholson, P.G. and Kasyap, V. (1993). Fly ash stabilization of tropical Hawaiian soils. *In*: K.D. Sharp, ed. *Fly ash for soil improvement. ASCE Geotechnical Special Publication NO. 36*. New York, 15–29.

Ogunwusi, A.A. (2014). Wood Waste Generation in the Forest Industry in Nigeria and Prospects for Its Industrial Utilization. *Civil and Environmental Research*, 6 (9), 62–69.

Osinubi, K.J. (1998). Permeability of Lime Treated Lateritic Soil. *Journal of Transportation Engineering*, 124 (5), 465–69.

Osinubi, K.J., Amadi, A.A. and Eberemu, A.O. (2006). Shrinkage characteristics of compacted laterite soil - fly ash mixtures. *NSE Technical Transaction*, 41, 36–48.

Osinubi, K.J., Edeh, J.E., and Agada, J.O. (2012). Rice Husk Ash Stabilization of Reclaimed Asphalt Pavement. *In*: *Testing and Specification of Recycled Materials for Sustainable Geotechnical Construction*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International, 468–480.

Oyediran, I.A. and Ayeni, O.O. (2020). Comparative effect of microbial induced calcite precipitate, cement and rice husk ash on the geotechnical properties of soils. *SN Applied Sciences*, 2 (7), 1157.

Oyediran, I.A. and Okosun, J. (2013). An attempt to improve geotechnical properties of some highway lateritic soils with lime. *Rmz – M&G*, 60, 287–296.

Rahaman, M.A. (1988). Recent Advances in the Study of Basement Complex of Nigeria. *In*: P.O. Oluyide, W.C. Mbonu, A.E. Ogezi, I.G. Egbuniwe, A.C. Ajibade, and A.C. Umeji, eds. *Precambrian Geology of Nigeria*. Geological Survey of Nigeria Publication, 11–43.

Reddy, N.G., Tahasildar, J. and Rao, B.H. (2015). Evaluating the Influence of Additives on Swelling Characteristics of Expansive Soils. *International Journal of Geosynthetics and Ground Engineering*, 1 (1), 7.

Sun, S., Liu, B. and Wang, T. (2018). Improvement of Expansive Soil Properties Using Sawdust. *The Journal of Solid Waste Technology and Management*, 44 (1), 78–85.

Toll, D.G. (2012). Tropical soils. *In*: J. Burland, T. Chapman, H. Skinner, and M. Brown, eds. *ICE manual of geotechnical engineering: Volume I*. Thomas Telford Ltd, 341–361.

Wihersaari, M. (2005). Evaluation of greenhouse gas emission risks from storage of wood residue. *Biomass and Bioenergy*, 28 (5), 444–453.

Zhang, T., Cai, G. and Liu, S. (2018). Application of Lignin-Stabilized Silty Soil in Highway Subgrade: A Macroscale Laboratory Study. *Journal of Materials in Civil Engineering*, 30 (4), 1–16.