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Treatment of Lateritic Soil Using Soya Beans Waste Ash for Landfill Liner and Cover

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ABSTRACT

This study evaluated the suitability of lateritic soil treated with Soya Beans Waste Ash (SBWA) as a liner material for municipal solid waste containment systems. SBWA was added at 0%, 4%, 8%, 12%, and 16% by dry weight of soil and compacted using British Standard Light (BSL), West African Standard (WAS), and British Standard Heavy (BSH) compactive efforts at varying moulding water contents. Leachate characterization revealed highly contaminated effluents with pH values ranging from 3.57 to 6.32, Total Dissolved Solids between 1,856 mg/l and 3,328 mg/l, lead concentrations of 0.03–0.640 mg/l, and iron concentrations as high as 46.075 mg/l, all exceeding permissible limits. Chemical Oxygen Demand ranged from 171 to 190 mg/l, indicating significant pollution strength. Geotechnical results showed that percentage fines reduced from 3.15% (natural soil) to 1.01% at 16% SBWA, indicating flocculation and agglomeration. Specific gravity decreased from 2.61 to 2.56 with increasing SBWA. Liquid limit increased from 44.50% to a peak of 48.15% at 4% SBWA, while plastic limit decreased from 25.00% to 23.24% at 8% SBWA. The plasticity index increased from 19.5% to 24.33% at 4% SBWA. Maximum Dry Density (MDD) decreased slightly with increasing SBWA, with values ranging from 1.60 Mg/m³ (natural soil, BSL) to 1.73 Mg/m³ (natural soil, BSH), reducing to 1.56 Mg/m³ (BSL) and 1.67 Mg/m³ (BSH) at 16% SBWA. Optimum Moisture Content (OMC) increased from 16.6% to 17.20% (BSL) and from 14.64% to 15.19% (BSH) with increasing SBWA. Unconfined Compressive Strength (UCS) improved significantly with treatment, increasing from a minimum of 248.01 kN/m² (natural soil at +4% OMC) to a maximum of 789.67 kN/m² at 8% SBWA under BSH compaction, far exceeding the recommended minimum value of 200 kN/m² for liner applications. Volumetric Shrinkage Strain (VSS) reduced from 5.2% (untreated soil) to as low as 1.6% at 8% SBWA, satisfying the 4% maximum design criterion. Hydraulic conductivity of the natural soil increased from 1.16 × 10^{-9} m/s to 3.01 × 10^{-8} m/s after leachate permeation, whereas 8% SBWA-treated soil showed comparatively lower long-term values of 2.24 × 10^{-8} m/s, indicating improved resistance to leachate attack. 8% SBWA compacted at 0% to +2% OMC under BSH effort produced the highest strength (789.67 kN/m²), lowest shrinkage (1.6%), and improved hydraulic performance, making it the optimum content for landfill liner applications.

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INTRODUCTION

Landfills play a crucial role in managing solid waste, but they also pose significant environmental risks if not properly constructed and maintained (Siddiqua *et al.,* 2022). A critical component of landfill design is the liner and cover system, which prevents the migration of leachate into the surrounding soil and groundwater. Traditionally, natural clayey soils are used for this purpose due to their low permeability (Rahmat et al., 2017). However, in many regions, the natural properties of available soils, such as lateritic soil, may not meet the stringent requirements for landfill applications without modification (Okonkwo *et al.,* 2022).

Laterite is a natural soil substance that is characterised by its vesicular structure, porous qualities, and lack of stratification. It contains ferruginous matter, which is yellow ochre in colour due to its high iron concentration. Because of its extensive usage in the production of mud bricks, this soil was referred to as laterite. The porous properties of laterite limit its application as a liner material in landfills, thus its stabilisation with cement is needed for effective application as landfill liner (Gupta et al., 2024). Lateritic soil, which is abundant in tropical regions, often exhibits properties such as high permeability and low shear strength that limit its effectiveness as a landfill liner or cover material (Ahmad *et al.,* 2018). stabilization techniques are employed to enhance its geotechnical properties. In recent years, the use of waste materials as stabilizers has gained attention due to their environmental benefits and cost-effectiveness (Eberemu *et al.,* 2019). Among these materials, soya beans waste ash (SBWA), a by-product of the soya bean processing industry, shows promise as an eco-friendly stabilizer

Soya Bean Waste Ash (SBWA) is a by-product derived from the processing of soybeans, particularly during oil extraction and food manufacturing operations. During soymilk and tofu production, substantial quantities of by-products are generated. It has been reported that for every 1 kg of dried soybeans processed into soymilk or tofu, approximately 1.2 kg of soybean curd residue commonly referred to as okara is produced (Ikeagwuani et al., 2015). This residue is typically considered a waste material and is often discarded without adequate utilization.

In light of the scarcity of landfill capacity, waste management is a pressing environmental and social issue. Therefore, landfills have diversity of environmental effects, such as the contamination of surface water and groundwater by leachate, the contamination of soil through direct contact with refuse or leachate percolation, and the transmission of diseases (Gupta et al., 2024). The environmental challenge posed by the disposal of Soya beans waste and the effective management of these wastes is a global issue that is becoming increasingly significant. This is due to the cost of storing and transporting waste, the loss of revenue from not reclaiming waste materials, and the associated potential environmental hazards.

The positive environmental effects of the use of industrial and agricultural residues, such as Soya beans waste Ash (SBWA) for soil improvement are significant in light of sustainable development (Etim et al., 2022). Given the current economic climate and the initiative of using locally accessible materials, it is crucial to identify more cost-effective and viable alternatives. The application of SBW as admixtures for application in hydraulic structures would offer an alternative to the conventional use of 100% cement, lime and other traditional stabilization. Soya Beans Waste ash (SBWA) is regarded as a viable method due to its cementitious properties. The outcome of the research will lead to effective stabilization of abundant lateritic soil; more economical engineering hydraulic structures will be constructed. The environmental challenge associated with the dumping of Soya beans shell would be minimized as a result of the beneficial use of the material

MATERIALS AND METHODS

Materials

Lateritic soil

The lateritic soil used in this study was obtained through disturbed sampling from a laterite formation in Shika, Zaria, Kaduna State

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(Latitude 11°15'N, Longitude 7°45'E). Samples were collected from depths of 1.5 to 2.0 m.

Water

Tap water used in the study was collected from the Soil Laboratory of the Department of Civil Engineering, Nigerian Defence Academy, Kaduna, Nigeria.

Soya Beans Waste Ash (SBWA)

Soya bean shells used in this research were obtained from sabon gari local government market of Kaduna state (Latitude 11°84'N, Longitude 7°13'E). The shell will be completely burn under atmospheric condition, sealed up in plastic bags and transported to the laboratory. The ash is first sieved through British Standard No. 200 sieve and kept in sealed container to be mixed with lateritic soil in appropriate percentages.

Leachate

The Municipal Solid Waste (MSW) leachate used in the research was obtained from a non-engineered active open landfill, located outside the premises of Ahmadu Bello University, Zaria, Nigeria. The leachate was obtained by scooping from a low-lying open point at three (3) different points in the landfill. The sources of wastes generated are waste from students, staff living off-campus and others which are dumped at the site

Methods

Atterberg Limits

The Atterberg limit tests (after Albert Atterberg) include the determination of the liquid limits, plastic limits, and the plasticity index for the natural soil and treated soil. We also conducted them in accordance with Test 1(A) BS 1377 (1990) Part 2.

Liquid limit

The soil sample for liquid limit (LL) was air dried, and 200 g of the material was sieved through BS No. 40 sieve (425 μm apertures). The dry sample was collected and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. The soil/water mixture was placed in the Casagrande apparatus cup, leveled it off parallel to the base, and divided it by drawing the grooving tool along the diameter through the hinge's center. The crank was turned to lift and drop the cup, ensuring that the two parts of the soil came into contact at the groove bottom. The number of blows that occurred was recorded, and small quantity of the soil was taken to determine its moisture content. The test was performed for well-spaced-out moisture content from the drier to the wetter states. The results were plotted to determined moisture content values and the corresponding number of blows on a semi-logarithmic graph to determine the liquid limit, which corresponded to 25 blows.

Plastic Limit

A portion of the soil used for the liquid limit test was retained for the determination of plastic limit (PL). The ball of the soil was moulded between the fingers and rolled between the palms of the hand until it dried sufficiently (even though the soil will be already relatively drier than the ones used for liquid limit). The sample was divided into approximately four equal parts. Each of the parts was rolled into a thread between the first finger and the thumb. The thread was then rolled between the tip of the fingers of one hand and the glass. This continued until the diameter of the thread reduces to about 3 mm in five to ten forward and backward movements of the hand. The movement continued until the thread sheared both longitudinally and transversely. The crumbled soil was put in the moisture container and the moisture content determined.

Plasticity index

The plasticity index (PI) of the soil is the difference between the liquid limit (LL) of the soil and the corresponding plastic limit (PL). The plasticity index was calculated as:

$$PI = LL - PL \quad (1)$$

Where:
PI =Plasticity Index (%)
LL =Liquid Limit (%)
PL = Plastic Limit (%)

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Compaction

The compaction tests were carried out for the natural soil and the treated soils (in different percentages of admixtures); all according to Head (1994), BS 1377 (1990) Part 4, Nigerian General Specifications NGS (1997) and BS 1924 (1990): British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). British Standard Light (BSL) compactive effort is produced by using 27 blows of 2.5 kg rammer dropped from 300 mm height on each layer of soil sample placed on 3 layers inside 1000 cm^3 moulds. On the other hand, WAS is a compactive effort is obtained by using 10 blows of 4.5 kg rammer from 450 mm height on each layer of soil sample placed in 5 layers inside 1000 cm^3mould while BSH is produced by 27 blows of 4.5 kg rammer on each layer of soil sample placed in 5layers inside 1000 cm^3 moulds.

The corresponding values of moisture contents at maximum dry densities (MDD), deduced from the graph of dry density against moisture contents, gave the optimum moisture content (OMC). The bulk density will be determined from the equation below;

$$Pb = \frac{Ms}{Vs} \quad (2)$$

where:
= Bulk density (g/cm³)
Ms = Mass of compacted soil (g)
Vs = Volume of Mould (cm³)
The dry unit weight will be determined using the expression

$$Pd = \frac{Pb}{1-w} \quad (3)$$

Where
Pd =dry unit weight (g/cm³)
Pb = bulk density (g/cm³)
W = optimum moisture content (%)

Unconfined Compressive Strength Test

The unconfined compressive strength (UCS) test was performed on the soil samples according to BS 1377; 1990 Part 7 using the British Standard light (BSL), West African standard (WAS) and British standard heavy (BSH)compactive effort. The natural soil sample and the treated soil samples were compacted in moulds at their respective OMC.

The samples were extruded from the mould and trimmed into a cylindrical specimen of 38.1 mm diameter and 76.2 mm length. The three cylindrical specimens from the mould were kept cured for 48 hours and then placed centrally on the lower platen of a compression testing machine and a compressive force was applied to the specimen with a strain control at 0.10 % mm. Record was taken simultaneously of the axial deformation and the axial force at regular interval until failure of the sample occurred.

The UCS of the sample was determined at the point on the stress–strain curve at which failure occurred. The unconfined compressive strength is calculated from:

$$\delta = \frac{[R \times C_T \times (100 - E\%) \times 100KN/M^2\,]}{100 \times A_O} \quad (4)$$

Where

$$E(\%) = \frac{V}{L_O} \quad (3.7)$$

V =amount of compression at any stage
R = load ring reading at strain E
L_O =initial length of specimen
G = mean calibration of load ring
A_O initial cross sectional are
δ= compressive stress at strain E

Hydraulic Conductivity Test

Falling head permeameter recommended by Head (1994) was used to perform the hydraulic conductivity test using three compactive efforts (BSL, WAS and BSH) and soaked in a water tank for a period of about 48 hours so that maximum saturation was achieved. While being saturated, the samples were restrained from vertical swelling. After saturation, the samples in the cell were then assembled in the falling head permeameter set up so as to carry out hydraulic conductivity test and permeation was done with water

During permeation, specimens were restrained from vertical swelling and the test lasted for 24 hours measuring the changes in the hydraulic head which was taken at 4 hours interval. The coefficient of permeability (k) in cm/s was calculated using eq (3.8) below:

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$$k = \frac{2.303aL}{At}\log_{10} h1/h2 \qquad (5)$$

Where: a = Cross-sectional area of the stand pope (m^2)
L=Length of the specimen (m)
A=Cross-sectional area of the soil sample (m^2)
h_1 and h_2=Initial and final heights of water levels in the stand pipe (m)
t=Time in second
k=Coefficient of permeability (m/s)

Volumetric Shrinkage

Natural and PSA treated samples was compacted using three compactive effort: BSL, WAS, and BSH energy levels. We will compact air-dried soil and PSA mixtures at -2%, 0%, +2%, and +4% of the optimum moisture content (OMC). The extruded cylindrical specimens were placed on a laboratory bench at a uniform temperature of 29 ± 2 °C for 30 days to dry naturally. Daniel and Wu (1993) used an air-conditioned building to dry compacted cylindrical specimens, but this method is considered better. This is because natural drying in the laboratory is considered to duplicate field conditions. Vernier caliper was used to take accurately measurement of each specimen's diameters and heights to within 0.05 mm of precision. The volumetric shrinkage strain was computed using the average diameters and heights.

RESULTS AND DISCUSSION

Chemical Compositions of Leachates

The analyzed leachate had a light colour with putrefying odor due to decomposition waste organic matter. It was rich in alkaline and alkaline earth metallic ions with low Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) as shown in Table 1.

Table 1: Compositional Properties of the Leachates used

Measured Parameter	Unit	Leachate A	Leachate B	Leachate C	Max. permitted Limit
pH	-	3.57	6.32	4.93	6.5 – 8.5
Temperature	0C	28.1	27.7	27.8	Ambient
Turbidity	NTU	186	102	188	5
Electrical conductivity	µm/cm	4.6	5.2	2.9	0.15 – 0.3
Total Dissolve Solid	mg/l	2944	3328	1856	500
Total Hardness	mg/l	128	101	120	150
Chloride	mg/l	816.5	106.5	88.75	<4
Iron	mg/l	46.075	44,687	2.83	0.3
Lead	mg/l	0.632	0.64	0.03	0.01
Nitrate	mg/l	5.8	7.2	38.74	45
Sulphate	mg/l	13.6	11.38	16.26	<10
Sodium	mg/l	680	560	230	<3
Zinc	mg/l	2.036	0.557	0.02	0
Chromium	mg/l	0.077	0.118	0.23	0
Calcium	mg/l	97.5	235	95	75
Potassium	mg/l	600	740	190	55
Magnesium	mg/l	26.33	63.45	25.65	20
Manganese	mg/l	1.072	2.043	0.21	0.2
Dissolve Oxygen	mg/l	4.12	3.76	3.88	6

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Measured Parameter	Unit	Leachate A	Leachate B	Leachate C	Max. permitted Limit
BOD	mg/l	3.21	3.75	3.46	3
COD	mg/l	171	184	190	<20

Specific gravity

The variation of specific gravity of the natural soil and the stabilize SBWA soil is shown in Fig. 1. The specific gravity of the soil generally decreases with increased *in SBA* Its values decreased from 2.61 for the natural soil to 2.56 at 16% SBWA content. this decrease may be caused by Soya beans ash has lower specific gravity than laterite with Increased voids and Ash particles might increase soil porosity. Also, the decrease can be attributed to Ash changes soil structure, affecting density (Moses, 2012). More ash lower composite specific gravity. which caused the soil particle to be flocculated within the soil matrix and hence particles are loosely parked. Similar result was also reported by Osinubi *et al.* (2017).

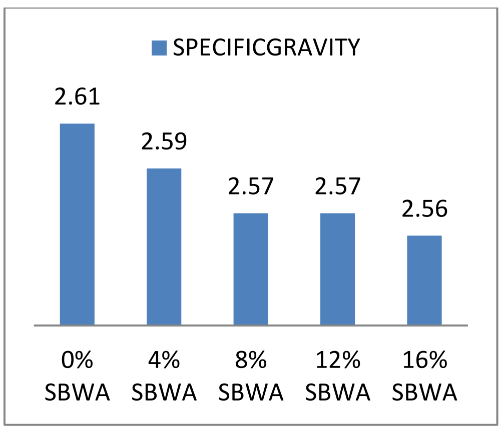

Fig. 1: Variation of the specific gravity of the soil treated SBA content

Atterberg Limits

Liquid Limits

The variation of liquid limit of the soil stabilize with SBA content is shown in Fig. 2. The reaction is in agreement with the concept of liquid limit, which is the water content at which the soil exhibits dynamic shear strength. The addition of SBWA, specifically, introduced calcium for its strength that caused a decrease in the repulsive force of the soil mixture; thereby requesting more water to take the soil to its dynamic shear strength (Osinubi et al., 2020).

The value of the liquid limit of the soil increased from 44.50% of the natural soil to a peak value of 48.15 at 4% SBA content. It was observed that the liquid limit increased steadily from its natural state to 4% SBA before the values reduced to 47.10%. This reduction may not be unconnected with the agglomeration and flocculation of the clay particles and a result of ion exchange at the surface of the clay particles; as the excess Ca2+ in the admixtures reacts with the lower valence metallic ions in the clay structure.

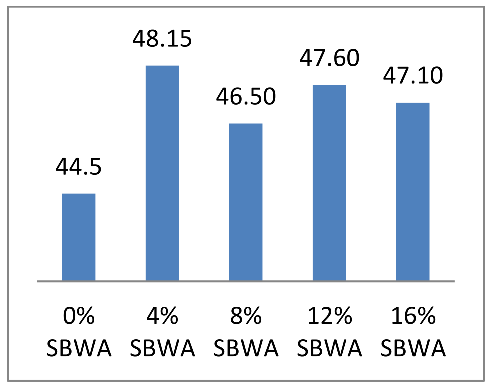

Fig. 2: Variation of the liquid limit of the soil treated SBWA content

Plastic limit

The variation of the plastic limit of the soil with SBWA contents is shown in Fig. 3. Plastic limit generally decreased with higher admixture contents, from a natural soil value of 25.00% to minimum value of 23.24% at 8% SBA. The reduction is in agreement with the findings of Osinubi et al., (2020). The reduction was due to the cation exchange reaction whereby the more active and higher valent cations (i.e. Ca^{2+}) in the admixtures replaced the weakly bonded ions in the clay structure; thereby leading to the flocculation and liberation of water bonded at the outer layers.

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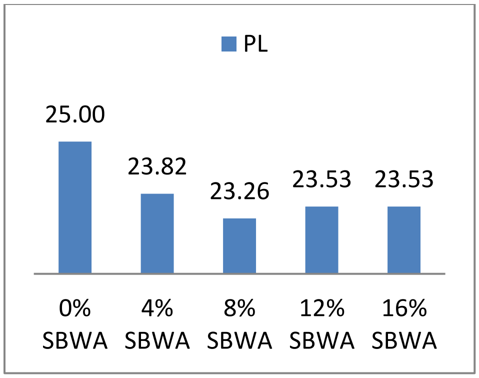

Fig. 3: Variation of the plastic limit of the soil treated SBWA content

Plasticity index

The variation of the plasticity index of soil with SWBA contents are shown in Fig. 4. The reduction in plastic limit and increase in liquid limit were accompanied by a general increase in the plasticity index value from a value of 19.5% to a peak value of 24.33 at 4% SBWA treatment. Akinmade (2008) reported the same trend of increasing LL, PI and decreasing PL with increasing admixture contents; on stabilizing black cotton soil with LBWA. The same trend was also reported by Stephen (2005) for the effect of bagasse ash on black cotton soil.

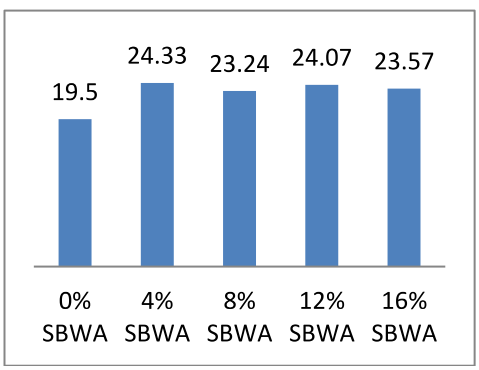

Fig. 4: Variation of the Plasticity index of the soil treated SBWA content

Compaction Characteristics

Maximum Dry Density

The variation of the MDD of stabilize SBWA soil is shown in Fig. 5. The MDD decreased with increasing SBA content. The MDD decreased from 0% SBA of 1.60mg/m³ to 1.56mg/m³, 1.68mg/m³ to 1.64mg/m³, and 1.73mg/m³to 1.67mg/m³ for compactive effort of BSL, WAS and BSH respectively of soil stabilize with up to 16% SBA content. The reduction in MDD is probably due to the lower specific gravity values as SBA content increases. This result is in conformity with the finding of Osinubi *et al*. (2017) and Abo-El-Enein *et al*. (2012).

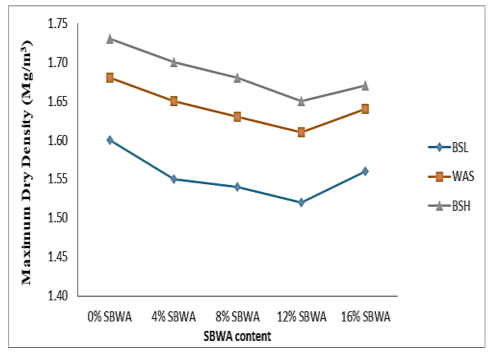

Fig. 5: Variation of the MDD of the soil treated SBWA using three compactive effort (BSL, WAS and BSH)

Optimum Moisture Content

The variation of the OMC stabilize SBA is shown in Fig. 6. The OMC generally increased with increased in SBA content. The OMC increased from the natural soil of 16.6% to 17.20%, 15.7% to 16.31% and 14.64% to 15.19% for compactive effort of BSL, WAS and BSH respectively of stabilize SBA with up to 16% SBWA content. The increased in OMC could be caused by cementation reagent to form larger surface areas that had greater affinity for water thereby leading to higher moisture content (Okonkwo *et al.,* 2022).

This can also be attributed to the quantity of calcite that bridged the soil particles together by clogging of the pore spaces within the soil thereby allowing for more affinity of water hence absorption. This result is in conformity with the finding of Osinubi *et al*. (2017) and Abo-El-Enein *et al*. (2012)

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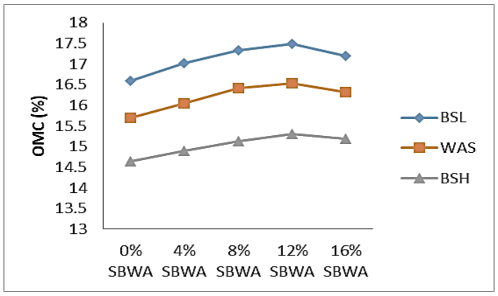

Fig. 6: Variation of the OMC of the lateritic soil treated SBWA using three compactive effort (BSL, WAS and BSH)

Unconfined Compressive Strength

The minimum required strength of soil to be used in compacted soil liners is not specified however, a minimum of 200kN/m^2 is arbitrarily selected to support the maximum bearing stress in a landfill. The variations of unconfined compressive strength UCS with moulding water content are shown in Figure 3. Generally, the UCS of the mixtures increases with increase in moulding water content in agreement with findings of other researchers (Osinubi et al., 2017).

The natural soil at 0% SBWA was 258.22 kN/m^2 of -2 OMC increases to 301.56 kN/m^2 and decreases to 248.01 kN/m^2 with increase in moulding water content of +4 OMC (See Fig. 7). But the treated SBWA soil at different effort shows variations in behavior due to the inclusion of pozzolanic soya beans ash. The highest peak value was 521.8 kN/m^2, 604.8 kN/m^2 and 789.67 kN/m^2 recorded at 8% SBA all at +2 OMC for BSL, WAS and BSH compactive effort respectively. The UCS values beyond 8% SBWA content using the three compactive effort exhibited trend that indicated reduction in strength. which did not yield better UCS value but a reduction in UCS value was recorded in agreement with the findings reported by Osinubi et al. (2017)

The minimum UCS value recommended by Daniel and Wu (1993) was satisfied by the SBWA treated soil prepared at moulding water content in the range -2 to +4 using the three compactive effort. (Osinubi and Eberemu, 2015). Specimens compacted with BSL energies produced satisfactory UCS values at moulding water which is higher at +2OMC followed by 0 OMC. Samples stabilize with 8% SBWA content recorded higher UCS values that were obtained at moulding water contents in the range of 0 and +2OMC for BSL, WAS and BSH compactions, respectively. After that that there was a decrease at 16% SBWA. Minimum UCS values were obtained at moulding water content ranges of -2 and +4OMC at BSL, WAS and BSH compactive efforts respectively. Finally, with a drop in UCS value at 16% SBA.

Higher SBWA content of 16% SBA recorded results that showed marked deviation from the regular pattern of UCS values. On the dry side of optimum, lower values were recorded. This trend could be as a result of the moulding water contents being insufficient to meet the hydration demand of the soya beans ash (Okonkwo *et al.*, 2022). Generally, UCS values increased with higher compactive effort. This trend is attributed to closer packing of the soil fabric at high energy level (Eberemu, 2007).

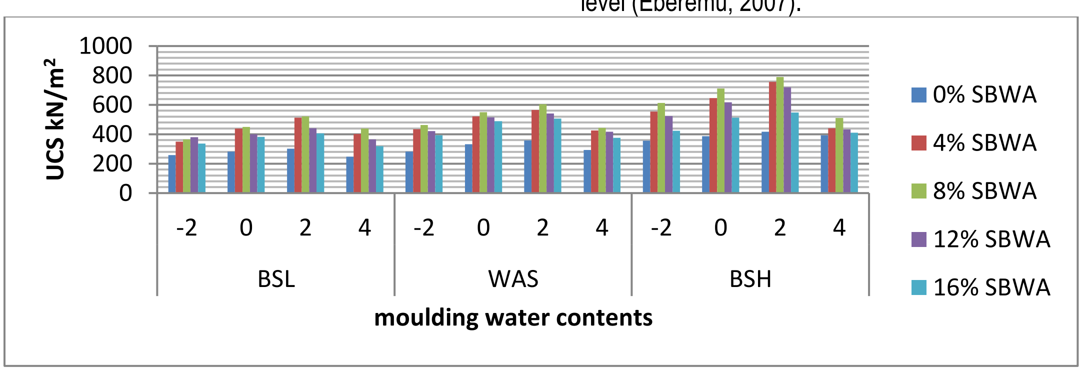

Fig. 7: Variation of the UCS of the lateritic soil treated SBWA using three compactive effort (BSL, WAS and BSH)

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Volumetric Shrinkage Strain

Effect of Moulding Water Content on Volumetric Shrinkage Strain

Figure 8 a – e shows the variation of VSS with moulding water content (MWC) for varying SBWA Content. Generally, VSS value increased non-linearly with higher moulding water content. The natural soil only met the requirement of less than 4% only at BSH between moulding water content of 14 % to 17.8%. But treatment beyond 4% at WAS and BSH compaction all met the minimum requirement of less than 4% for all moulding water content considered. The calcite precipitated in the voids may have been responsible for the lower VSS values recorded therefore higher volumetric shrinkage is expected to be significant in the prepared at higher moulding moisture content than at lower moulding water content in agreement with the findings reported by Osinubi and Nwaiwu, (2008); Cheng et al. (2013) and Mujah et al. (2017). Based on the results recorded, it implies that VSS values are linearly related to moulding water content respective of soya beans waste ash (SBWA) Content.

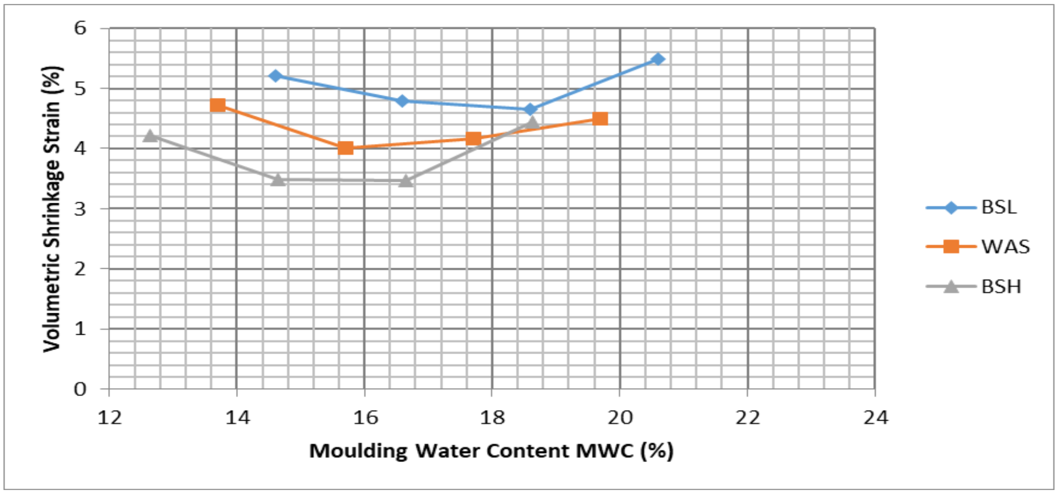

Fig. 8a. Variation of VSS against MWC at 0% SBWA

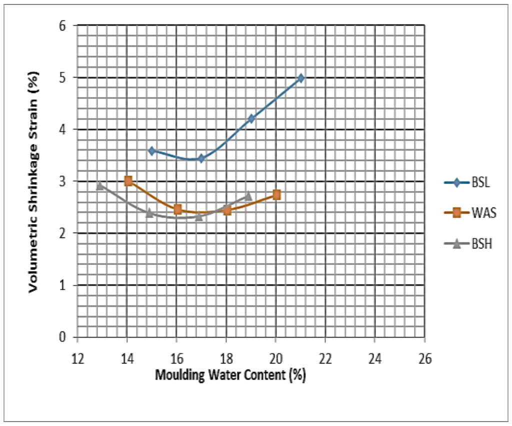

Fig. 8b. Variation of VSS against MWC at 4% SBWA

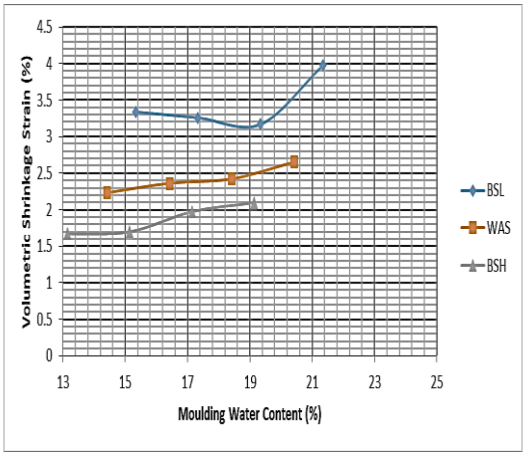

Fig. 8c. Variation of VSS against MWC at 8% SBWA

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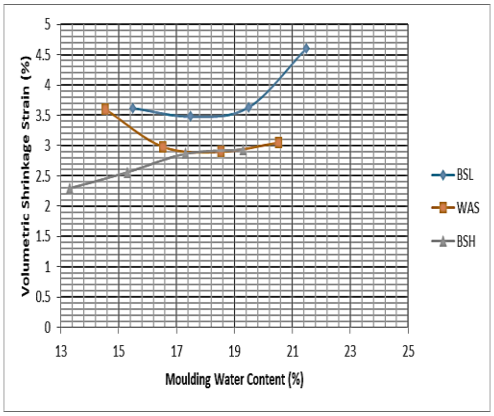

Fig. 8d. Variation of VSS against MWC at 12% SBWA

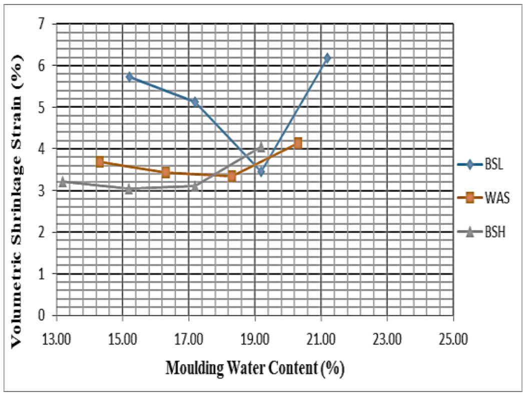

Fig. 8e. Variation of VSS against MWC at 16% SBWA

Effect of leachate on long-term hydraulic conductivity

Variation of hydraulic conductivity with time for the sample permeated with municipal solid waste leachate shown in Fig. 9. The hydraulic conductivity values obtained for the soil increased at the beginning of permeated up to 60 days and later shows decreased. The hydraulic conductivity values obtained for SBWA stabilize soil shows slightly decreased at 8% SBWA and shows slightly increased at 12% and 16% SBA. At 8%SBA the hydraulic conductivity values were very low compared to other SBWA content. The hydraulic conductivity of the natural soil increased at the beginning was $1.16\text{x}10^{-9}$ cm/s while the values at the end permeation with leachate was $3.01\text{x}10^{-8}$ cm/s which indicating an increase by a factor of 25.949. while for the SBA Stabilize soil. the hydraulic conductivity values recorded at the beginning of permeated were $1.00\text{x}10^{-9}$cm/s, $2.07\text{x}10^{-9}$cm/s, $1.66\text{x}10^{-9}$cm/s and $1.95\text{x}10^{-9}$cm/s, the values recorded at the end permeated (90 days) were $5.42\text{x}10^{-8}$cm/s, $2.24\text{x}10^{-8}$ cm/s, $3.43\text{x}10^{-8}$cm/s, and $4.23\text{x}10^{-8}$cm/s for 4%, 8%, 12% and 16% SBWA content respectively.

Stabilize SBWA of 4%, 8%, 12% and 16% were increased by factor of 54.038, 10.841, 20.597 and 21.674 respectively. On the other hand, the hydraulic conductivity values decreased from $2.24\text{x}10^{-8}$m/s to $2.07\text{x}10^{-9}$m/s with the increase in factor of 10.841 for 8% SBA content. The trend recorded is similar to the gradual decrease in hydraulic conductivity reported by other researcher (Moses, 2012; Oluremi, 2015; Osim, 2017).

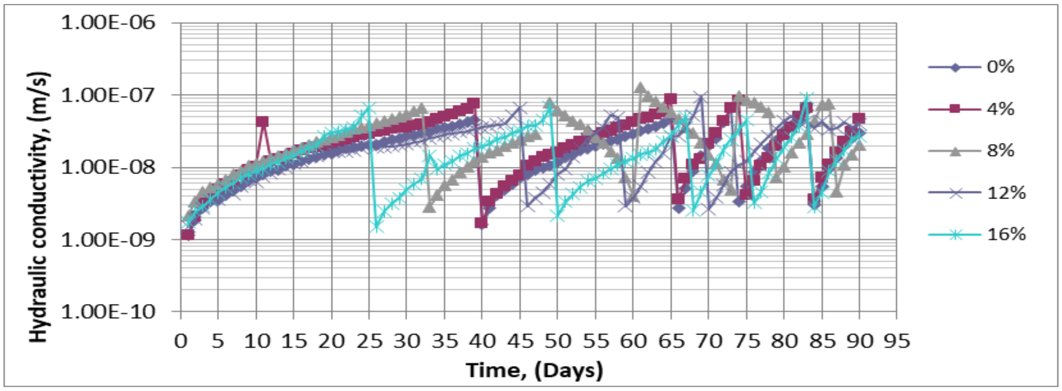

Fig. 9: Variation of hydraulic conductivity of SBWA treated soil with time (Permeation with leachate)

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CONCLUSION

The following conclusions can be drawn from the research work:

1. The Atterberg limit of both natural and stabilize soil increase from 45.50 to 47.60 with clear reduction in plastic limit from 25.0 to 23.2. at 12% and 8% SBA respectively. With the highest PI of 24.3 at 4% SBA content. The specific gravity of the natural soil was found to be 2.61 which decrease to 2.56 at16% SBA content.
2. The Maximum Dry density decreased from natural value of 1.60 to 1.52 at 12% SBWA under BSL effort, while WAS and BSH effort natural values were 1.68 and 1.73 which also reduces to 1.61 and 1.65 all at 12% SBWA respectively. The Optimum Moisture increased from natural value of 16.6 to 17.49% for BSL while WAS and BSH effort also increased from natural value of 15.7 and 14.64 to 16.53 and 15.30 all at 12% SBWA respectively.
3. For the UCS Samples stabilize with 8% SBWA content recorded higher UCS values that were obtained at moulding water contents in the range of 0 and +2 OMC with value 521 kN/m², 604.8 kN/m² and 789.67 kN/m² for BSL, WAS and BSH compactions, respectively. Minimum UCS values of greater than 200 kN/m² were obtained at moulding water content ranges of -2 and +4 OMC at BSL, WAS and BSH compactive efforts respectively.
4. The VSS value of natural soil only met the requirement of less than 4% only at BSH between moulding water content of 14 % to 17.8%. But treatment beyond 4% at WAS and BSH compaction all met the minimum requirement of less than 4% for all moulding water content considered
5. Long term hydraulic conductivity of specimens permeated with leachate for 90 days showed slightly increased especially the natural soil and the stabilize soil with SBWA decrease under 4% to 12% SBA content. which was achieved at 74 days, but thereafter decreased. The minimum required hydraulic conductivity value of $1.0 \times 10^{-7} cm/s$ was achieved at treatment beyond 4% SBWA content at +2 OMC.
6. 8% SBWA compacted at 0% to +2% OMC under BSH effort produced the highest strength (789.67 kN/m²), lowest shrinkage (1.6%), and improved hydraulic performance, making it the optimum content for landfill liner applications.

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