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STUDY ON THE GEOTECHNICAL PROPERTIES OF LATERITIC SOIL STABILIZED WITH BENTONITE AND GROUNDNUT SHELL ASH AS ADMIXTURE FOR CLAY LINER IN WASTE CONTAINMENT

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Abstract

Waste management in Nigeria is characterized by poor landfilling practices in low-lying areas with improper planning of waste dumping. Whenever the soil on site is unfit for a barrier, it is blended with conventional stabilizers, but these additives are costly, hence the need to partially replace them with cheaper materials to achieve the desired results is essential. Consistency limit and engineering properties tests were conducted on the virgin and treated soil specimens. The Bentonite was added at a constant ratio of 6% whilst the groundnut shell ash was increased in the ratio of 0%, 2%, 4%, 6%, 8% and 10%. Samples were prepared at a moulding water content of (-2% ≥ OMC ≤ 4%), adopting BSL and BSH energy levels. Preliminary laboratory test on the natural soil indicated that the soil is A-4(3) and SM according to AASHTO and USCS classification systems, respectively. From the compaction test carried out, it was observed maximum dry density (MDD) increases and optimum moisture content (OMC) decreases upon stepped addition of Groundnut shell ash (GSA). Hydraulic conductivity, volumetric shrinkage strain and UCS values recorded at 6% bentonite/ 6% groundnut shell ash content gave satisfactory results that met the acceptable values of ≤ 1× 10-9 m/s, ≤ 4%, and ≥ 200 kN/m2 for BSL and BSH energy levels, respectively. The overall acceptable range for groundnut shell ash stabilized bentonite-lateritic soil was obtained at 6% bentonite/ 6% groundnut shell ash blend for samples prepared at moulding moisture content of 19.5 – 21.0% and 16.5 – 20.0% respectively. Investigation of leaching capability of groundnut ash into the environment using batch equilibrium test showed that the desorbed values of iron and pH for the optimally modified soil falls within the acceptable values endorsed by the Nigeria industrial standard (NIS) and world health organization (WHO).

Keywords: Barrier; hydraulic conductivity, volumetric shrinkage, unconfined compressive strength, acceptable zone

1.0 INTRODUCTION

Malaysia is working actively towards achieving a high-income status year over year A soil (usually clay) is used as a clay liner to migrate the movement (migration) of contaminated liquid from groundwater below the landfill. Bentonite clay mineral mixture is usually accustomed if the available soil on site does not meet the required design criteria [1]. The infiltration of contaminated liquids into the groundwater and to the neighboring soil can be reduced by compacted lateritic soil [2]. Compacted lateritic soils have been depicted to have good hydraulic barriers and covers in landfill waste facilities (clay liners); meeting the minimum regulatory value of 1×10-9 m/s for hydraulic conductivity.

Bentonite material has been shown to possess good pollutant attention and retention capacity when used as a stabilizing agent for clay liner in waste containment. For it to yield the least hydraulic conductivity value the soil should be compacted and placed from dry to wet state between (2-4%) optimum moisture content. The innate characteristic of landfill barriers makes them visible to the atmosphere. However, in relatively arid locations the clay layers are liable to damage by shrinkage or desiccation. Wet compacted clays that are left to dry may result in large. Seasonal changes affect compacted clay liners in landfill covers in as much of the depth, as a result of seasonal alteration in evapotranspiration and precipitation [3].

Desiccation (Dehydration) can result in large cracks according to field studies, and also can result in an increase in hydraulic conductivity of the barrier material, as such making it go beyond the minimum acceptable value of hydraulic conductivity used for landfill containment. It is generally accepted that for a material to be suitable for the construction of liner it must have a volumetric shrinkage strain of not more than 4%. However, to reduce shrinkage cracking in clayey barrier soils under environmental pressures, distinct stabilizing materials have been employed. These materials (agents) involve aqueous polymers, bagasse ash, fly ash, asphalt, and blast furnace slag [2].

A huge amount of waste materials generated daily from domestic, agricultural, mineral, and industrial by-products has drawn the attention of researchers globally on the safe disposal of these waste materials [4]. Consequently, safeguarding the ecosystem (environment) against waste pollutants by artificial activities and disposal systems by humans have become a matter of concern in developing countries. This was due to the negative effect on the ecosystem, specifically on soil and groundwater which eventually affects the health of the populace. The research will focus on the utilization of groundnut shell ash, an agro-industrial waste, for the improvement of lateritic soil because of the abundance of the material.

Worldwide, Nigeria provides about 7% of the groundnut used, this positions Nigeria as the 3rd world largest country in producing groundnut. However, this will result in bulk waste of groundnut shells. In Nigeria groundnut is found in both rural and urban places. After the milling process of groundnut, the waste generated is referred to as groundnut shells. About 20-24% of the groundnut harvested occupies the shell, albeit the proportion varies with a variety [5].

In Nigeria groundnut are cultivated in the northern region of the country (Kano, Niger, Sokoto, Kebbi, Katsina), these states produce groundnuts on relatively large scales. The shell is the residue obtained after the palatable seeds are removed from the shell. The ready availability of groundnut shell as the incidental product (by-product) of groundnut in the factory, has perpetually made it a desirable fuel for the milling company, henceforth tends to be the most prudent way of disposal.

Groundnut shell ash is a by-product of the residue (remaining) after the combustions process of the shell in an incinerator. Groundnut shell ash is regarded as waste material, as such stocked piled; it is a pozzolanic rich in amorphous silica, the ash from groundnut shell has been classified under pozzolana [6], with about 8.66% Calcium Oxide (CaO), 1.93% Iron Oxide (Fe_2O_3), 6.12% Magnesium Oxide (MgO), 15.92% Silicon Oxide (SiO_2), and 6.73% Aluminum Oxide (Al_2O_3). Nonetheless, with the enforcement of environmental laws and the rising cost of waste (solid waste) disposal, groundnut shell ash can be beneficially used as a stabilizing agent for certain geotechnical engineering applications [1].

The research work was aimed at mixing bentonite with groundnut shell ash by dry weight at different percentages to stabilize lateritic soil as a clay liner material.

2.0 MATERIALS AND METHODOLOGY

2.1 Material

Major materials used for this work include lateriticsoil, Groundnut Shell Ash (GSA) and Bentonite. Natural soil specimen: The aterite soil pecimen used in the study was obtained from a borrow pit along Gaya Road in wudil (Latitude 110 48 33.73" N and Longitude 80 50' 39.19" E), Kano state, Nigeria. adopting the method of disturb sampling at a specific depth between 1.0 to 1.5m. The soil specimen was then kept in plastic sacks in order to stop or prevent moisture loss before transporting. Bentonite: The bentonite material adopted in the investigation was refined in fine particles (powdered) form and was bought from a supplier at Sabon Gari Kano state, Nigeria. This bentonite represents the type of bentonite used for engineering construction. Groundnut shell ash: The groundnut shell ash adopted in the study was acquired from Dawanau area of Kano State, Nigeria. The shell was spread out on the ground and air-dried for easy burning. After well dried in the air by spreading it out on the ground before burning. Following in time, the groundnut shells were heated by burning them to ash in a close incinerator system as shown in Figure 1. The ash was allowed to cool as shown in Figure 2, after cooling the ash was put in polythene sacks before storing it under a normal room temperature. The cooled ash sample was then followed by sieving through sieve number 200.

Figure 1 Calcination of Groundnut shell to ash in the muffler furnace

Figure 2 Groundnut shell ash after sieving through sieve No. 200

2.2 Methods

The purpose of the laboratory test is to find out the effect of the addition of the groundnut shell ash to the mixture of soil-bentonite on various geotechnical properties like specific gravity, grain size distribution, Atterberg limits test, hydraulic conductivity test, volumetric shrinkage strain test, and UCS test, etc., and also check the suitability of the composite material for utilization in landfill liner or barrier for waste containment facility.

Index Properties: Laboratory tests were carried out to determine the index properties of the natural soil and the treated soil blend with bentonite and groundnut shell ash in accordance with [7] and [8], respectively. The index properties and compaction characteristic tests were conducted in accordance with [7] and [8] on the natural and soil mixtureswith the significant quantities of bentonite and groundnut shell ash, respectively as shown in Figure 3 and Figure 4.

Figure 3: Atterberg limits test

Figure 4: Grain size distribution test

Preparation of specimens: Plate 4: Grain size distribution test Preparation of specimens: The soil specimen was dried by air (air dried), before passing it through sieve number 40 (0.425mm). The treated samples containing bentonite and groundnut shell ash as admixture, were mixed with dry soil sample at a step concentration of (0, 6%) and (0, 2, 4, 6, 8, and 10%) for bentonite and groundnut shell ash, respectively. The 0% bentonite/ 0% groundnut shell ash represent the virgin soil. The required ratio of domestic water required by dry weight of 2% dry of optimum moisture content and 4% wet of optimum moisture content, was added to give the desired amount of moisture content. The required quantity of moisture was mixed thoroughly until a uniform consistent paste was obtained [9,10]. The specimens were compacted using the compactive effort adopting British standard light and British standard heavy (BSL and BSH Compactive energy effort), as shown in figure 5. The BSL compactive effort was deduced from a rammer of size 2.5kg, released from a height of about 300mm, on to 3layers in a 1000cm3 British mould were each individual layer received 27blows. Whilst, the BSH effort was deduced from 4.5kg rammer released from a height of about 450mm on to 5layers in a 1000cm3 British cylindrical mould, were each individual layer received 27blows.

Figure 5: compaction test

Hydraulic conductivity test: The rigid wall parameter under falling head condition after soaking for 24 hours in accordance with method highlighted in [7] was used in the determination of hydraulic conductivity of compacted blends. The modified specimens were compacted and soaked in water for a period of a day (24 hours), before starting the permeation process as shown in figure 6. The liquid passing was taped water and the process was stopped after a steady flow was obtained [11, 12].

Figure 6: Falling head permeameter test

Volumetric shrinkage test: the samples were compounded by compacting refined soils specimen as in above method. The VSS on desiccation was quantified by removing dense (compacted) cylindrical specimens from the compaction moulds and drying the specimen on a laboratory table [13]. Shrinkage in the samples was meticulously observed for at least 28 days by taking the circumferential height and diameter to compute volume, hence the volumetric shrinkage strains.

Unconfined compressive strength test: UCS test was carried out on samples compounded as in the above process. The Test was carried out in cylindrical specimens of diameter 38mm and length 76mm respectively, after which were extruded from a larger cylindrical mould for easy compaction. The specimens were tested in a compression test machine and a compressive force is applied to the specimen with a strain control at 0.10% mm as per [7], as shown in figure 7.

Figure 7: Unconfined compressive strength test

Batch equilibrium adsorption: The procedure used for batch adsorption test was in compliance with that expound by [14]. The natural and stabilized soil blend were stored in plastic bottles and placed in a table shaker for a period of 48hrs. Henceforth, the slurry was decanted and filtered onto new set of plastic bottles using filter papers for laboratory test. The tests were conducted to find the leaching capability of iron (Fe^{2+}) from soil – bentonite – groundnut shell ash blend into the environment. Cation concentrations were quantified using Atomic Adsorption Spectrometer (AAS). The pH test was carried on samples leachate using pH meter.

Cation exchange capacity (CEC): CEC tests were carried out on the natural and improved soil to further measure its water retention ability. The ability of a soil to retain on to cations such as calcium, magnesium, sodium, aluminium and iron (Ca, Mg, Na, K, Al and Fe) is called cation exchange capacity [15]. These cations are held by electrostatic forces: the negative soil particles in clayey or organic soil attract the positive cations. This simply means that the CEC of a soil deduced the overall number of replaceable cations that the soil can occupy. It is mostly measured as centimol positive charge per kilogram of soil (cmol/kg) or milli-equivalent per 100 grams of soil (meq/100g), both units are numerically similar.

3.0 RESULTS AND DISCUSSION

Table 1 and Figure 8 present the summary of the index properties and particle size distribution of the natural soil, respectively.

Table 1 Engineering properties of the natural soil

Property	Quantity
Natural moisture content, %	11.81
Specific gravity, %	2.62
Liquid limit, %	36.4
Plastic limit,%	26.8
Plasticity index, %	9.6
Linear shrinkage, %	13.3
Percentage of fine particle passing sieve No. 200	48.66
Free swell, %	41.77
AASHTO classification	A-4(3)
USCS classification	SM
Optimum moisture content, %	
BSL effort	22.4
BSH effort	19.0
Maximum dry density, Mg/m^3	
BSL effort	1.65
BSH effort	1.72
pH	5.46
Colour	reddish brown
Dominant Soil Mineral	Quartz

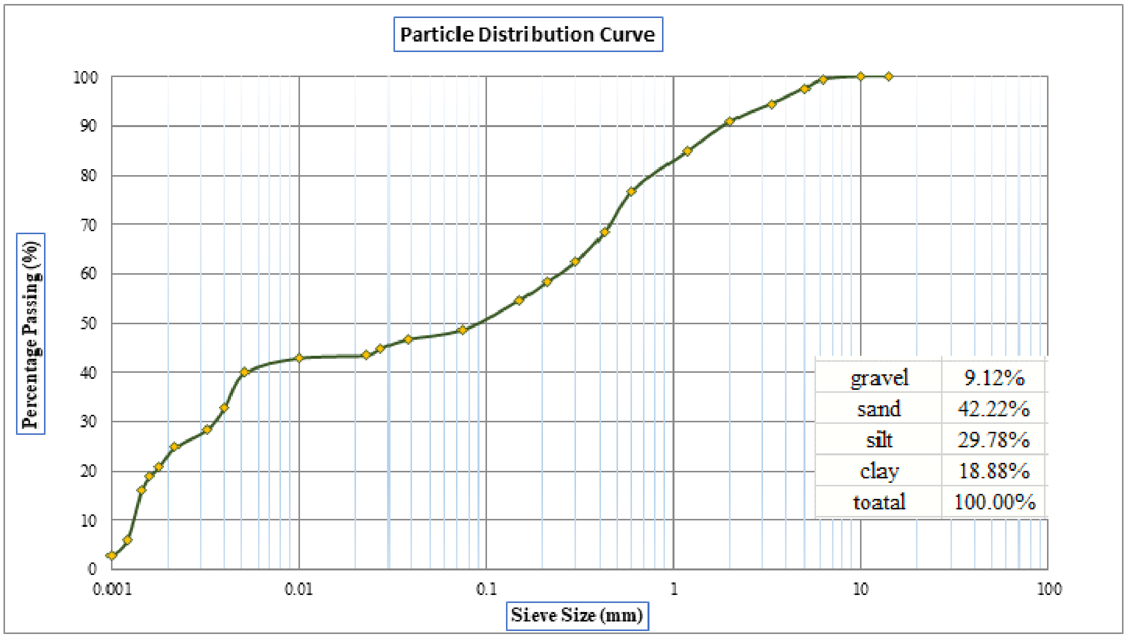

Figure 8: Particle size distribution curve of the natural soil

3.1 Mineralogical Composition

The test result of the mineralogical composition carried out using X-Ray Diffraction at Kaduna state, Nigeria in the National Steel Raw Material Exploration Agency (NSRMEA), on the natural soil shows that Quartz, Feldspars, Mica and Kaolinite are found in the soil as shown in Figure 9. The high presence of Quartz and Feldspars content in the soil mineralogy (XRD), result in the formation of coarse- particle soil material, as such makes it permeable.

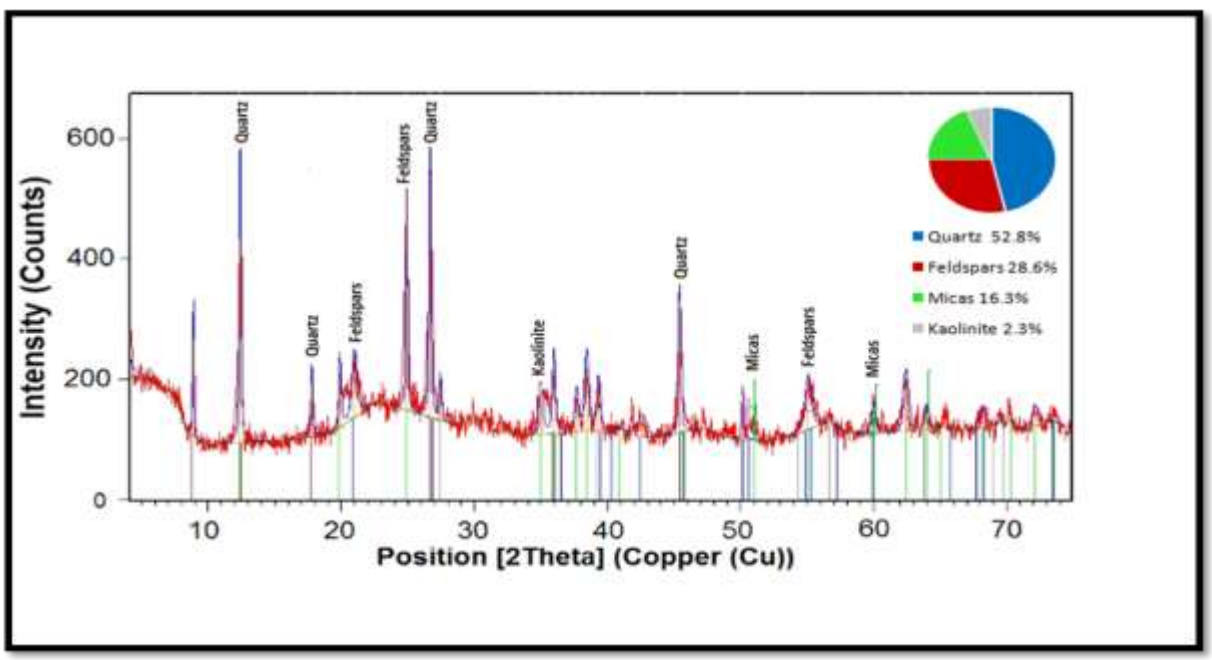

Figure 9: mineralogiacal composition of the natural soil

3.2 Chemical composition of Additives

The test result of the chemical composition (oxide composition), carried out using X-Ray fluorescence at Kaduna state of Nigeria in the National Steel Raw Material Exploration Agency (NSRMEA) as shown in table 2, shows that the both admixtures contained more than 50% of combined silica, alumina and ferric oxide (SiO_2+ $Al2O_3$ + Fe_2O_3), as such possesses a good pozzolanas and pozzolanic reactivity's as specified by [16].

Table 2: chemical proportion of admixtures (Bentonite and groundnut shell ash)

Chemical constituent	% proportion of Bentonite	% proportion of Groundnut shell ash
SiO_2	65.44	26.76
Al_2O_3	14.50	13.06
Fe_2O_3	6.54	15.24
Na_2O	4.03	3.53
K_2O	0.76	5.75
CaO	0.77	11.23
TiO_2	0.22	2.65
PbO	0.48	-
MgO	3.22	5.86
SO_3	0.37	1.21
ZrO_2	-	0.09
Rb_2O	-	0.0056
P_2O_5	-	3.89
Nd_2O_3	-	0.05
MnO	-	2.48
ZnO	-	0.05
CuO	-	0.86
V_2O_5	-	0.09
Cr_2O_3	-	0.09
Bi_2O_3	-	0.26
BaO	0.11	0.78
Cl	0.5	0.77
LOI	3.36	5.29

LOI: loss on ignition

3.3 Effect of Groundnut shell ash on Bentonite stabilized Lateritic soil

The effect of graoundnut shell ash on bentonite will be looked through the engineering test on the soil, such as compaction characteristics test, hydraulic conductivity test, volumetric shrinkage strain test, unconfined compressive strength test and leaching potential test.

3.4. Compaction Characteristics Test

3.4.1 Maximum Dry Density

The change in MDD versus groundnut shell ash content with bentonite mixture corresponding to BSL and BSH compactive effort are depicted in figure 10a nd 10b. Result values shows increased in MDD with higher bentonite and GSA contents for the two respective energy level adopted in the research (BSL and BSH compactive energy level). This result pattern corresponds with the investigations of [17, 18].

The modified MDD result values increases to an optimum values of 1.79 and 1.95 Mg/m^3 at 6% bentonite/ 6% GSA blend from 1.65 and 1.72 Mg/m^3 for the virgin soil while adopting BSL and BSH energy level, respectively.

The increase in MDD with addition of admixture was concievably due to swelling potentials of bentonite that result in the formation of gel around the soil particle. As gel forms within the soil particles, its effective size increase, which result to high void volume, as such, increases the MDD.

The subsequent decrease beyound the optimum value obtain at 6% bentonite/ 6% GSA ontent was as a result of excess addmixture that occupies the pore space of the soil, making the mixture to require more amount of water to complate the hydration process.

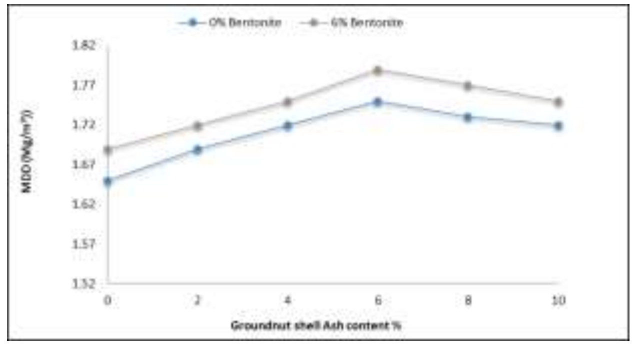

Figure 10a variation of MDD in soil-bentonite mixtures blend with groundnut shell ash blend (BSL compactive effort)

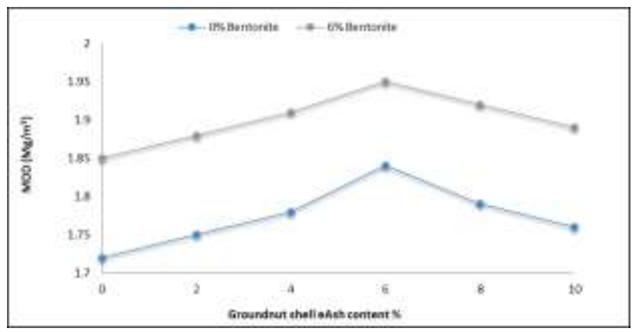

Figure 10b variation of MDD in soil-bentonite mixtures blend with groundnut shell ash content (BSH compactive effort)

3.4.2 Optimum Moisture Content

The change in OMC versus groundnut shell ash blend with bentonite mixture corresponding to BSL and BSH compactive effort are depicted in Figure 11a and 11b

The OMC results for the virgin soil decrease from 22.4 and 19.0% to 14.3 and 11.68 at 6% bentonite/ 6% GSA blend corresponding to BSL and BSH compactive effort, respectively. This result pattern corresponds with that of [17, 18]

The decrease in OMC with more addmixture was due to sufficient amount of water needed by the blend, so as to complate hydration reaction resulting from higher surface area.

Another reason for the reduction in values of OMC can be due to the absorption ability of the admixtures as a result of their porosity.

The subsequent increase beyond 6% bentonite/ 6% GSA content, could be due to increasing surface area affected by the high amount of the additives, which needed sufficient water for the lubrication of the entire matrix.

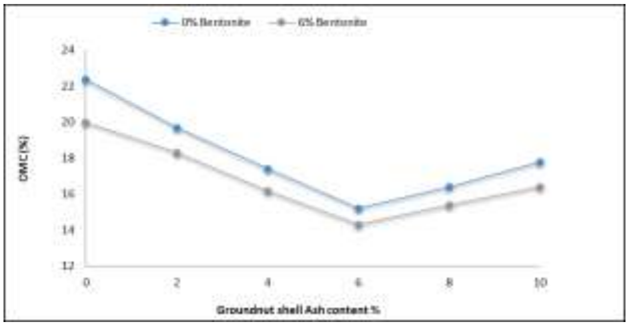

Figure 11a variation of OMC of soil-bentonite mixtures blend with groundnut shell ash blend (BSL compactive effort)

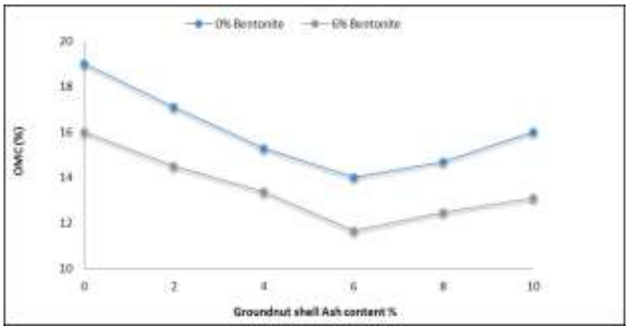

Figure 11b variation of OMC of soil-bentonite mixtures blend with groundnut shell ash content (BSH compactive effort)

3.5 Design parameter for Clay Liner Barrier

[19], stated that material for landfill liners/covers are usually investigated for a number of parameters which are considered to be relevant to their proper fuctioning under service condition. These design parameters include hydraulic conductivity, desication induced volumeteric shrinkage and unconfined compressive strength of the soil. Although only the three afore-mentioned design parameters have been considered in this study, other parameters considered in clay liner design include indirect (splitting or Brazilian) tensile strength, bearing capacity, trafficabillity, internal and interface shear strength as well as compresssibility [20]. The criteria for the selected design parameters are shown in Table 3.

Table 3: Clay Liner Design Parameters Requirement

Design parameter	Design limits
Hydraulic conductivity	$\leq 1.0 \times 10^{-9}$ m/s
Volumetric shrinkage strain	≤ 4%
Unconfined compressive strength	≥ 200 kN/m^2

.

3.6 Hydraulic Conductivity

3.6.1 Effect Of Moulding Water Content On Hydraulic Conductivity

The change in hydraulic conductivity against moulding moisture content are shown in figure 12a-12b and 13a-13b

The values obtained for BSL and BSH compactive effort at 6% bentonite/ 6% groundnut shell ash (GSA) blend, gave satisfactory needed hydraulic conductivity results of equal or less than 1.0×10^{-9} m/s. These optimum precise results were found at moulding moisture content between 15.5-21.0% and 10.0- 20.0% respectively. The optimum allowable values were obtained at 18.5 and 14.5 moulding water contents respectively.

The reason for the decrease in hydraulic conductivity with increase in moulding moisture content was as a result of the large extent of dispersion in the soil fabric with more moisture content as a result of enlargement of double layer and an increased inter-particles repulsion, which give room for the particle to go over one another more conveniently into a more arranged form of packing together [21].

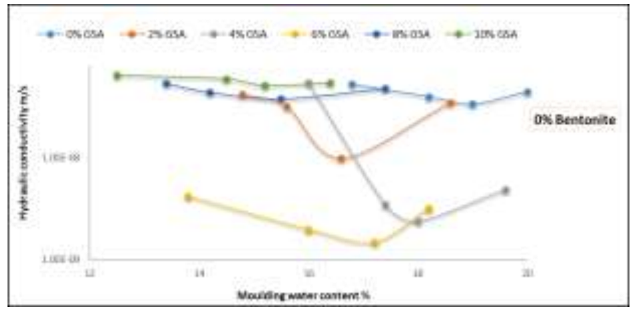

Figure 12a variation of hydraulic conductivity against moulding water content (BSL compactive effort)

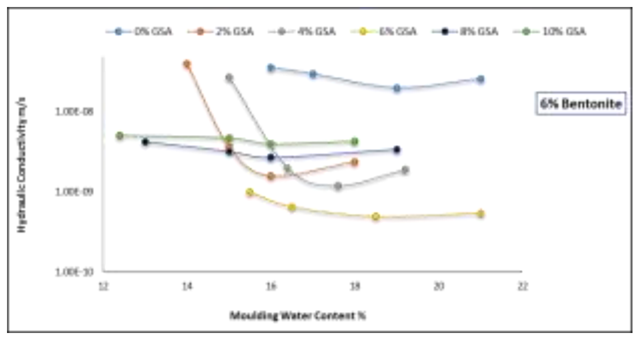

Figure 12b variation of hydraulic conductivity against moulding water content (BSL compactive effort)

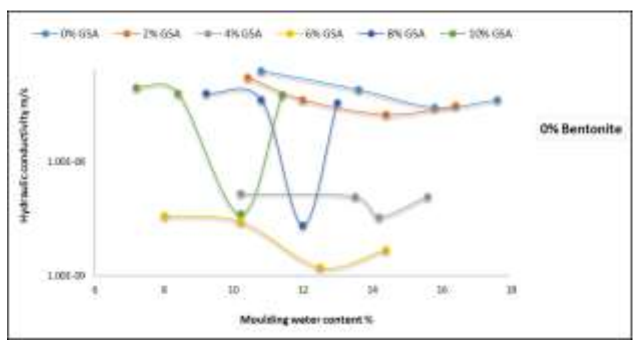

Figure 13a variation of hydraulic conductivity against moulding water content (BSH compactive effort)

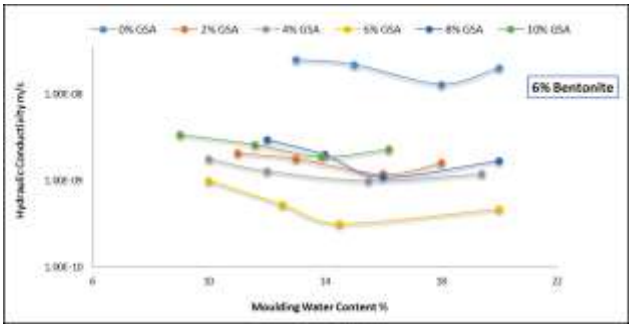

Figure 13b variation of hydraulic conductivity against moulding water content (BSH compactive effort)

3.6.2 Effect Of Groundnut Shell Ash On Hydraulic Conductivity In Soil-Bentonite Mixtures

The change in hydraulic conductivity results of the stabilize and natural soil specimen compacted between 2% dry to 4% wet of optimum moisture content for BSL and BSH compactive effort are portrayed in figure 14a-14b and 15a-15b

It was found that the hydraulic conductivity result decreases as both admixtures were increased, before the value experiences an increase with much higher admixture.

The BSL energy level compacted between 2% wet to 4% dry optimum moisture content gave a satisfactory value of 1× 10^{-9}, 7.0 × 10^{-10}, 3.5 × 10^{-10} and 5.5 × 10^{-10} m/s at 6% bentonite/ 6% Groundnut shell ash content, respectively. Likewise, the BSH energy level compacted between 2% wet to 4% dry optimum moisture content gave a minimum satisfactory value of 1× 10^{-9}, 6.3 × 10^{-10}, 2.1 × 10^{-10} and 4.4 × 10^{-10} m/s at 6% bentonite/ 6% Groundnut shell ash content, respectively.

The reduction in hydraulic conductivity with increment in admixture content was as a result of a layer extent of dissipation in the soil matrix with more moisture content. This was as a result of expression of multiple (double) layer and an increased inter-particle repelling force within the soil, which allows the particle to go over each other smoothly into a better cluster [22].

The subsequent increase in hydraulic conductivity upon increasing the additives beyond 6% was due to the higher amount of the admixture that occupies the pore space of the soil particle, consequently a higher attraction for moisture, for such specimen with more amount of admixture had much amount of water to be eliminated during drying process [23].

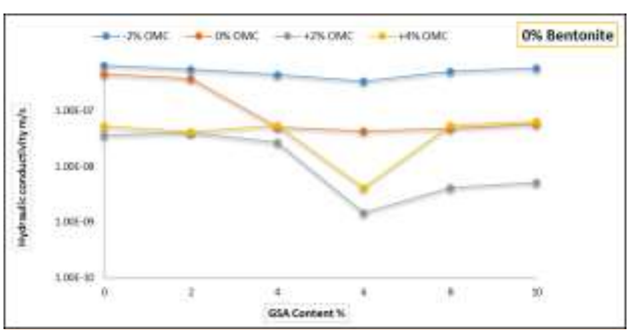

Figure 14a variation of hydraulic conductivity of soil-bentonite mixtures blend with groundnut shell ash content (BSL compactive effort)

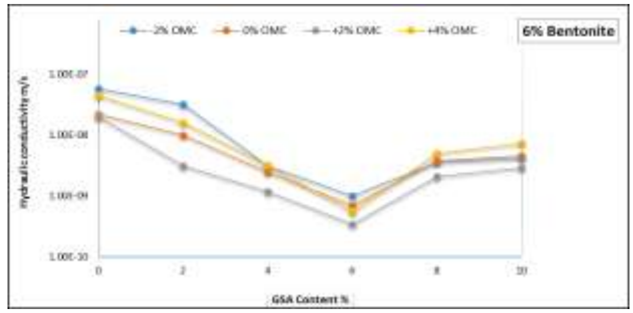

Figure 14b variation of hydraulic conductivity of soil-bentonite mixtures blend with groundnut shell ash content (BSL compactive effort)

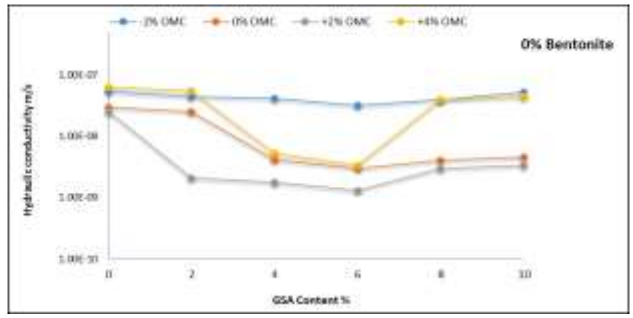

Figure 15a variation of hydraulic conductivity of soil-bentonite mixtures blend with groundnut shell ash content (BSH compactive effort)

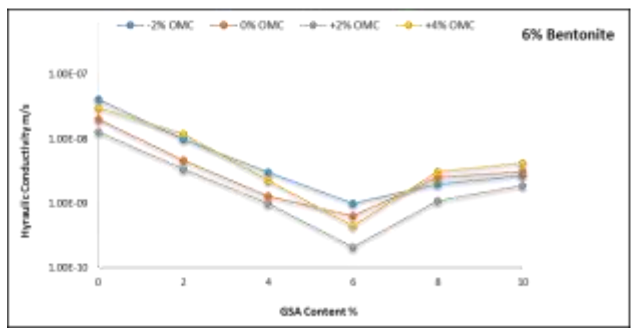

Figure 15b variation of hydraulic conductivity of soil-bentonite mixtures blend with groundnut shell ash content (BSH compactive effort)

3.7 Volumetric Shrinkage Strain (VSS)

3.7.1 Effect of Moulding Water Content On Volumetric Shrinkage Strain

The change in volumetric shrinkage against moulding water content is depicted in figure 16a-16b and 17a-17b

The samples compacted in between -2% - 4% of optimum moisture adopting BSL and BSH compactive energy produced desired volumetric shrinkage values of equal or less than 4% at 6% bentonite/ 6% GSA blend. These optimum recommended values were determined at moulding water content between 19.5-29.5 and 16.5- 24.5 corresponding to BSL and BSH compactive effort respectively. The optimum permissible result were obtained at 19.5 and 16.5% respectively.

Soil samples compacted with more moulding moisture content shrank more as it dry, due to desiccation in fine-particle soils and pore water pressure as a result of particle motion by capillary tension [24]. A soil saturated is permitted to dry, a meniscus developed by each void at surface of the soil. Formation of such a menicus causes tension in the soil-water, resulting in compression on the soil structure and consequently reducing the volume. The force in material with tiny pores space is much, due to the capillary presure indispensable dragging the particles togerther. The larger the capillary pressure ,the smaller the meniscus, and the larger the inter-granular attractive pressure between the particle [25]. Equally, VSS is directly propotional to the volume of moisture escaping the interstice of compounded soil specimens [24].

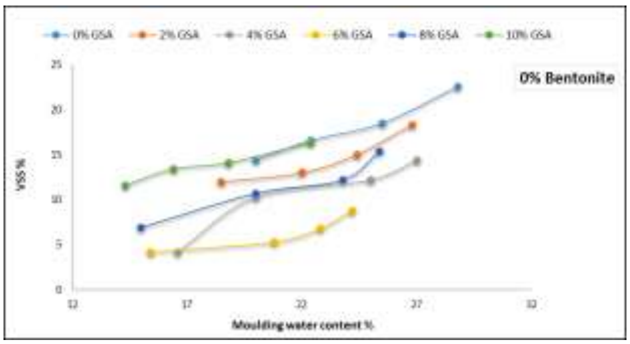

Figure16a variation of volumetric shrinkage strain against moulding water content (BSL compactive effort)

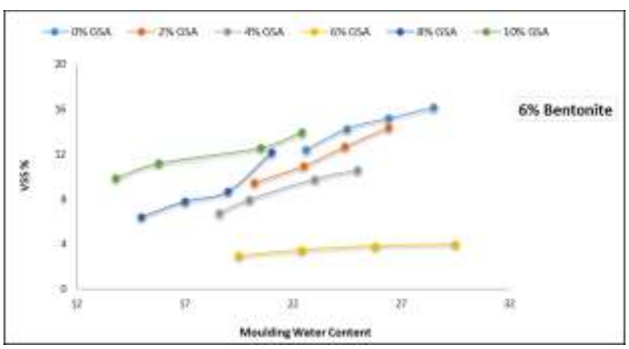

Figure 16b Variation of volumetric shrinkage strain against moulding water content (BSL compactive effort)

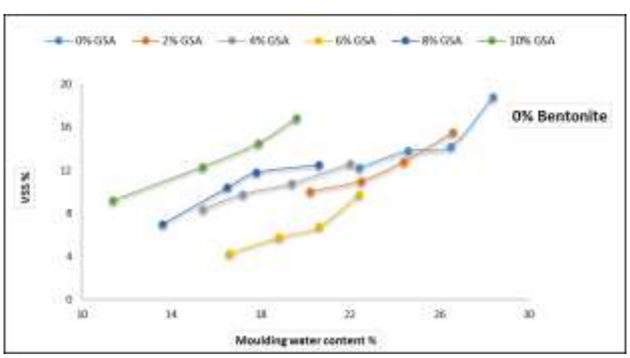

Figure 17a Variation of volumetric shrinkage strain against moulding water content (BSH compactive effort)

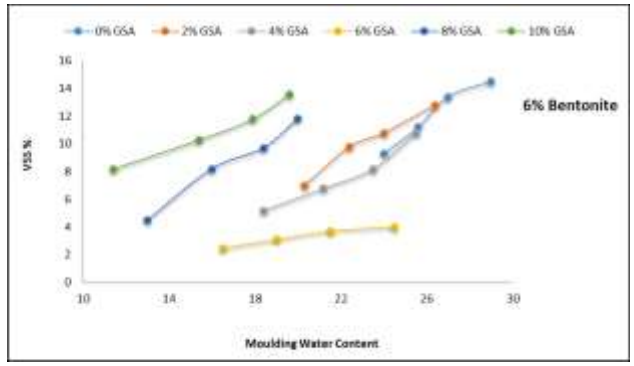

Figure 17b Variation of volumetric shrinkage strain against moulding water content (BSH compactive effort)

3.7.2 Effect of Groundnut Shell Ash On Volumetric Shrinkage Strain Of Soil-Bentonite Mixtures

The variation of hydraulic conductivity values of the stabilized and untreated soil sample compacted between 2% dry to 4% wet of optimum water content, for BSL and BSH compactive effort are shown in figure 18a-18b and 19a-19b

It was found that the volumetric shrinkage strain result decreases with higher number of admixtures, before the value experiences an increase with much higher admixture.

It was observed that a minimum specified volumetric shrinkage strain values of equal or less than 4% was obtained at 6% bentonite / 6% GSA content for both compactive effort adopted (BSL and BSH)

The BSL energy level compacted between 2% wet to 4% dry optimum moisture content gave a minimum satisfactory value of 4.0, 3.51, 3.0 and 3.86% at 6% bentonite/ 6% GSA content, respectively. Likewise, the BSH energy level compacted between 2% wet to 4% dry optimum moisture content gave a minimum satisfactory value of 4.0, 3.4, 2.5 and 3.72% at 6% bentonite/ 6% GSA content, respectively.

A general decease in the VSS was recorded with increment of admixture contents adopting BSL and BSH compactive efforts; this was as a result of pozzolanic reactions of the admixtures which decrease the fine-grained content in the soil. Coarser fractions of soils were developed as a result of development of bonds [26].

The subsequent increase in VSS upon increasing the admixtures beyond 6% was due to the higher amount of the admixture that occupies the pore space of the soil particle, consequently a higher attraction for water, for such specimen with more amount of admixture had much amount of water to be eliminated during drying process [23].

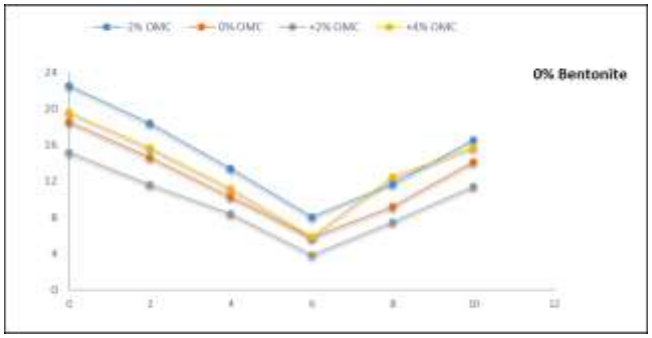

Figure 18a variation volumetric shrinkage strain of soil-bentonite mixtures blend with groundnut shell bagasse ash content (BSL compactive effort)

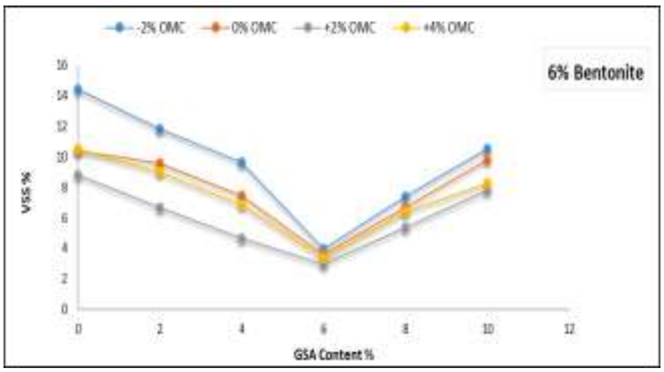

Figure 18b variation volumetric shrinkage strain of soil-bentonite mixtures blend with groundnut shell ash content (BSL compactive effort)

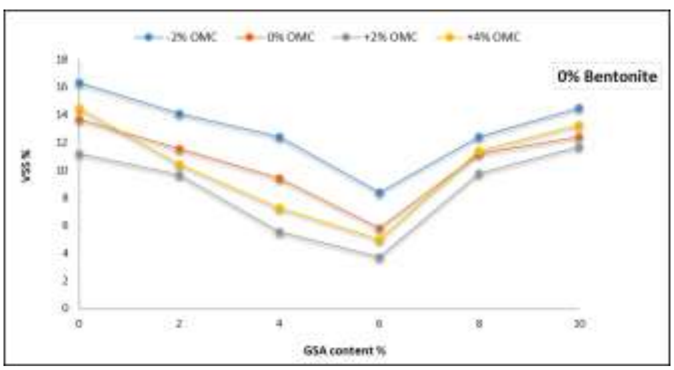

Figure 19a variation volumetric shrinkage strain of soil-bentonite mixtures blend with groundnut shell ash content (BSH compactive effort)

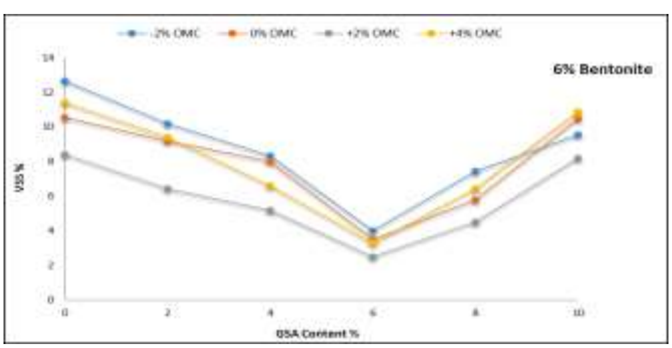

Figure 19b variation volumetric shrinkage strain of soil-bentonite mixtures blend with groundnut shell ash content (BSH compactive effort)

3.8 Unconfined Compressive Strength (UCS)

3.8.1 Effect of Moulding Water Content On Unconfined Compressive Strength

The change in UCS versus moulding water content are depicted in figure 20a-20b and 21a-21b

The values corresponding to BSL and BSH compactive efforts at 6% Bentonite /6% groundnut shell ash (GSA) content gave satisfactory UCS values of more than 200kN/m^2. These specified values were determined at moulding water content ranging 15.5- 19.5% and 16.5- 24.5% for both BSL and BSH compactive effort respectively. The optimum allowable values were determined at 24.0% and 21.4% for both BSL and BSH respectively.

The increment in UCS result with increase in moulding water content was attributed that for any pozzolana there is a peak blend measure of moisture it can obtain to give acceptable strength [27].

Another reason could be due to the pozzolanic action of the admixtures that contributed to the strength gain.

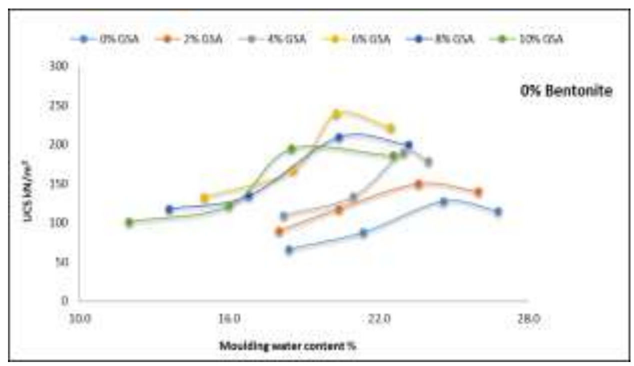

Figure 20a variation of unconfined compressive strength against moulding water content (BSL compactive effort)

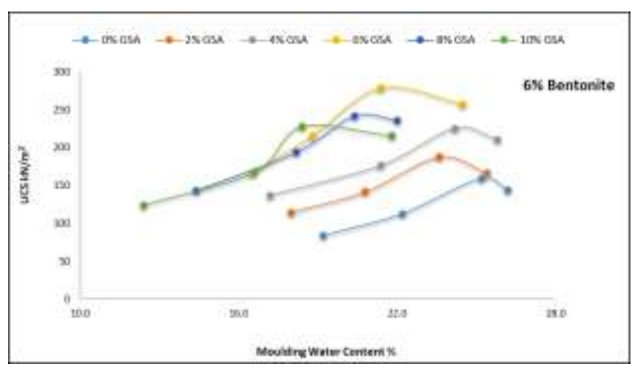

Figure 20b variation of unconfined compressive strength against moulding water content (BSL compactive effort)

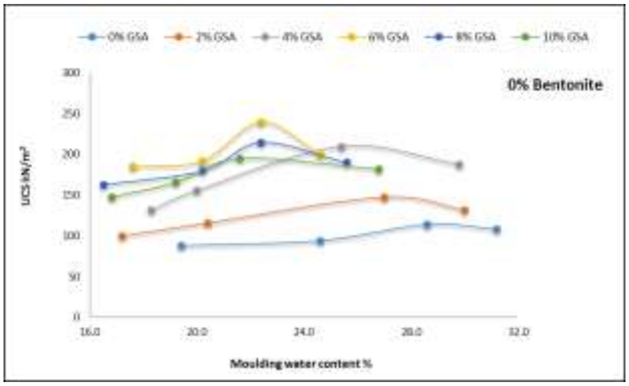

Figure 21a variation of unconfined compressive strength against moulding water content (BSH compactive effort)

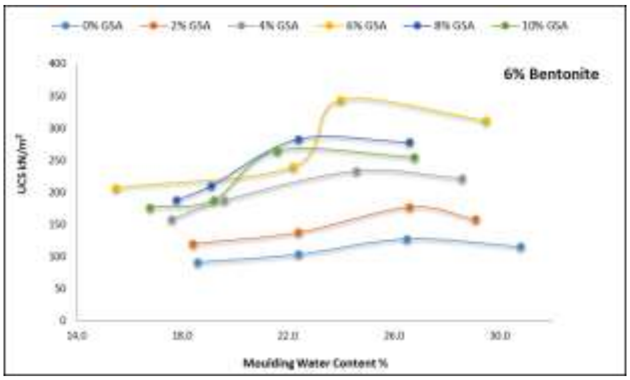

Figure 21b variation of unconfined compressive strength against moulding water content (BSH compactive effort)

3.8.2 Effect of Groundnut Shell Ash On Unconfined Compressive Strength Of Soil-Bentonite Mixtures

The change in UCS values of the stabilized and virgin soil sample compacted between 2% dry to 4% wet of optimum water content, for BSL and BSH compactive efforts are shown in figures.22a-22b and 23a-23b.

It was found that the UCS test result increases with more admixtures, before the value experiences a decrease with much higher admixture.

It was determined that a satisfactory UCS results of ≥ 200 kN/m^2 was found at 6% bentonite/ 6% groundnut shell ash (GSA) content for both compactive effort adopted

The BSL energy level compacted between 2% wet to 4% dry optimum moisture content gave a satisfactory value of 200, 245, 275 and 320 kN/m^2 at 6% bentonite/6% Groundnut shell ash content, respectively. Likewise, the BSH energy level compacted between 2% wet to 4% dry optimum moisture content gave a minimum satisfactory value of 240, 279, 315 and 355kN/m^2 at 6% bentonite/ 6% Groundnut shell ash content, respectively.

The increment in the UCS values with respect to increase in admixtures was due to the much amount of Ca^{2+} coming from the added admixtures which combine with the reactive alumina and silica or both, to form an insoluble calcium or aluminate silicate and other pozzolanic substances which are add to strength gain [3].

The subsequent decrease in UCS upon increasing the additives beyond 6% was due to the higher amount of the admixture that occupies the pore space of the soil particle, consequently a greater attraction for water, as such specimen with more amount of admixture blend had much amount of water to be eliminated during drying process [21].

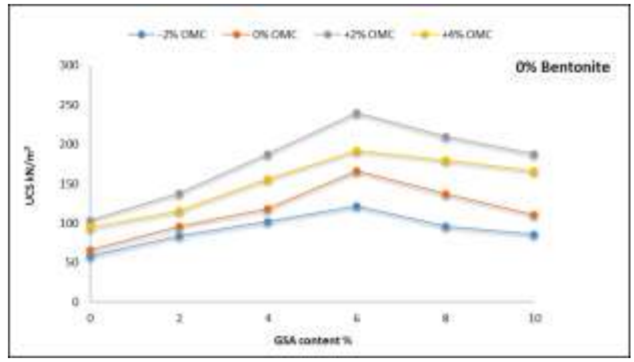

Figure 22a variation UCS of soil-bentonite mixtures blend with groundnut shell ash content (BSL compactive effort)

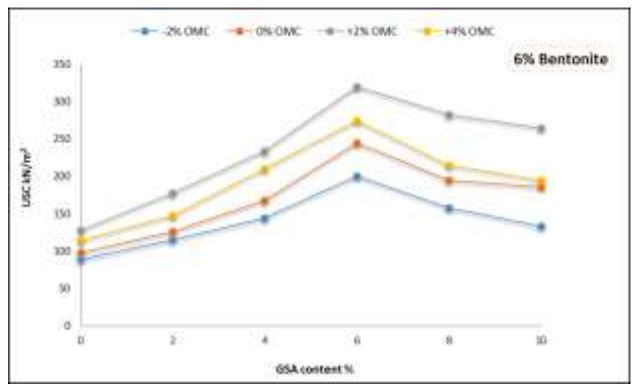

Figure 22b variation UCS of soil-bentonite mixtures blend with groundnut shell ash content (BSL compactive effort)

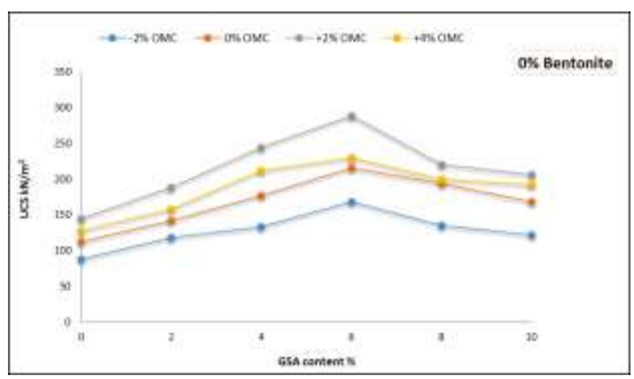

Figure 23a variation UCS of soil-bentonite mixtures blend with groundnut shell ash content (BSH compactive effort)

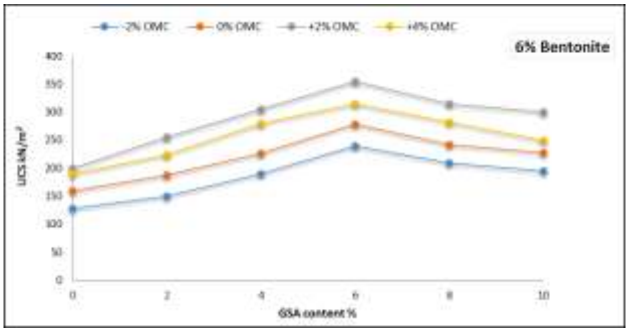

Figure 23b variation UCS of soil-bentonite mixtures blend with groundnut shell ash content (BSH compactive effort)

3.9 Acceptable Zones:

The recommendable (acceptable) zones based on volumetric shrinkage strain and strength conditions were combined on the previous specified acceptable moisture content/dry unit weight ranges which were based on hydraulic conductivity only. This methodology is in accordance with the recommendations of [24] and concurs with that adopted by [13] as shown in table 4. The values of the superimposition are depicted in Figure. 24a-24c and 25a-25c. Prior to an acceptable zone was explained for the three design features each, they are superimposition to determine the net acceptable zone as depicted in Figure. 25d and 25d adopting adopting the mean dry weight (density) values from k, UCS and VSS test samples [13, 22].

3.10 Design of Overall Acceptable Zones Based on Modern Criterion

The recommendable (acceptable) zones based on volumetric shrinkage strain and strength conditions were combined on the previous specified acceptable moisture content/dry unit weight ranges which were based on hydraulic conductivity only.

This methodology is in accordance with the recommendations of [24] and concurs with that adopted by [13]. The values of the superimposition are depicted in Figure. 15a-15c and 16a-16c.Prior to an acceptable zone was explained for the three design features each, they are superimposition to determine the net acceptable zone as depicted in Figure. 15d and 16d adopting BSL and BSH compactive effort, respectively.

Table 4: Acceptable ranges of molding water contents for BSL and BSH compactive efforts

Engineering Criteria	% Admixtures (6% Bentonite / 6% Groundnut shell ash)	
	Moulding water content	
	BSL	BSH
Hydraulic conductivity (m/s)	15.5-21.0	10.0-20.0
Unconfined compressive strength (kN/m²)	19.5-29.5	16.5-24.5
Volumetric shrinkage strain (%)	15.5-29.5	16.5-24.5
Overall acceptable range	19.5-21.0	16.5-20.0

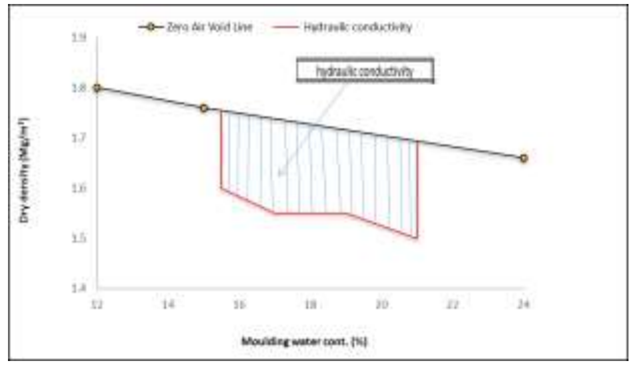

Figure 24a Acceptable zone for hydraulic conductivity at (6% bentonite/ 6% groundnut shell ash contents) (BSL compactive effort)

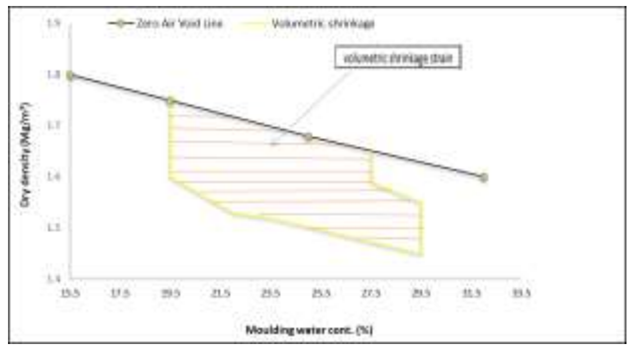

Figure 24b Acceptable zone for volumetric shrinkage strain at (6% bentonite/ 6% groundnut shell ash contents) (BSL compactive effort)

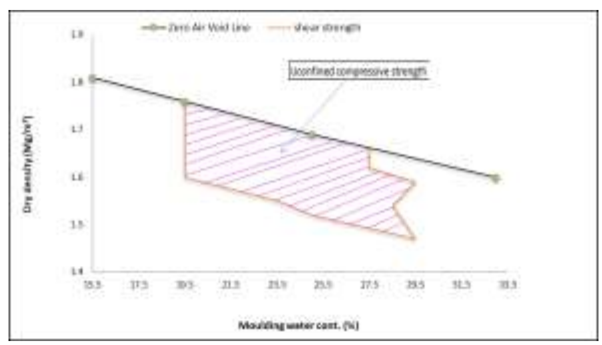

Figure 24c Acceptable zone for shear strength at (6% bentonite/ 6% groundnut shell ash contents) (BSL compactive effort)

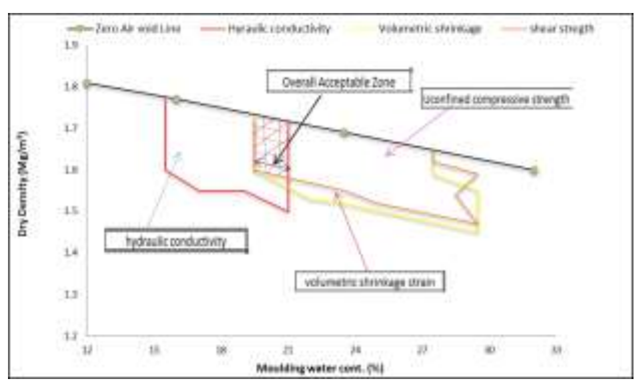

Figure 24d Overall acceptable zone at (6% bentonite/ 6% groundnut shell ash contents) (BSL compactive effort)

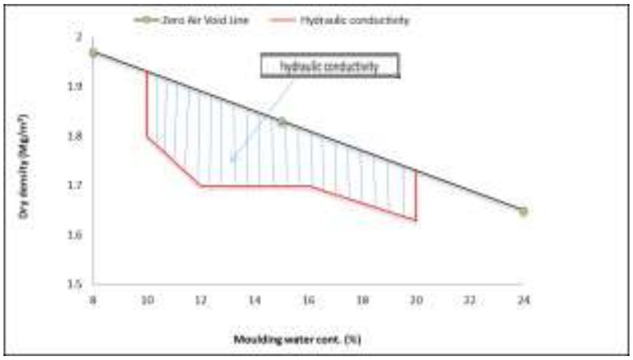

Figure 25a Acceptable zone for Hydraulic conductivity at (6% bentonite/ 6% groundnut shell ash contents) (BSH compactive effort)

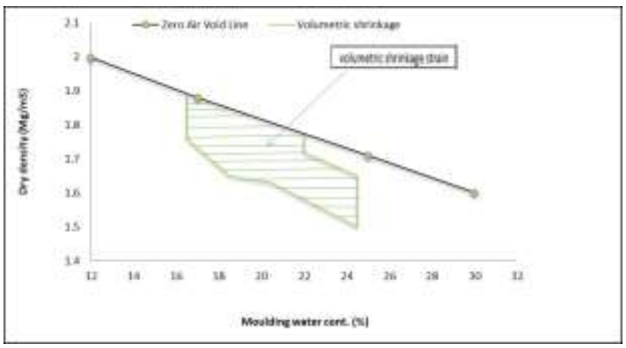

Figure 25b Acceptable zone for volumetric shrinkage strain at (6% bentonite/ 6% groundnut shell ash contents) (BSH compactive effort)

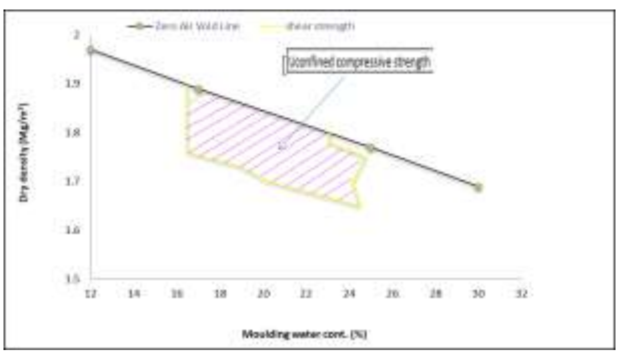

Figure 25c Acceptable zone for shear strength at (6% bentonite/ 6% groundnut shell ash contents) (BSH compactive effort)

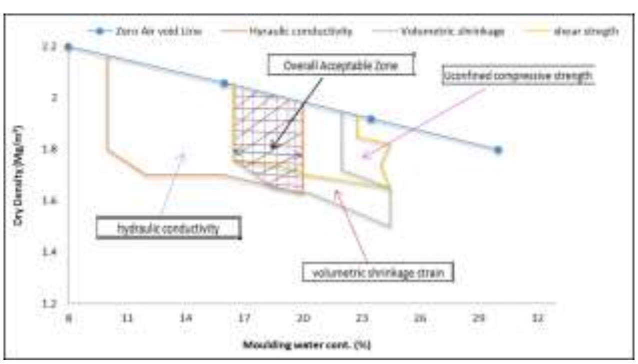

Figure 25d Overall acceptable zone at (6% bentonite/ 6% groundnut shell ash contents) (BSH compactive effort)

3.11 Leaching Potential

The soil leaching potential gives information on the likehood of a potential that is applied to the soil surface filtering through the soil and reaching groundwater. It depends on the soil permeability and porosity of the soil to ratain elements and compounds.

3.12 Effect of pH

The change in pH of soil-bentonite mixture with GSA blend is depicted in figure 26a. it was found that the pH value of the natural soil increased from 6.3 to 8.2 at 6% bentonite / 6% groundnut shell ash blend.

The increased in the pH result, upon increasing the admixtures content was as result of increase in unconstrained lime in the soil with more admixtures content that brought in higher alkalinity (for example. pH) of the treated soil [29]. A comparative study was documented by [30].

It was observed that pH value latter diminishes with a lot of higher admixtures content (i.e., beyond 6% bentonite/ 6% groundnut shell ash blend); the decrease was due to the decreased in CEC of the soil-bentonite mixtures with bagasse ash content. Similar observation was made by [31 and 32].
Soil pH is critical to the portability of waste impurity, particularly metalloids and metals. Less value of pH relates intimately with low metal content in the soil and high dissolved metals. High pH value associates with minimal dissolved metals and high metals content in the soil [33]. Notwithstanding, the pH value for the optimum blend at 6% bentonite 6% GSA falls within the acceptable range of 6.5 - 8.5 for drinking water suggested by [34 and 35].

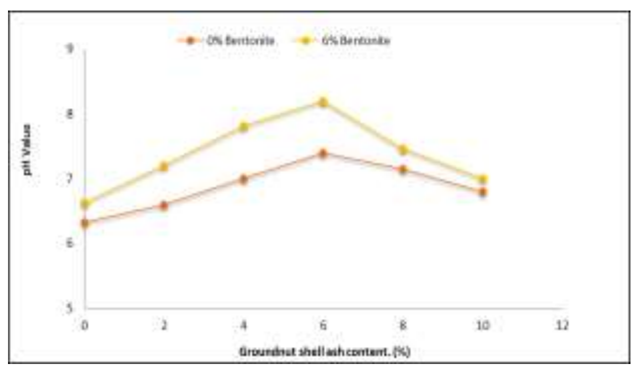

Figure 26a variation of pH of soil-bentonite mixtures with groundnut shell ash contents

3.13 Cation Exchange Capacity (CEC)

The variation of cation exchange capacity (CEC) of soil-bentonite mixtures with GSA content is depicted in figure 26b. it was observed that the CEC of the natural soil increased from 7.4 cmol/kg to 28.6 cmol/kg at 6% bentonite /6% GSA blend, before the value decreases with a lot of higher admixture contents.

The increased in CEC is as a result of the increasing electrostatic attraction between the negative charged clay particles and increasing cation concentrations as the admixtures content are increased.

While the subsequent decrease beyond 6% bentonite / 6% GSA content was due to minimal amount of clay particle present in the soil as a result ion exchange reaction (CEC) [34].

Another reason for the subsequent reduction in CEC of soil could also be due to the reduction in pH of soil by GSA that had a higher amount of calcium hydroxide ($Ca(OH)_2$) content which supplied unconstrained Ca^{2+} needed for the ion exchange reaction between the clay mineralogical particles [36]

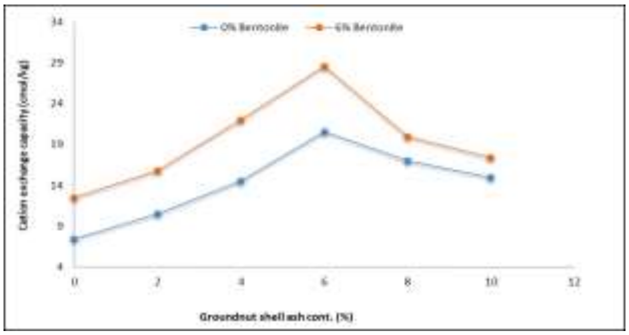

Figure 26b: variation of CEC of soil-bentonite mixtures with groundnut shell ash contents

3.14 Batch Equilibrium

The desorbed concentration of iron (Fe^{2+}) obtained from batch equilibrium adsorption test of soil- bentonite mixtures blend with bagasse ash contents using Atomic Absorption Spectrophotometry (AAS) is shown in figure 26c.

The elution pattern noticed with higher groundnut shell ash contents in the soil-bentonite blend portrayed a significant reduction in desorption values of Fe^{2+} into the environment.

The presence of Fe_2O_3 in the admixtures (from the chemical composition test), increment the pH value which improve the state that results to fixed stand of the cationic ion [37].

Whilst the subsequent increase in the desorption values of iron (Fe^{2+}) beyond 6% bentonite/ 6% groundnut shell ash contents was due to the decrease in pH values beyond (6% bentonite/ 6% groundnut ash content) as shown in figure 17a. The simple reason for the change is that a condition was developed to form an attractive electrostatic force that improve the absorption of cation species [38].

The desorbed value of 0.006mg/l concentration observed at 6% bentonite/6% GSA content lies within the allowable range of not greater than 0.3mg/l Fe^{2+} concentration for consumable water suggested by [32 and 33].

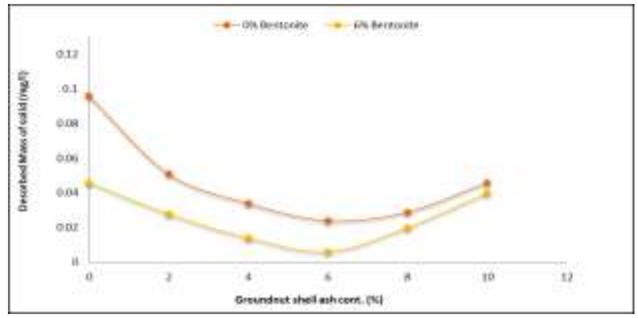

Figure 26c variation of Desorbed iron (Fe^{2+}) concentration of soil-bentonite mixture with groundnut shell ash blend

4.0 CONCLUSION AND RECOMMENDATION

1. The soil was classified according to AASHTO soil classification system as A-4(3) and USCS as Silty Sand (SM). The general properties of the natural (untreated) soil do not satisfy the requirements based on the three most important parametric design criteria for landfill facilities.
2. The maximum dry density (MDD) values generally increased with increasing content of admixture while the optimum moisture content values (OMC) decreased with increasing content of admixture. Samples were compacted between optimum moisture content of (-2, 0, 2 and 4%) adopting compactive effort of BSL and BSH energy level. An assessment to produce a converging optimum moisture content that will produce a standard recommended (acceptable) zone for the three most essential features (Hydraulic conductivity, Volumetric shrinkage strain and Unconfined compressive strength) for liner and covers were classified.
3. The hydraulic conductivity value was found to decrease with more amount of moulding water content, water content relative to optimum and also with improve compactive energy. Hydraulic conductivity values, decreased with more percentage of admixture at all moulding moisture content relative to optimum in-respective to the compactive energy adopted. As such, all the values at 6% bentonite/ 6% GSA blend, corresponding to BSL and BSH compactive energy used, fell within the allowable range of $\leq 1\times10^{-9}$m/s for consideration in clay liner formation. The volumetric shrinkage strain (VSS) was found to increase with more amount of moulding water content and moulding moisture content relative to optimum. However, the VSS value decreases with improve compactive energy. Volumetric shrinkage strain value reduces with more percentage of admixture at all moulding moisture content relative to optimum in-respective to the compactive energy used. However, all the values at 6% bentonite/ 6% GSA content lies within the allowable range of ≤4% for consideration in clay liner formation.
4. It was observed that UCS increased with more amount of moulding water content and moulding moisture relative to optimum, while the value increased with improve compactive energy. UCS values generally reduced with more percentage of admixture at all moulding moisture content relative to optimum in-respective to the compaction energy adopted. However, all the values at 6% bentonite/ 6% GSA content lies within the allowable or recommended range of $\geq 200 kN/m^2$ for consideration in clay

liner formation. Based on the result obtained, the overall acceptable zone of the three most crucial properties for the design of clay liner/cover were obtained between the ranges of moulding water content of 19.5-21.0 and 16.5-20.0 at 6% bentonite / 6% GSA content, corresponding to BSL and BSH compactive energy, respectively. As such reducing the quantity (cost) of bentonite needed for stabilization and the environmental menace cause by the waste.

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