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Geotechnical Assessment of some Clay Deposits in Southwestern Nigeria for use as Sanitary Landfill Liner

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Abstract

Urbanization cum Industrialization enhance generation of solid wastes that pose different threats to the environment and human health. The potential threat posed by these wastes determine the type of Landfill liner required to safe our aquifers .This study investigates the geotechnical properties of three soils from southwestern Nigeria for their use as liners in landfill. Three samples of clay were collected and subjected to grain size analysis, moisture content, specific gravity, bulk density, atterberg limits, permeability, compaction, shear strength, consolidation, unconfined compressive strength and California bearing ratio tests. The grain size analysis and the atterberg limit, the soil is classified as a clayey material. The percentage of fines ranges from 23-34%. The bulk density ranges from 1.34-1.47g/cm3. The moisture content values are within the range of 0.8-4.2%. The specific gravity ranges from 2.56-2.66. The liquid limit ranged from 27.5%-34.5%, the plastic limit ranged from 15.3%-18.0% and its plasticity index ranged from 11.0%-19.2% which implies that the clay can withstand volumetric shrinkage on drying and exhibit a low to medium swelling potential when wet. Hydraulic conductivity values ranges from 1.46 x 10-7-1.18 x 10-4cm/sec. The compaction test reveals an optimum moisture content (OMC) ranging from 14.0-17.0% and a maximum dry density (MDD) that varied from 1.73-1.8g/cm3. The shear strength values of the samples are within 10-30KN/m2. Coefficient of consolidation and volume of compressibility ranges from 1.0-1.9 x 10-7m2/min and 1.5-2.6 x 10-3m2/KN respectively. Unconfined compressive strength for both cured and uncured samples ranges from 373-420KPa and 100-120KPa respectively. The California Bearing Ratio values for unsoaked test ranges from 53-60% while for soaked test the values ranges from 16-24%. This research work showed that the studied clay were in favour of being used as landfill liner material.

Keywords: *Clay Deposit, Landfill liners, Containment, Geotechnical characteristics, Southwestern Nigeria*

Introduction

Liner simply means a removable cover or lining. A liner in a landfill serves as a defending wall against every form of contaminants that tends to affect to public health from the pollution of water. Engineered containment systems are modern landfills which are planned to reduced solid waste impact on the environment and human health at large. In modern landfills, a liner system harbours the waste. Clay is normally used as the bottom liner in sanitary landfill. Clay acts as the protection layer of landfill [1]. Clay liner will protect the leachate from the solid waste to migrate to groundwater. Clay have low hydraulic conductivity and able to attenuate contaminants in leachate. However, the potential of the clay liner is based on the clay type and its characteristic, different type of clay will have different characteristic. Liners designed for the leachate management in sanitary landfill in form of containment need to be evaluated assessed geotechnically so as to know its suitability and thereby restraining the contaminants migration into the environment[2].

They are constructed to prevent release of uncontrollable leachate [3]. The main problems are to achieve the required specification for landfill liner, especially for hydraulic conductivity and sorption of heavy metal. It is very dangerous if the leachate transfers to the groundwater. The aim of the liner system is to protect the groundwater and soil from pollution originating from the landfill, this is achieved by isolating landfill contents from the environment [4]. The control of leachate is of great importance in the mitigation of surface water and groundwater pollution and public health protection [5]. Indiscriminate disposal of wastes caused by human activities pose threats to community health and the environment. The type of liner system required for each

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type of landfill is dogged by potential threat posed by the waste. Liners are of different types single or simple, composite or double liners [4].Hydraulic conductivity of the clay follow by the sorption of heavy metal is the main consideration of landfill. Compacted natural clays are characterized by high contaminant attenuation and cost effectiveness and low hydraulic conductivity and this made them suitable for liners in the engineering landfills . In the absence of clayey soils ,natural clay , high-swelling clay can be mixed with local soils [6]. Various types of clays are natural materials with a very low hydraulic conductivity commonly applied in construc¬tion of sealing liners of landfills [7]. Permeability shrinkage potential and the plasticity, are the properties of clay that determines it application as landfill liner [8]. It is generally taken that the overriding requirement for a material for the use as a landfill lining is its capability of achieving a permeability of 1x10-9m/s or less following compaction. It must have acceptable mass characteristics of strength and structure to facilitate handling, trafficking and recompaction to from a low permeability barrier [9]. The degree of permeability is sometimes defined as "practically impervious" and often taken as distinguishing clays from higher permeability silts [10].

Engineering problems such as water flow through engineering structures and clay foundation consolidation under applied load is being governed by permeability [11][12]. Liners from landfill are anticipated to be a low permeability barrier below engineered landfill sites [13]. Control of leachate and safe containment of waste is very significant public health protection and alleviation of underground water and land pollution. Remoulded wet clay was used as seal in canal construction, where it was puddled against the sides and bottom of the canals to produce an almost watertight seal [9]. In a modern landfill, two leachate collection layers are of two types ; the primary and secondary [14]. Different types of liners used in leachate collection and control are geogrids, geocomposites, geotextiles, geonets, geomembranes and geosynthetic clay liners. The most sophisticated synthetic materials broadly used in impermeable liner material in modern landfills construction is Clay liner [15]. The research investigates the suitability of some clay soils in some parts of southwestern Nigeria for landfill liners.

Location and accessibility

Osun State is located in South-Western Nigeria within latitudes 6°50^{11} N and 8°10 ^{11}N and longitudes 4°00^{11} E and 5°l0^{11} E (Figure 1). The location of where the samples were taken are; Ipetumodu located on longitude 7^0 3.423N and latitude 4^0 26.694N, Ikire on longitude 7^0 21.644N and latitude $4^0$12.186N and Edun-Abon on longitude 7^0 32.736N and latitude $4^0$27.326N.

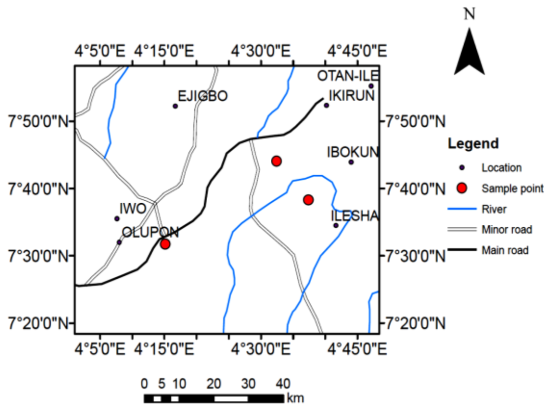

Figure 1: Location map of the study area

The topography is undulating with inselberg landscape . The established climate is specifically characterized with two seasons- dry and rain season. The major rock in the study area are Undifferenciated schist, schist, amphibolites complex; Chanockitic; Granodiorite [16],[17],[18]. Minor rock types are found within the Gneisses which are widespread throughout the crystalline basement complex of southwestern Nigeria. The Quartz veins and lenses occur in all the major rock types of the basement complex and they are small varying in thickness from a few millimetres to a metre (Figure 2). Dykes are also associated with the Gneisses bodies cross cutting the host rocks and are regarded by [19] as the youngest member of the basement complex. They range in thickness from about a few millimetres to half a metre.

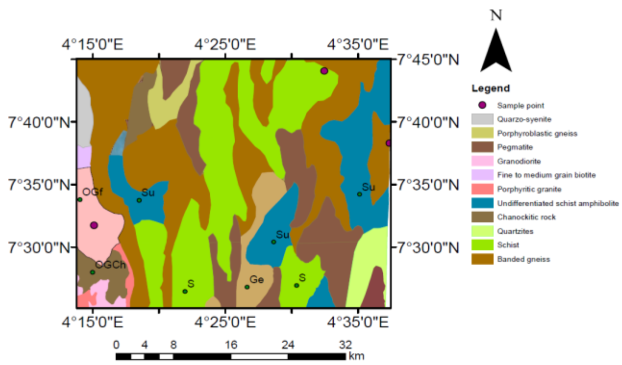

Figure 2: Map Showing the Local Geology of Study area

Methodology

Soil samples (disturbed and undisturbed) were taken at 3 different locations (Ikire, Ipetumodu and Edun-Abon) in Osun state. Sample collection was done using standard methods. The core cutter was used to take undisturbed sample and sealed at both ends with polythene bag to prevent moisture exchange while the digger and shovel was used to take disturbed sample. The sampling area was first cleaned and the surface materials were scraped off. The received soil samples were air dried. Geotechnical tests such as specific gravity by density bottle method, triaxial test in standard triaxial test cells 76mm high and 38mm, Grain size analysis (GSA), linear shrinkage, Atterberg limits, compaction test, and California Bearing Ratio (CBR) were subjected to laboratory tests according to procedures and methods of **[20].** GSA entailed samples washing through sieve number 200 (0.075mm) through which mechanical sieve shaker was used to separate the sand into the various particle sizes thereby classifying soils (clay and silt fraction).The moisture content and dry density relationships of the soils were determined by the standard Proctor test. Permeability were determined by the constant head test method. Shear strength were used to determine the consolidated-drained shear strength of a sandy to silty soil. Linear shrinkage tests were carried out to determine the water content level by which no further decrease in soil volume is experienced. Soil Compressibity were carried out to determine the rate and magnitude of volume decrease that a laterally confined soil specimen undergoes when subjected to different vertical pressures.

Results and Discussion

Grain Size

The results of the grain size for the three samples collected were reflected in Figure 3 and Table 1 . It was shown that contain gravel, sand, silt and clay fraction were contained in the studied samples. For sample AY1 6% gravel, 22% sand, 7% silt and 25% clay. For sample AY2, gravel fraction is 10%, sand fraction is 56%, silt fraction is 9% and clay fraction is 25%.

For sample AY3 gravel fraction is 15%, sand fraction is 62%, silt fraction is 3% and clay fraction is 20%. The presence of higher sand and clay fraction helps to classify the three soil samples as sandy-clay. Clay content for the studied soils are AY1=25, AY2=25 and AY3=20. However, these results are more than 10% as suggested for materials suitable for landfill liners [5],[21]. Percentage gravel in the studied soils are AY1=22%, AY2=10%, and AY3=15%,this agrees with <-30%, recommended by [2]and [7] .Results of percentage fine in the studied soils are AY1=32%, AY2=34% and AY3=23%.This compare favourably with values greater than or equal to 30% and 15% suggested by [2] and [22] respectively. The lower the fines proportion in a soil, the better the quality as a landfill liners. Fine grained soils in the silt and clay class may go through volume changes on getting in touch with with water which results in declining of the soil fabric and decline in overall strength. The result of the studied soil samples showed that they are suitable for a landfill liner .

Specific Gravity

In the soils studied, the specific gravity value obtained as shown in Table 2. AY1= 2.63, AY2= 2.66 and AY3= 2.56. Specific gravity of $\geq$ 2.7 is typical for clayey soils as expected by [23]. [22] also recommended specific gravity of $\geq$ 2.2 for soils to be suitable as landfill liners. According to [24] in Table 3 , Sample AY1 is an organic clay, Sample AY2 is an organic clay and Sample AY3 is also an organic clay. In accordance to previous works it can be said that the soil samples investigated are suitable for landfill liners.

Table 1: Grain size distribution characteristics of the samples

	SIZE FRACTION (%)								
	Coarse		Fines						
Sample no	Gravel	Sand	Silt	Clay	D_{10}	D_{30}	D_{60}	C_u	C_c
AY1	6	22	7	25	0.0007	0.03	0.19	271.4	6.767
AY2	10	56	9	25	0.0008	0.01	0.290	362.5	0.431
AY3	15	62	3	20	0.0009	0.05	0.212	235.56	13.10

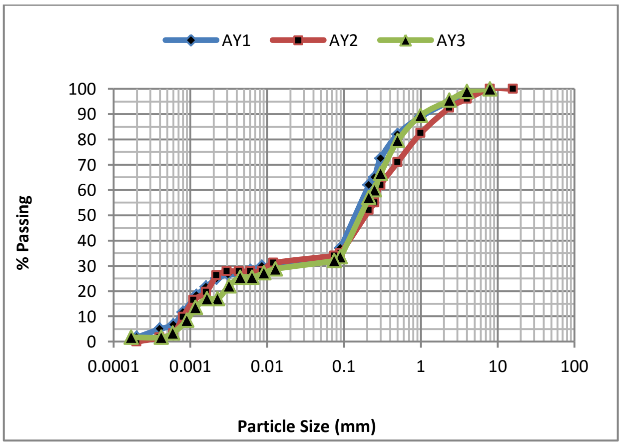

Figure 3: Grain size analysis Curve

Table 2: Specific Gravity Values

Sample no	Specific gravity
AY1	2.63
AY2	2.66
AY3	2.56

Table 3: Classification of Specific Gravity [24]

Soil	Classification
Sand	2.65-2.68
Gravel	2.65-2.68
Clay (organic)	2.52-2.66
Clay (inorganic)	2.68-2.72
Silty	2.65-2.68
Sand-Silty materials	2.50-2.60-2.64

Atterberg Limit

The summary results from Atterberg limit are shown in the Table 4. Liquid limit (W_L)of Sample AY1 is 27.5%, Sample AY2 is 34.5% and Sample AY3 is 32.0%. Researches have shown that the soils meant for landfill liners should have minimum liquid limit of 20 [6],[3]also [21] recommended liquid limit of less than 90% for landfill liner . Liquid limit results were greater than 20% but less than 90% indicating that the studied soil samples are recommended as landfill liner. Plasticity index (I_p) of Sample AY1 is 11.0%, Sample AY2 is 19.2% and Sample AY3 is 14.0%.[21] recommended plasticity index not less than 65% while plasticity index of 7% minimum was proposed by [7] and [2] for soils meant for landfill liners . The more the plasticity index of a soil, the more the engineering problems related with the use of the soil as a foundation support [1]. Soils exhibiting very high plasticity index showed excessive shrinkage. Linear shrinkage of Sample AY1 is 8.9%, Sample AY2 is 10.6% and Sample AY3 is 8.5%. .This showed that the studied soil sample can hold up shrinkage on drying and show evidence of a low medium swelling potential when wet. The results of these study correlates with the standards..In Cassagrande Chart (Figure 4),all samples lie above the A-line within CL zone representing inorganic soil with medium plasticity (Figure 4) ,this agrees with [5] . In Clay activity classification, studied samples range between 0.44-0.77, AY1 and AY3 be classified as inactive clay while AY2 is normal clay Table 5. These values conform with [3].

Table 4: Atterberg Limit of Studied Soils

Sample no	Liquid limit W_L(%)	Plastic limit W_p (%)	Plasticity index I_p (%)	Plots on the plasticity diagram	Activity index (A_c)
AY1	27.5	16.5	11.0	Above A-line	0.44
AY2	34.5	15.3	19.2	Above A-line	0.77
AY3	32	18	14	Above A-line	0.7

Table 5: Colloidal activity of typical clays

Clay mineral present in soil	Value of activity observed for the samples examined	Skempton's activity group (Skempton, 1953)
Hydrated halloysite	0.4 (1); 0.5 (1)	Inactive (< 0.75) (e.g Kaolinite)
Metahalloysite	0.5 (5); 0.6 (2)	
Kaolinite	0.6 (1)	
Metahalloysite (dark brown)	0.7 (1)	
Illite	0.7 (2)	Normally active (0.75-1.25)
Montmorillonite	0.7 (1); 0.8 (3)	Active (>1.25) (e.g Montmorillonite)

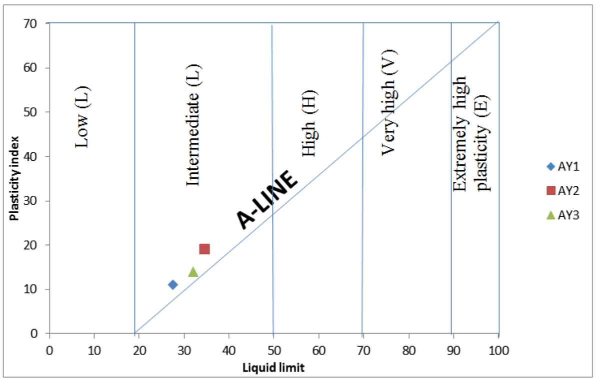

Figure 4: Cassagrande Chart Showing plots of Studied Samples

Permeability

Permeability features of a soil samples is a crucial factor in the construction of landfill liner. The coefficients of permeability of clay soils for Sample AY1, AY2 and AY3 is 1.70 x 10^{-5}cm/s, 1.5 x 10^{-5}cm/s and 1.71 x 10^{-5}cm/s as shown in Table 6. According to [26], the value of permeability from 10^{-5} to less than 10^{-7}cm/s showed extremely low to essentially impervious soil which is a landfill liner requirement . Permeability of soil equal or less than 1 x 10^{-7}cm/s meet the criteria for landfill liners [2].Considering these results with range of standards, the permeability values of studied soils are regarded as clay rich liners which are suitable for dwindling of contaminants in engineered landfills. According to Table 7, sample AY1 can be classified as a clay soil, AY2 as a clay soil and AY3 also has a studied soil, the three soil samples fall within the ranges cited from previous works therefore sample AY1, AY2 and AY3 are suitable for landfill liners.

Table 6: Hydraulic Conductivity of the Soils

Sample no	Effective size (D_{10}) (cm)	Effective size (D_{30}) (cm)	Effective size (D_{60}) (cm)	K(cm/sec)	Soil type
AY1	0.0007	0.03	0.19	1.7 x 10^{-5}	Clay
AY2	0.0008	0.01	0.290	1.5 x 10^{-5}	Clay
AY3	0.0009	0.05	0.212	1.7 x 10^{-5}	Clay

Table 7: Permeability standard in relation to soil type

Soil type	K (cm/sec)	(Ft/min)
Clean gravel	1.0-100	2.0-200
Coarse sand	1.0-0.01	2.0-0.02
Fine sand	0.01-0.001	0.01-0.002
Silty	0.001-0.00001	0.002-0.00002
Clay	Less than 0.000001	Less than 0.000002

Compaction

The values of Maximum Dry Density (MDD) for sample AY1, AY2 and AY3 is 1.8g/cm3, 1.73 g/cm3 and 1.77 g/cm3 respectively as shown in Table 8. The corresponding Optimum Moisture Content (OMC) of sample AY1, AY2 and AY3 is 14.0%, 17.0 % and 14.8% respectively. The geotechnical properties of the soil is enhanced generally by elevated level of compaction of soil, thereby achieving the preferred degree of relative compaction required to meet particular properties of soil (Figure 5) [27]. MDD greater than 1.45g/cm3 for basement rocks derived soils according to [6], can be used for landfill liners , therefore all the three soil samples with MDD greater than 1.71g/cm3 met compaction test prerequisite making them suitable for liners in landfills .

Table 8: Density-Moisture Content Values

SAMPLE	OPTIMUM MOISTURE CONTENT (OMC)	MAXIMUM DRY DENSITY (MDD)
AY1	14.0%	1.8g/cm^3
AY2	17.0%	1.73g/cm^3
AY3	14.8%	1.77g/cm^3

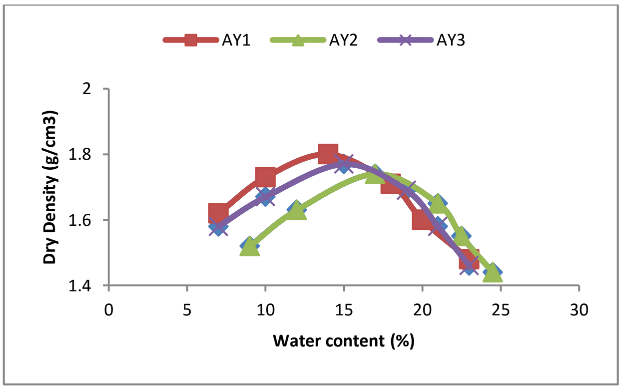

Figure 5: Density-Moisture Content Relationships

Unconfined compressive strength

The results of Uncured and Cured UCS test are shown in Table 9 .Uncured sample AY1 has 100KPa, AY2 has 130 KPa and AY3 has 120 KPa. For the cured sample AY1 has 470 KPa, sample AY2 has 373 KPa and sample AY3 has 400 KPa (Figure 6-8). A minimum value of 200kPa was reported reported by [**7**] for soil used for liner system. Therefore it can be depicted that the cured samples are suitable for landfill liners.

Table 9: Uncured and Cured of Unconfined Compressive strength

	Unconfined Compressive Strength	
Sample no	Uncured (KPa)	Cured (KPa)
AY1	100	420
AY2	130	373
AY3	120	400

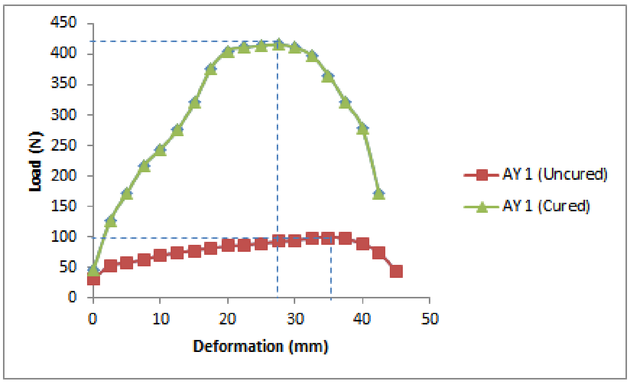

Figure 6: Graph of UCS for sample AY1

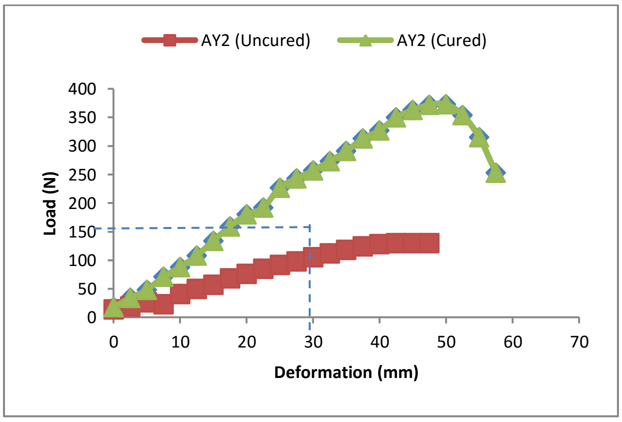

Figure 7: Graph of UCS for sample AY2

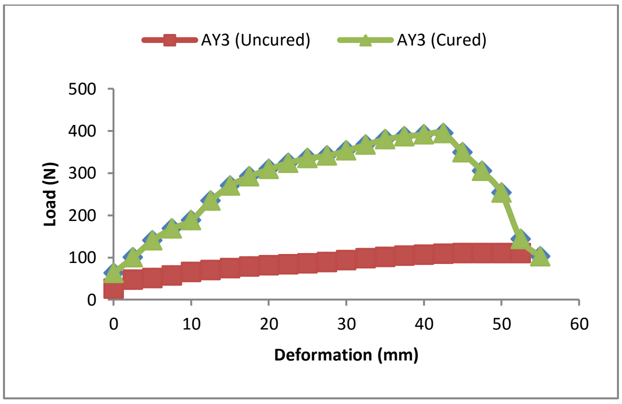

Figure 8: Graph of UCS for sample AY3

California bearing ratio

The unsoaked value for samples AY1, AY2 and AY3 is 60%, 53% and 57% respectively while the soaked values are 24%, 16% and 23% respectively Table 10. The strengths of the soaked CBR are reduced considerably. However, sufficient drainage must be provided to avoid seepage of water. All the soil showed relatively increased CBR value at the modified proctor energy (Figure 9-11). The soils also showed increased CBR value after stipulated a minimum CBR of 8% for sub-grade/fill, this means soaking will cause increase in the strength of the soils because the soaked CBR falls above the minimum requirements. Based on this, the soils studied can be classified as having very poor to poor CBR and can only be used as sub-grade and fill materials. Under unsoaked conditions, the soils will retain the field compactive strength, the CBR should be more than 30% after 24 hours of soaking at OMC indicating that the soils are suitable for the foundation liners.

Table 10: Unsoaked and Soaked CBR values

	Unsoaked CBR			Soaked CBR		
Sample no	Bearing value at 2.5mm (%)	Bearing value at 2.5mm (%)	Accepted CBR (%)	Bearing value at 2.5mm (%)	Bearing value at 2.5mm (%)	Accepted CBR (%)
AY1	60	50	60	24	21	24
AY2	53	43	53	13	16	16
AY3	57	46	57	23	19	23

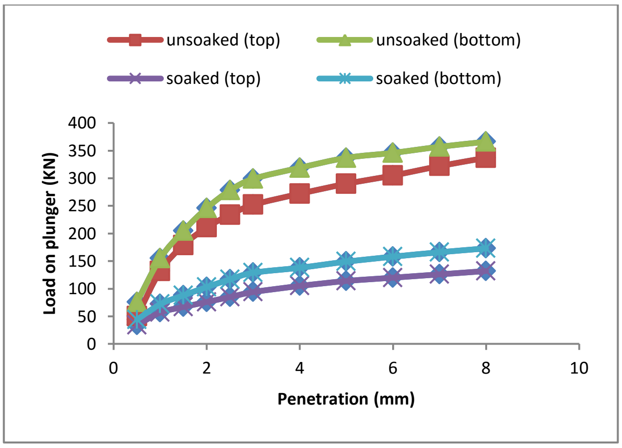

Figure 9: Graph of Load against Penetration for sample AY1

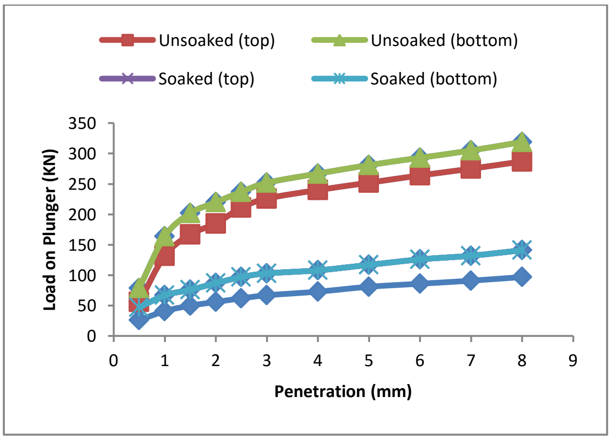

Figure 10: Graph of Load against Penetration for sample AY2

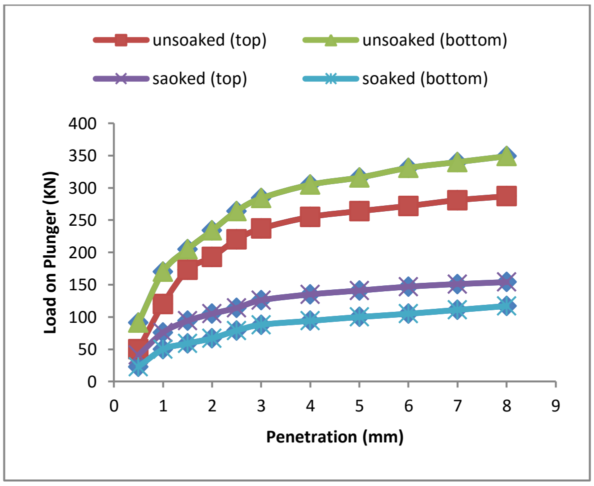

Figure 11: Graph of Load against Penetration for sample AY3

Conclusion

The geotechnical assessment of some clays materials have been characterized so as to determine their suitability for landfill liner. Percentage fines of soils of not less than 23% is considerably better for landfill liners. The specific gravity of the samples meets the specified requirement. The coefficient of permeability is very low and essentially impervious soil falling within the class of landfill liner requirement for attenuation. The atterberg limit revealed medium expansive inorganic clay .The maximum dry density not less than 1.73g/cm^{3}is recommended for a landfill liners. They are good materials for landfill liners and give in moderate dry density when compacted at the optimum moisture content of the standard proctor method. The soaked CBR values is considerately reducing ,however, sufficient drainage must be provided to avoid seepage of water during construction.The studied samples are suitable for liners in landfill with respect to recommendations from previous researches .Therefore , all samples are recommended as liner in landfill for waste containment.

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