GEOTECHNICAL CHARACTERIZATION OF ABANDONED DUMPSITE SOIL

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ABSTRACT

Geotechnical laboratory investigations were carried out on Abandoned Dumpsite Soils from Orita-Aperin, Ibadan Southwestern Nigeria to determine the basic unconfined compressive strength of the soil samples which is an important factor to be considered when considering materials as liners in waste containment structure. Clay mineralogy, major element geochemical analyses were carried out by means of X-ray diffractometry and X-ray fluorescence spectrometry, respectively. The engineering tests such as sieve size analyses, atterberg limits, natural moisture contents, specific gravity and compaction using four different compactive efforts namely Reduced Proctor (RP), Standard Proctor (SP), West African Standard (WAS) and Modified Proctor (MP). The tests were carried out in line with the procedures of the British Standard 1377 of 1990 and Head of 1992. The soils were found to contain kaolinite as the major mineral with some mixtures of smectite, quartzite, biotite, annite and alluminium silicate. Values of the unconfined compressive strength obtained within 13.9 and 18.1% moulding water contents equal to or greater than 200kN/m^2 which is the minimum acceptable value required for containment facilities. Hence, unconfined compressive strength values were found to be greater than 200kN/m^2 at dry unit weight of 16.10kN/m^3 especially when WAS and modified Proctor compactive efforts were used which met the minimum required unconfined compressive strength of 200kN/m^2 for hydraulic barriers in waste containment structures.

Keywords: abandoned dumpsite soils, clay mineralogy, unconfined compressive strength, geotechnical tests, compactive efforts.

INTRODUCTION

The Problem of solid waste disposal in our cities has become a key issue in these environmentally conscious times. Coincidentally, there has been a phenomenal increase in the volume and range of solid waste generated daily within the past few years. This is due largely to the increasing rate of population growth, urbanization and industrialization. This scenario has really brought the culmination of knowledge into environmental geotechnics (a diverse discipline relative to several other disciplines concerned with subsurface environmental control and protection). This includes a wide range of soils and materials, such as synthetically manufactured materials (e.g., geosynthetics and geosynthetic clay liners), low-permeability fine-grained soils used in containment barriers, and high-permeability coarse-grained materials (e.g., aquifer materials) typically associated with subsurface pollution of ground water. Environmental geotechnics is also concerned with a wide range of conditions, including both unsaturated soil conditions related to water migration through engineered soil covers for waste disposal facilities as well as saturated soil conditions related to the migration of miscible contaminants in the subsurface (Benson, 1999; Bello, 2012).

Many communities in Nigeria rely on surface and groundwater as a primary source of drinking water of which a variety of threats to its quality exist. Rapid industrial development in developing countries has increased hazardous waste generation several folds. Heavy metals, organic compounds and other toxic effluents continue to be deliberately released into the environment by manufacturing mining, oil firm etc. Streams and other sources of domestic water consumption especially those in rural areas are now known to have recorded lethal levels of toxicity with attendant risks to human lives (Olajire, and Ayodele, 1998; Frempong and Yanful, 2008). Although, there are some efforts to reduce and recover the waste, disposal in landfills is still the most common method for waste destination.

Liner system is a significant component part of waste disposal system. A liner has a main purpose of preventing/minimizing the migration of fluids (mainly leachate) directly into the underlying subsurface during both the active disposal period, typically 10 to 20 years as well as the inactive, or post-closure period. According to (Daniel and Wu, 1993) natural clay liners (e.g., aquitards and aquicludes) and engineered liners are types of liners which are used in waste disposal systems around the world. For a compacted natural soil to be used as hydraulic barriers it must possess a hydraulic conductivity of less than or equal to 1x10^{-9}m/s, volumetric shrinkage upon drying (maximum of 4%) and shear strength (minimum of 200 kPa).

Hydraulic barriers used for waste containment structures in landfills design play a vital role in impeding fluid flow and attenuating inorganic contaminants. The structural integrity of these hydraulics barriers must be ensured by making sure that the constructed facility has adequate shear strength. According to (Edil *et al*., 1992; Stark and Poeppel, 1994; Osinubi and Bello, 2009) the material should have adequate shear strength (a minimum unconfined compressive strength of 200KN/m^2) and be durable to withstand destructive forces of alternating wet/dry and freeze/thaw cycles. This strength is the lowest value for very stiff soils based on the consistency classification according to (Osinubi and Bello, 2009).

Further required characteristics of the liners and the total lining system are described in the European regulations and its national document (Witt and Zeh, 2005; Zeh and Witt, 2005). In spite of several research projects such as (Abichou *et al*., 2000; Albrecht and Benson, 2001), some problems dealing with cover lining system are not solved definitely. In this paper, geotechnical tool such as shear strength otherwise known as unconfined compressive strength has been used to give a vivid account of the structural integrity of the abandoned dumpsite soil as containment facilities.

MATERIALS AND METHODS

Sampling of soils

The soil samples used in this study work are a natural material that is yellowish brown soil from a borrow pit at Orita -Aperin abandoned dumpsite, Ibadan, (latitude $7^o30^{'}$ and longitude $4^o56^{'}$) Oyo state, Nigeria using the method of disturbed sampling. The soil samples were obtained at depths of 1.80 - 3.90m and designated as AB1, AB2 and AB3. The soil samples were collected in large-to -medium-sized bags and thereafter transported to the Soil Mechanics Research Laboratory of the Department of Civil Engineering, Ahmadu Bello University (ABU), Zaria. Each soil sample was spread and allowed to air-dry under laboratory conditions.

Mineralogical composition

The mineralogical compositions of the soils were determined using X-ray diffraction (XRD) techniques as outlined by Brown and Brindley (1989) at the Engineering Materials Development Institute (EMDI), Akure, Ondo State. The X-ray diffraction patterns or diffractograms were recorded with a Rigaku Rotating Anode X-ray diffractometer. Powder diffractograms of the soil samples were obtained by scanning the samples at a rate of $10^0$20 per minute over an angular range of $2\text{-}82^0$. Slides of specimens of the natural soils were prepared from the <2μm size soil fractions of the samples. The slides were subsequently water saturated, air dried, ethylene glycol solvated, and heat treated (at 550^0C for 30 min) and then scanned to obtain preferred oriented diffractograms. Mineral identification on the diffractograms followed procedures established by Brown and Brindley (1989) and Moore and Reynolds (1997).

The determination of the fabric was carried out by the field emission scanning electrons microscopy (FESEM) to supplement the X-ray data for mineral identification at the Department of Material Science, International Islamic University, Malaysia. Energy dispersive x-ray fluorescence (EDXRF) was also employed to show the elemental composition of each of the samples.

Chemical composition of soils

Chemical composition analysis for each of the samples was determined using standard laboratory procedures outlined by Shackelford and Redmond (1995) for analyzing the chemical constituents of soils including oxides expressed as percentage. The evaluation of soil chemical composition was conducted in the Soil Chemistry Laboratory of the Department of Soil Science, Ahmadu Bello University, Zaria.

Determination of physical properties

Sieve analysis

Hydrometer method was used to obtain values of the clay-size (percent < 0.002 mm) fraction of the soil constituents or particles. 250 grams of each soil samples was first measured and soaked using tap water for at least 2 days to ensure that the dry soil clods were softened. After soaking, the specimen was washed through BS No 200 (i.e., 0.075 mm) sieve. The material retained on the sieve after washing was collected into a small metal bowl, oven dried and sieved based on procedures outlined in BS 1377 (1990). Sieving was done in three replicates for each specimen.

Specific gravity

Specific gravity tests were conducted based on procedures outlined in BS 1377 (1990) and Head (1992). The tests were carried out in three replicates. The specific gravity for each of the specimen was calculated using the expression (Head, 1992):

$$G_s = \frac{\rho_L(m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)} \qquad (1)$$

where ρ_L = density of liquid used (ρ_L was assumed to be equal to 1.000 g/ml for this purpose since distilled water was used); m_1 = mass of density bottle (g); m_2 = mass of bottle + dry soil (g); m_3 = mass of bottle + soil + liquid (g); m_4 = mass of bottle + distilled water only (g). Average of three measurements was calculated and recorded in each case. Specific gravity tests were repeated whenever any one value differed from the average value by more than 0.03.

Atterberg limits

Atterberg limits tests which are otherwise known as plasticity tests were conducted on air-dried soils that had previously been passed through sieve with 425 μm aperture (Head, 1992). Distilled water was used throughout the tests to determine the plasticity of the soils. The liquid limit was determined with the use of the Casagrande apparatus in agreement with Clause 4.5, Part 2 of BS 1377 (1990).

The grading modulus was calculated from the expression (TRRL, 1990):

$$Grading\ modulus = \frac{300-(\%Passing\ 2.0mm + \%<0.425mm + \%0.075mm)}{100} \quad (2)$$

In this study, percentage of soil fraction passing the 2.40 mm sieve was used instead of 2.00 mm sieve. It was the one available in the laboratory at the time of the experimental programme and the two sizes are interchangeably used in practice. The plasticity product is defined as the plasticity index multiplied by the soil fraction passing 75 µm. The plasticity modulus is the product of the plasticity index and the percentage of soil fraction passing 425 µm (CIRIA, 1988). These terms are often used to show the contribution of the soil's plasticity and particle size distribution to its behaviour.

Compaction

The sample specimens tested were prepared by mixing the relevant quantity of dry soil samples previously crushed to pass through BS No.4 sieve with 4.76 mm aperture as outlined by Head (1992) as well as Albrecht and Benson (2001). The specimens were moulded at water content in the range 5.25 - 25.5% and four different compactive efforts similar to those that might be achieved in the field.

The compaction methods used included the Reduced Proctor (RP) effort described by Benson and Trast (1995) which is equivalent to the Reduced British Standard Light (RBSL). The Standard Proctor (SP) or British Standard Light (BSL) and Modified Proctor (MP) or British Standard Heavy (BSH) are in accordance with BS 1377 (1990). The West African Standard (WAS) compaction is outlined in the Nigerian General Specification (1997).

Five to seven batches of soil each weighing 2.5 kg was placed in a tray and mixed with tap water. The reduced and standard Proctor compactions utilized 3 layers applying 15 and 27 blows each of a 2.5kg rammer falling from a height of 300mm using 1000cm^3 mould, respectively. The modified Proctor compactive effort involved the use of the same mould with a 4.5 kg rammer falling from a height of 450 mm applying 27 blows each and compacting in 5 layers. For the West African Standard compactive effort which is the conventional energy level commonly used in the region (Osinubi, 1998) consist of energy level derived from a 4.5 kg rammer falling through 450 mm height onto five layers using 10 blows each.

The calculation of dry densities and moisture contents followed procedures described in Head (1992). Calculated values were used to obtain the appropriate compaction curves, from which the maximum dry densities (or maximum dry unit weights) and the corresponding optimum water contents were estimated.

Unconfined compressive strength (UCS) were conducted on soil specimens previously mixed with tap water and compacted at moulding water contents ranging between 6.5% and 22.5% using the four compactive efforts. Compacted specimens were sealed in plastic lugs and allowed to stand for at least 24 hours before trimming (for UCS test specimens) and testing. At least two trimmed specimens (38 mm diameter by 76 mm high) per moulding water were used in the UCS testing.

RESULTS AND DISCUSSIONS

Mineralogical composition

The clay mineralogy of the soil samples were quantitatively analyzed using x-ray diffraction (XRD), at the Engineering Materials Development Institute (EMDI), Akure. The results showed that the soils samples contain biotite, annite, alluminian and clintonite.

The results did not show the predominant clay mineral but it may be inferred to be kaolinite based on the values of specific gravity of the samples and in agreement with Bolarinwa (2001).

XRD carried out at the Department of Material Science, International Islamic University, Malaysia showed that the specimens consist of kaolinite as their major clay minerals combined with other minerals such as smectite, quartzite, biotite, annite and alluminium silicate (see Figures 1-3).

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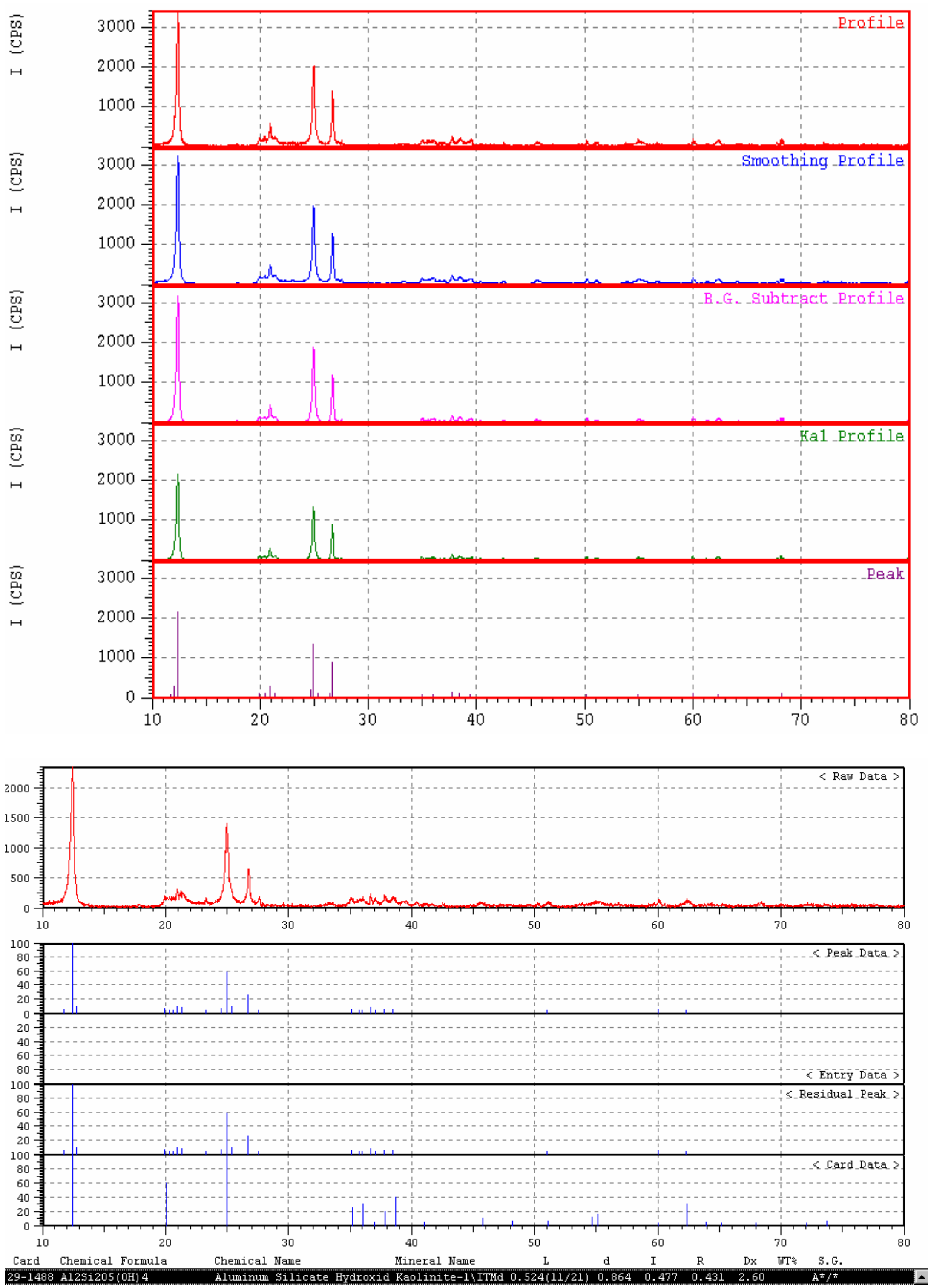

Figure-1. Mineralogical composition of AB1.

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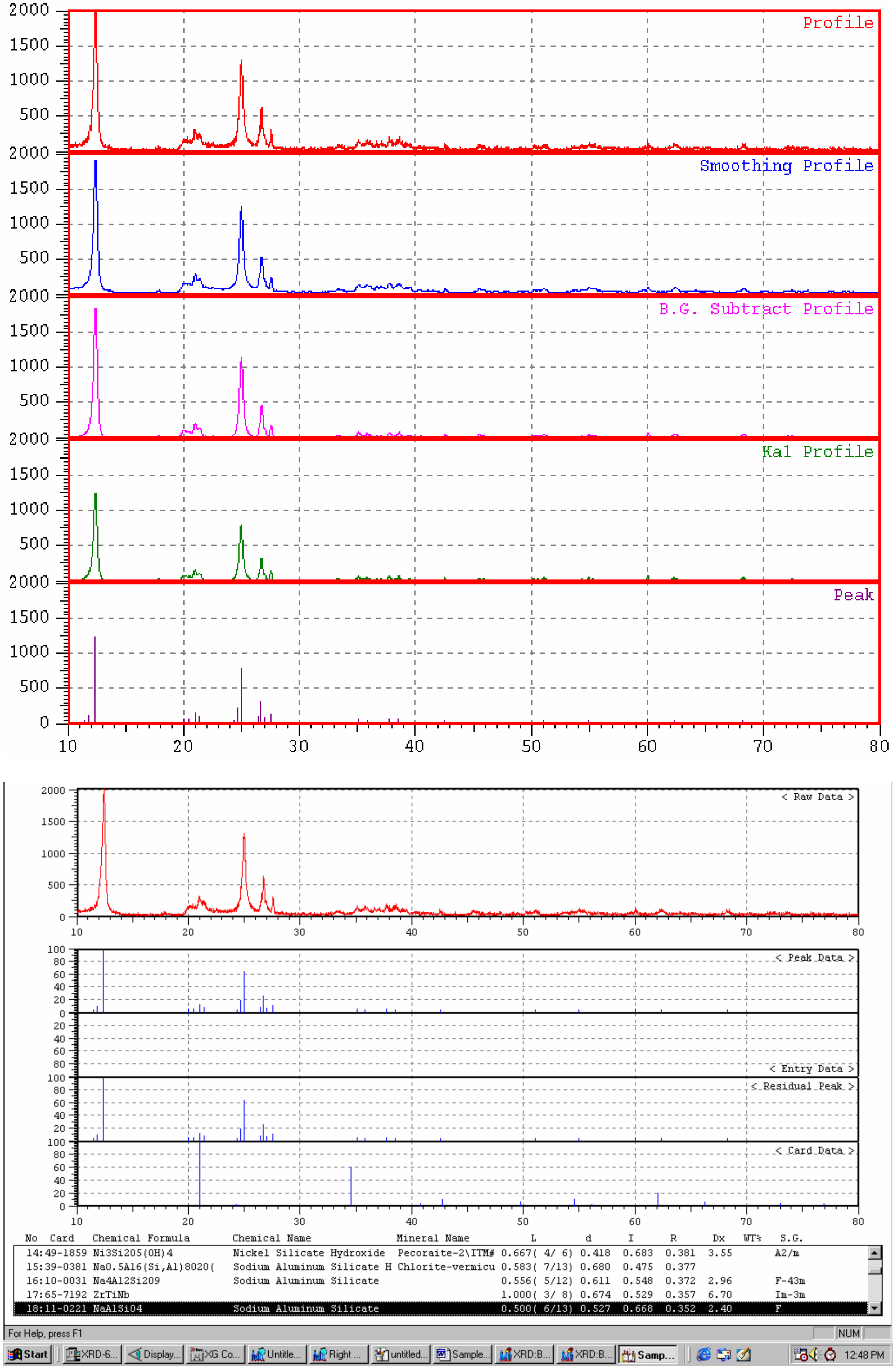

Figure-2. Mineralogical composition of AB2.

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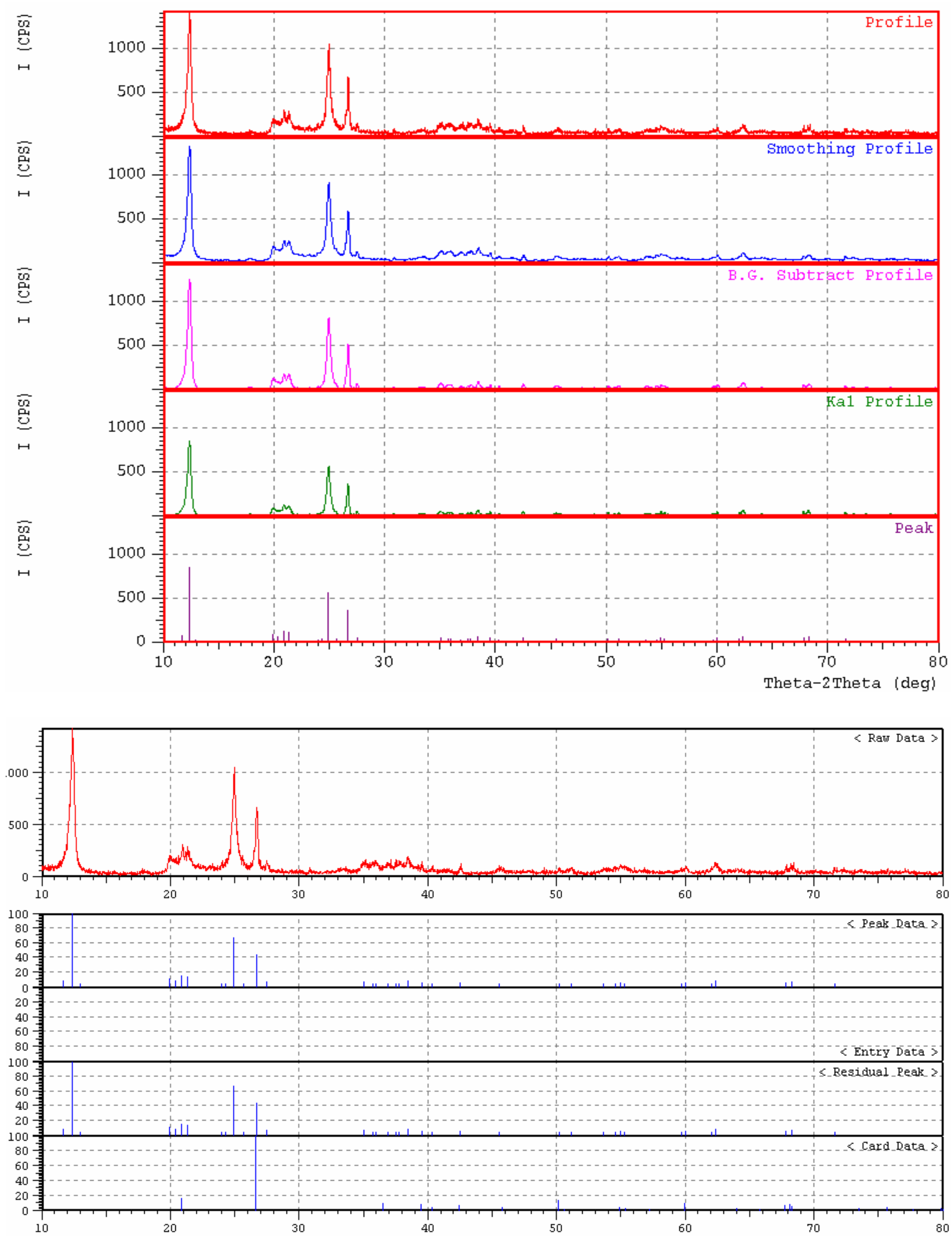
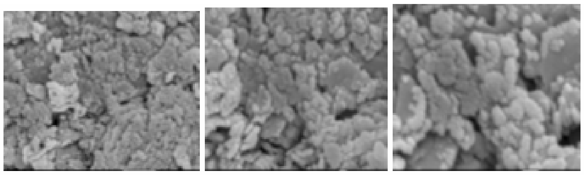


Card	Chemical Formula	Chemical Name	Mineral Name	L	d	I	R	Dx	WT%	S.G.
46-1045	SiO2	Silicon Oxide	Quartz	0.591(13/58)	0.795	0.685	0.322	2.65		P3221
65-0466	SiO2		Quartz low	0.591(13/64)	0.789	0.595	0.277	2.65		P3221
43-0596	SiO2	Silicon Oxide		1.000(6/ 6)	0.560	0.423	0.237	2.68		P3221

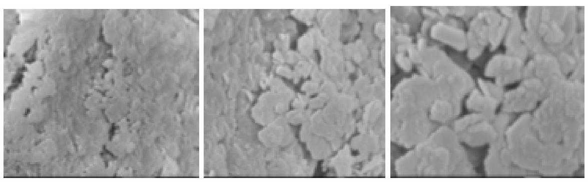
Figure-3. Mineralogical Composition of AB3.

This was backed up with the fabric (geometric arrangement of soil particles)/structure test using the field emission scanning electrons microscopy (FESEM). FESEM has been reported to be 6 times better than the scanning electron microsopy (SEM). The FESEM micrographs (see Figures 4-6) show the presence of kaolinite flakes and smectitic tubes in the specimen. By this, there are visible flocs which seem to be sandy silt-sized particles.



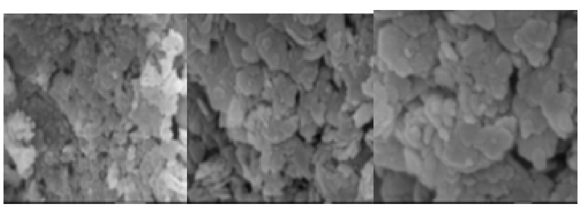
(a) (b) (c)

Figure-4 (a, b, c). Micrographs showing Kaolinitic and Smectite flakes at 20, 000, 50, 000 and 100, 000 magnification using FESEM for AB1.



(a) (b) (c)

Figure-5 (a, b, c). Micrographs showing Kaolinitic and Smectite flakes at 20, 000, 50, 000 and 100,000 magnification using FESEM for AB2.



(a) (b) (c)

Figure-6 (a, b, c). Micrographs showing Kaolinitic and Smectite flakes at 20, 000, 50, 000 and 100,000 magnification using FESEM for AB3.

Energy dispersive x-ray spectrometry (EDX) and energy dispersive x-ray fluorescence (EDXRF) were also employed to show the elemental composition of each of the samples and the result is as shown in Table-1. It is apparent that Potassium (K), Calcium (Ca) and Iron (Fe) occur in larger quantities than other elements while Nickel (Ni), Manganese (Mn), Copper (Cu) and Zinc (Zn) occur in lower quantities. It further reveals that AB3 has appreciable high composition of Ca. This may limit biologically induced clogging in AB3 under unsaturated condition.

The chemical composition of the abandoned dumpsite soil is summarized in Table-2. The concentrations of Fe_2O_3 are in the ranges 5.5 - 6.4% for soil samples, respectively in agreement with Bolarinwa (2001). It can be stated that as ferruginous soils, they contain free iron oxides which have been transformed to the active forms (Bolarinwa, 2001).

The pH values of the abandoned dumpsite soils were in the range 6.30 - 7.0 indicating that the soil samples are more of acidic than basic in nature. When pH is 7, it is stated that such composition is neutral. The organic carbon content of these soil samples is low indicating low loss on ignition.

Table-1. Elemental composition of soil samples.

Minerals	Samples		
	AB1	**AB2**	**AB3**
K (ppm)	218	142	177
Ca (ppm)	129	430	106
Ti (ppm)	59.3	54.6	31.2
V (ppm)	16.3	-	23.6
Cr (ppm)	12.0	13.7	10.8
Mn (ppm)	6.47	6.71	3.55
Fe (ppm)	147	410	186
Ni (ppm)	22.5	-	2.08
Cu (ppm)	14.0	16.4	1.58
Zn (ppm)	9.74	10.9	11.1
Ga (ppm)	9.65	-	8.3
As (ppm)	6.69	7.88	9.04
Pb (ppm)	2.83	11.1	3.32

Table-2. Chemical composition of soil samples.

Oxides	Soil samples		
	AB1	**AB2**	**AB3**
Fe_2O_3 (%)	6.4	6.0	5.5
CaO (%)	7.1	4.0	18.1
MnO_3 (%)	0.2	0.23	0.73
K_2O (%)	1.1	0.6	1.9
Cr_2O_3 (%)	0.2	0.14	0.11
Al_2O_3 (%)	1.6	2.4	3.2
SiO_2 (%)	3.8	3.4	1.1
Organic Carbon	0.13	0.18	0.11
pH	6.30	6.70	7.00
EC μmhos/cm	0.25	0.35	0.29

Index properties

The index properties of the soil samples are summarized in Table-3. The results of the particle size distribution are shown on Figure-7. The percentages passing the No. 200 sieve were in the ranges 56.15 - 58.99%. The clay (percentage passing 2μm) fraction contents were 18.20 - 19.92%. Appreciable quantities of fines are desirable in soils that are to be used as hydraulic barrier materials. The plasticity indices and activity were generally in the ranges 13 - 16% and 0.7 - 0.75, respectively. These values of activity, A (plasticity index, PI/clay fraction) are typical of those reported for kaolinitic soils (Oweis, and Khera, 1998).

All the soil samples are classified as A-7-6 according to the AASHTO classification system, while the

Unified Soil Classification System (USCS) classifies the samples as CL, which is an indication of low plasticity clay (Coduto, 2003; Punmia *et al*., 2005). On the basis of the Casagrande plasticity chart, these soils are inorganic clays of low to medium plasticity or sandy silty clays (Coduto, 2003). According to the engineering use chart (Lambe, and Whitman, 1979), these soils are impervious with respect to their permeability when compacted. The soils should be of medium compressibility when compacted and saturated and should be of good workability as construction materials for liners.

Table-3. Index properties of abandoned dumpsite soils.

Properties	**Soil Samples**		
	AB1	**AB2**	**AB3**
Natural moisture content, %	4.1	4.3	4.2
Specific gravity	2.61	2.61	2.64
Liquid limit, %	36	43	40
Plastic limit, %	23	27	24
Plasticity index, %	13	16	16
Linear shrinkage, %	6.25	6.40	8.59
% Passing BS No. 40 sieve	74.15	71.6	75.95
% Passing BS No. 200 sieve	56.15	57.9	58.99
% < 2 μm	18.2	18.90	19.92
AASHTO classification	A-7-6 (4)	A-7-6(6)	A-7-6(7)
USCS classification	CL	CL	CL
Activity	0.70	0.75	0.75
Derived Parameters			
Grading modulus	0.61	0.67	0.60
Plasticity product	889.7	947.2	982.4
Plasticity modulus	1121.4	1236.0	1304.8

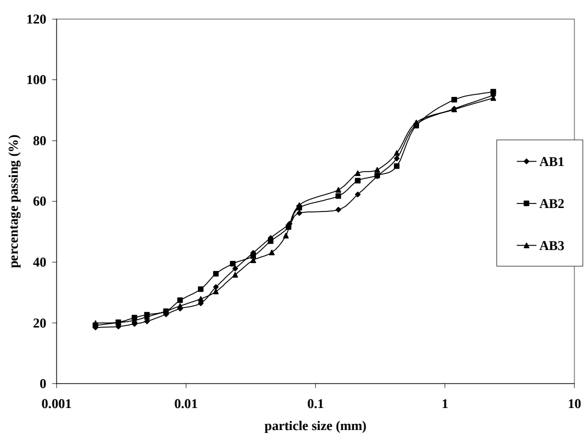


Figure-7. Particle-size distribution curves for Orita-Aperin abandoned dumpsite soils.

Compaction characteristics

The results of the compaction tests are shown graphically in Figure-8 (a-c) for AB1, AB2 and AB3, respectively. It is observed that the samples compacted using the modified Proctor has the highest maximum dry unit weight with a corresponding lowest optimum moisture content. This is followed by West African Standard, standard proctor and reduced Proctor. Thus, it could be suggested that for this samples to be used for liners, compactive efforts in the other of MP, WAS, SP and RP in this other.

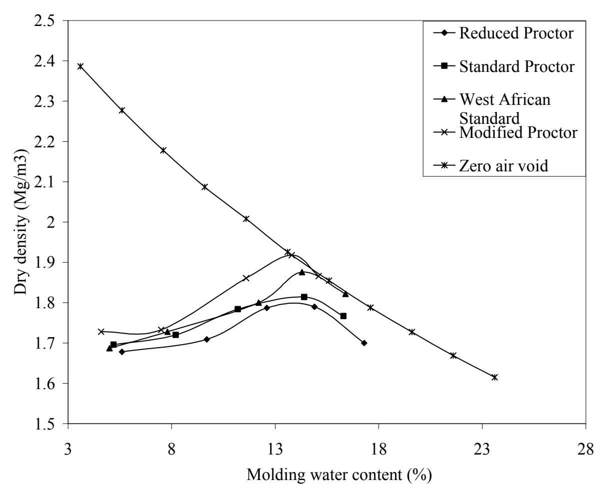


Figure-8 (a). Compaction curves for soil sample AB1.

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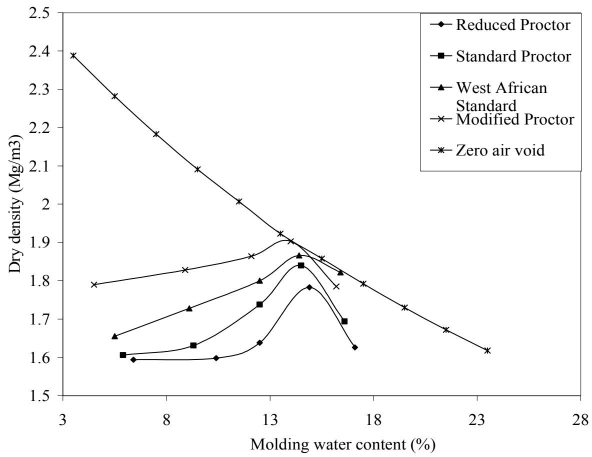

Figure-8 (b). Compaction curves for soil sample AB2.

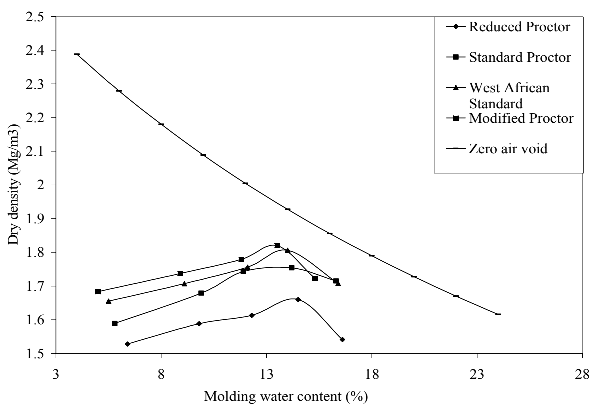

Figure-8 (c). Compaction curves for soil sample AB3.

Unconfined compressive strength

Structural integrity of liners and covers must be ensured by making sure that the constructed facility has adequate shear strength. Daniel and Wu (1993) stated that each landfill liner project would have to be determined and evaluated individually to find minimum strength requirements. Unconfined compressive strength (UCS) of the compacted specimens was determined for the range of water contents and compactive efforts employed in this study.

Effect of compaction water content and compactive effort

The variations of unconfined compressive strength (UCS) values with compactive efforts and moulding water contents are illustrated in Figures 9 - 11 for AB1, AB2 and AB3, respectively. UCS values generally increased with moulding water content in the range 11.6 - 17.5%, depending on the compactive effort and thereafter decreased to very low values as water contents increased. UCS values recorded for modified Proctor and West Africa Standard compactive efforts were very high near their optimum water contents. Lowering of compactive efforts resulted in decrease in UCS values. Nevertheless, irrespective of sample specimen and compactive effort, UCS values obtained at compaction water contents equal to or greater than 19% were less than 200 kN/m^2 which is the minimum required for containment structures except for AB1 with WAS compactive effort.

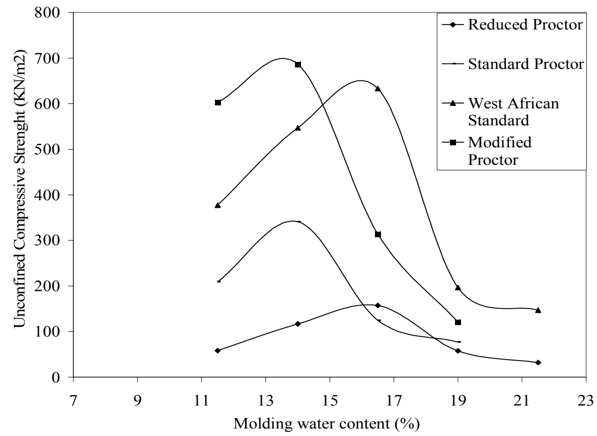

Figure-9. Unconfined compressive strength versus moulding water content for AB1.

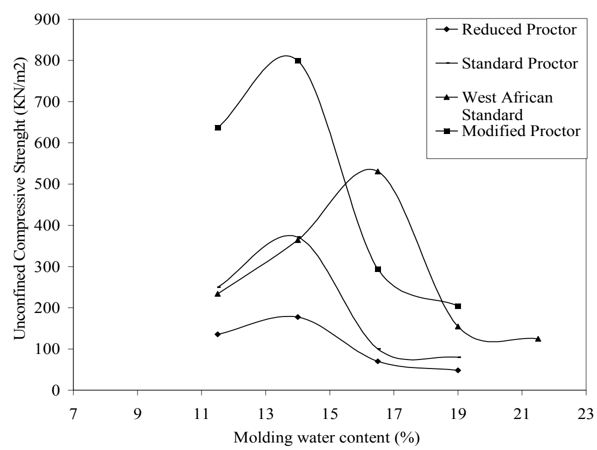

Figure-10. Unconfined compressive strength versus moulding water content for AB2.

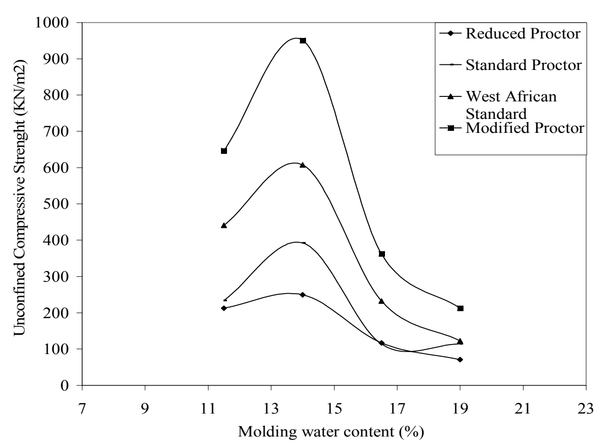

Figure-11. Unconfined compressive strength versus moulding water content for AB3.

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Effect of variation in dry unit weight

Unconfined compressive strength was plotted against dry unit weights as shown in Figures 12-14 for soil specimen AB1, AB2 and AB3, respectively. Generally, non-linear increase in UCS values with higher dry unit weight was observed. It is possible to obtain UCS values greater than 200 kN/m^2 at dry unit weight greater than 16.70 kN/m^3 especially when WAS and modified Proctor compactive efforts are used.

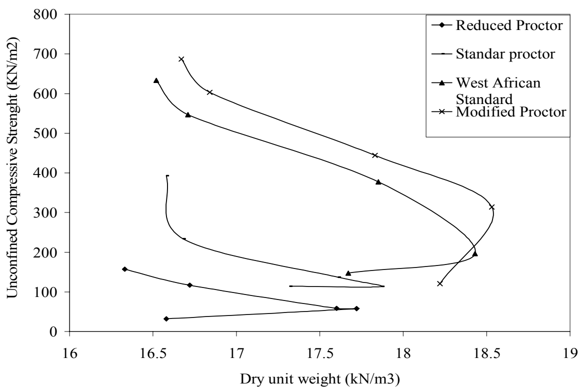

Figure-12. Unconfined compressive strength versus dry unit weight for AB1.

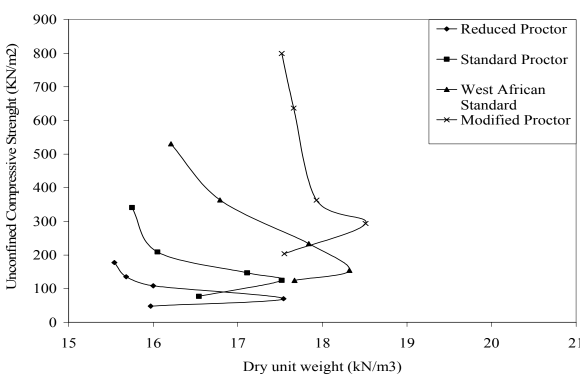

Figure-13. Unconfined compressive strength versus dry unit weight for AB2.

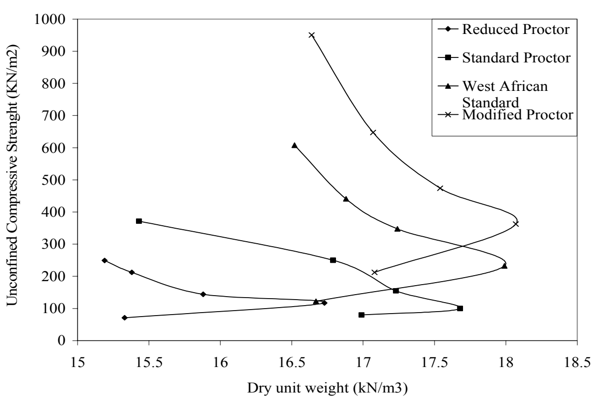

Figure-14. Unconfined compressive strength versus dry unit weight for AB3.

CONCLUSIONS

Laboratory analyses of Abandoned Dumpsite soil from Orita-Aperin, Ibadan Southwestern Nigeria have been carried out. XRD test showed that the specimens consist of kaolinite as their major clay minerals combined with other minerals such as smectite, quartzite, biotite, annite and alluminium silicate. The percentages passing the No. 200 sieve were in the ranges 56.15 - 58.99%. The clay (percentage passing 2μm) fraction contents were 18.20 - 19.92%. This showed the appreciable quantities of fines that are desirable in soils that are to be used as hydraulic barrier materials. The plasticity indices and activity were generally in the ranges 13 - 16% and 0.7 - 0.75, respectively. These values of activity, A (plasticity index, PI/clay fraction) are typical of those reported for kaolinitic soils. Four compactive efforts namely, reduced Proctor, standard Proctor, West African Standard and modified Proctor procedures were employed in the determination of the compaction characteristics. It is observed that the samples compacted using the modified Proctor has the highest maximum dry unit weight with a corresponding lowest optimum moisture content. Laboratory tests were carried out on specimen, to determine its suitability as hydraulic barrier with great emphasis on the shear strength. The samples were compacted using four compaction energies.

UCS values generally increased with moulding water content in the range 11.6 - 17.5%, depending on the compactive effort and thereafter decreased to very low values as water contents increased. UCS values recorded for modified Proctor and West Africa Standard compactive efforts were very high near their optimum water contents. Lowering of compactive efforts resulted in decrease in UCS values. Nevertheless, irrespective of sample specimen and compactive effort, UCS values obtained at compaction water contents equal to or greater than 19% were less than 200 kN/m^2 which is the minimum required for containment structures. Unconfined compressive strength (UCS) generally increased as the grading modulus decreased particularly for reduced Proctor and modified Proctor compactions while those of standard Proctor and WAS compaction were not clear. UCS values greater than 200 kN/m ^{2} at dry unit weight greater than 16.70kN/m^3 especially when WAS and modified Proctor compactive efforts are used. It can thus be safely concluded that if the material is to be used as hydraulic barrier, it must be compacted within a moulding water content of 11.6 and 17.5% and at a dry unit weight greater than or equal to 16.70kN/m^3 to possess the basic shear strength properties required for hydraulic barrier in waste containment structure.

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