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Geotechnical evaluation of some residual soils from south-western Nigeria as mineral seals in sanitary landfills

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Abstract: *Some residual lateritic soils derived from crystalline basement complex rocks of south-western Nigeria were investigated for some geotechnical properties to ascertaining their suitability as mineral seals in sanitary landfills. Investigative tests include specific gravity, grain size analysis, consistency limits, compaction, permeability and unconfined compression. The liquid limit, plastic limit and plasticity index (PI) values varied from 32.3 to 41 %, 19.2 to 21.3 % and 12.2 to 20.3 % respectively. Casagrande chart indicated inorganic clayey soils with low to medium plasticity. The computed clay activity ranged from 0.58 to 0.84 (Samples A, B and D) and 1.39 (Sample C), indicating Illite and Smectite as constituent clay minerals in the soils respectively. The PI values (12.2 to 20.3 %) implied that the soils will exhibit low to medium swelling potential when wet. The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) values ranged from 1.67 to 2.01 g/cm^3 and 12.9 to 22.9 % respectively. Hydraulic conductivity values varied from 4.272 x 10^{-10} to 4.4284 x 10^{-8}. Only samples A and D possessed Unconfined Compressive Strengths (208.2 and 214.8 kPa respectively) greater than the recommended ≥ 200 kPa. Generally, the results indicated that sample A satisfied all requirements and is therefore adjudged suitable as mineral seal in sanitary landfill. Test results for samples B, C and D compare well with recommended values for mineral seal materials except hydraulic conductivity and UCS. The three soil samples should be compacted at higher energies and water content slightly higher than their respective OMC for optimal performance as mineral seals.*

Keywords: ***C****ontainment, groundwater contamination, hydraulic barriers, permeability, waste disposal.*

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I. Introduction

Water and soil are two indispensable natural resources on earth, and basic necessities for socio-economic development of any nation. Water is a natural and universal solvent which dissolves and carry solutes in solution. The chemistry of natural water is a function of its dissolution history from the atmosphere, rock weathering, solution and precipitation reactions taking place in the subsurface environment, and anthropogenic activities. Over the last few decades, reports had shown an increasing concern of groundwater and soil degradation as a result of unregulated disposal and mismanagement of urban wastes in Nigeria (Eni *et al.*, 2011; Efe, 2013; Amuda *et al.*, 2014). This in most cases had resulted in cases of leachate pollution (Benka-Coker and Bafor, 1999; Ogbona *et al.*, 2002; Bayode *et al.*, 2012; Ali and Young, 2014). In many parts of the country and other parts of the sub-Sahran Africa, serious health implications of groundwater contamination include epidemics of cholera, poliomyelitis, diarrhea, schistosomiasses, and typhoid fever (Erah *et al.*, 2002; Idiata, 2007; Adewusi, 2012; Forstinus *et al.*, 2016). Worst still, millions of people reportedly die of water-borne diseases annually (Lefort, 2006). Sanitary landfills are reliable preventive measures commonly employed to tackle such urban environmental menace and the resulting health issues.

Contemporary sanitary landfills are engineered containment facilities designed and constructed to isolate solid wastes and give optimal environmental (soil and groundwater) protection (Amadi *et al.*, 2013). The use of landfills in waste disposal is an effective way of waste management when it is well designed and constructed (Arasan and Yetimoglu, 2008). In selecting sealing materials for use in waste disposal landfills, the permeability and strength characteristics of such materials are major considerations among other properties. Ideally, landfills are often designed with both the top and base sealing systems. The top sealing system is situated above the wastes and helps to prevent infiltrating precipitation or surface water from reaching the disposed wastes thereby regulating the volume of leachates produced from the wastes (Ogunsanwo, 1996). The base sealing system however, is positioned beneath the wastes and serves the purpose of preventing interaction between the leachates from the wastes and the underlying soils and groundwater thereby limiting as well as controlling contaminant migration and eventual anthropogenic contamination of the subsurface environment, especially soil and groundwater resources (Rowe *et al.*, 1995). Suitable compacted natural soils could substitute for artificially synthesized seals at considerably reduced construction cost and without environmental implications (Ige and Ogunsanwo, 2009). The current study is aimed at evaluating the geotechnical properties of four genetically different residual soils from urban Akure and environs in south-western Nigeria for possible use as mineral seals in sanitary landfills at reduced cost.

II. Materials and Methods

The samples used for this study are lateritic soils developed on crystalline basement complex rocks of south-western Nigeria. The tropical weathering products were sampled from excavated test pits at a depth of about 1 metre (Table 1). The soil samples were tested for (i) textural characteristics (particle size distribution), (ii) plasticity behaviour (consistency limits), (iii) compaction characteristics, and (iv) specific gravity of soil grains, (v) compressive strength, and (vi) permeability characteristics. The determination of the basic index properties followed BS 1377: Part 2 (1990) and ASTM D4318 standards.

III. Results and Discussion

The geotechnical properties of the residual soil samples investigated for use as mineral seals in sanitary landfills were compared with recommended limits and are presented in the subsequent sections.

3.1 Specific gravity

The specific gravity values recorded by the soil samples tested are presented on Table 1. All the four soils possessed specific gravity values ranging from 2.711 to 2.735 which are greater than the 2.2 limit recommended by Onnorms (1990). Based on specific gravity, the soils have potentials for use as mineral seals.

Table 1 Specific gravity and grain size distribution

Sample code	Sampling locality	Depth of sampling	Specific gravity	Grain size fractions (%)					Soil description
				clay	silt	sand	gravel	Fines	
A	Idanre Rd.	1.0 m	2.735	26.6	20.8	49.9	2.7	47.4	Clayey sand
B	Igbatoro Rd.	1.0 m	2.720	21.2	16.2	59.2	3.4	37.4	Clayey sand
C	Ondo Rd.	1.0 m	2.718	14.6	16.9	48.0	20.4	31.5	Gravelly sand
D	Eyinke	1.0 m	2.711	15.6	16.3	64.7	3.4	31.9	Clayey sand

3.2 Grain size distribution

The results of the grain size distribution analysis are presented on Table 1 and as curves in Fig. 1. Materials for mineral seals in landfills are expected to possess clay fractions > 10 % (Declan and Paul, 2003) and amount of fines (silt and clay size particles) ≥ 30 % (Daniel, 1993; Benson *et al.,* 1994; Rowe *et al.,* 1995). Daniel (1993) suggested amount of gravels ≤ 30 % for a mineral seal. Based on the recommended amount of clay fractions and fines, all the four soil samples are adjudged suitable materials as mineral seals. The soils also contains sufficient amount of sand to provide enough strength as well as protect against volumetric shrinkage. All the soil samples possess amount of gravels within the recommended range (≤ 30 %) for materials to be considered as mineral seals.

3.3 Consistency limits

The liquid limits (LL), plastic limits (PL), plasticity index (PI) and linear shrinkage (LS) values are shown on Table 2. Fig. 2 presents the Casagrande chart for the soils. Materials for mineral seals in landfills are expected to possess 20 ≤ LL < 90 (Benson *et al.,* 1994; Declan and Paul, 2003; Kabir and Taha, 2004) and 7 % ≤ PI < 65 % (Daniel, 1993; Rowe *et al.,* 1995: Declan and Paul, 2003). All the soil samples under investigation possess liquid limits (32.3 to 41.0 %) within the recommended range. Daniel (1991) opined that excessive shrinkage can result when plasticity index value exceeds 35. The soil samples have appropriate plasticity characteristics with PI varying between 12.2 and 20.3 %. With these PI values, hydraulic conductivity and potential for shrinkage can be minimized for optimal engineering performance.

Table 2 Consistency limits, linear shrinkage and USCS classification

Sample code	Consistency limits (%)			Linear shrinkage (%)	USCS classification	Activity	Clay mineral
	PL	LL	PI				
A	21.3	41.0	19.7	9.3	CI (inorganic soil with medium plasticity	0.740602	Illite
B	21.3	33.5	12.2	5.0	CL (inorganic soil with low plasticity	0.575472	Illite
C	19.2	39.5	20.3	9.3	CI (inorganic soil with medium plasticity	1.390411	Smectite
D	19.2	32.3	13.15	6.4	CL (inorganic soil with low plasticity	0.842949	Illite

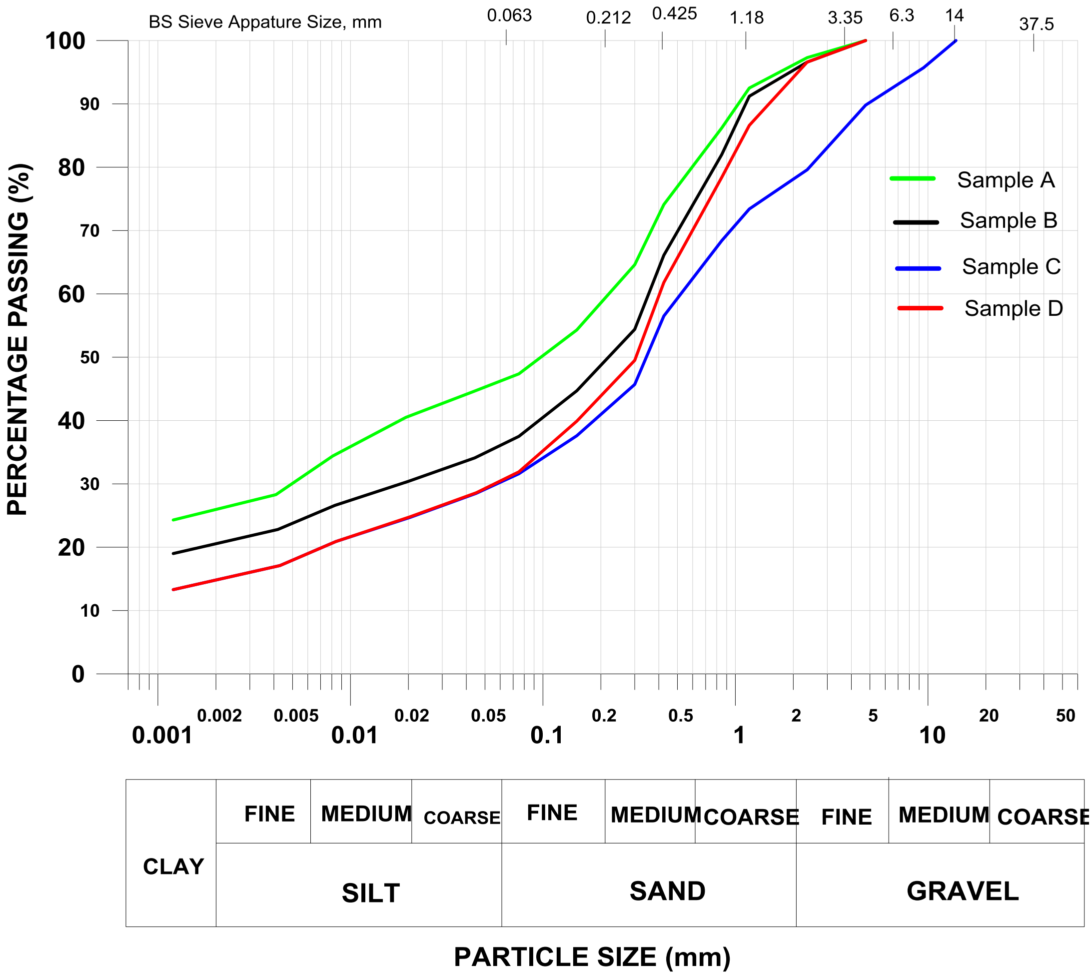

Figure 1 Grain size distribution curves for the soils

3.4 Clay Activity

The computed clay activity is presented on Table 2. Using the classification scheme of Mitchell (1976), samples A, B and D indicated Illite while sample C indicated Smectite as the predominant clay minerals in the soil samples. Benson *et al.* (1994) and Rowel *et al.* (1995) suggested activity of ≥ 0.3 for materials to be used as mineral seals so as to get hydraulic conductivity that does not exceed 1 x 10^{-7} cm/s. All the soil samples had Activity ranging from 0.58 to 1.39 which satisfies the suggested condition and as such are adjudged suitable as mineral seals. Moreover, they are inactive clayey soils by their activities and are therefore suitable materials for mineral seals (Rowe *et al.*, 1995).

3.5 Maximum dry density (MDD)

The MDD values for the soils are given on Table 3. Materials for mineral seals in landfills are expected to possess MDD > 1.45 g/cm^3 (Kabir and Taha, 2003). Based on this MDD requirement, all the soils (with MDD values ranging from 1.67 to 2.01 g/cm^3) have the potential as mineral seals.

3.6 Coefficient of permeability (*k*) values

The hydraulic conductivity is about the most important geotechnical property of materials for mineral seals for effective protection of the adjoining environment (soil and groundwater) from leachate contamination. The results of permeability test are shown on Table 3. Materials for use as mineral seals should have hydraulic conductivity value, $k < 1 \times 10^{-9}$ m/s (Onorm S2071, 1990), $k \leq 5 \times 10^{-10}$ m/s (Oeltzschner, 1992) or $k \leq 1 \times 10^{-9}$ m/s (Daniel, 1993; Seymour & Peacock, 1994). Only sample A satisfied this requirement with a value of 4.272 x 10^{-10} at standard Proctor energy level. Other samples with higher values than recommended (2.3159 x 10^{-9} to 4.4284 x 10^{-8} m/s) would require higher compactive efforts at higher OMC to attain the maximum hydraulic conductivity value for optimized performance as mineral seals (Daniel and Benson, 1990).

3.7 Unconfined Compressive Strength (UCS)

The UCS values obtained for the soils samples tested are presented on Table 3. Materials for mineral seals in landfills should have minimum unconfined compressive strength of 200 kPa (Daniel and Wu 1993) for stability under static load of the overlying wastes.

The UCS values for the soil samples (Table 7) indicated that samples A and D possessed UCS values of 208.2 and 214.5 kPa respectively which are greater than the recommended 200 kPa and are therefore potential materials for use as mineral seals in sanitary landfills. However, samples B and C had lower values (159.9 and 166.7 kPa respectively) than the recommended and may therefore not be suitable.

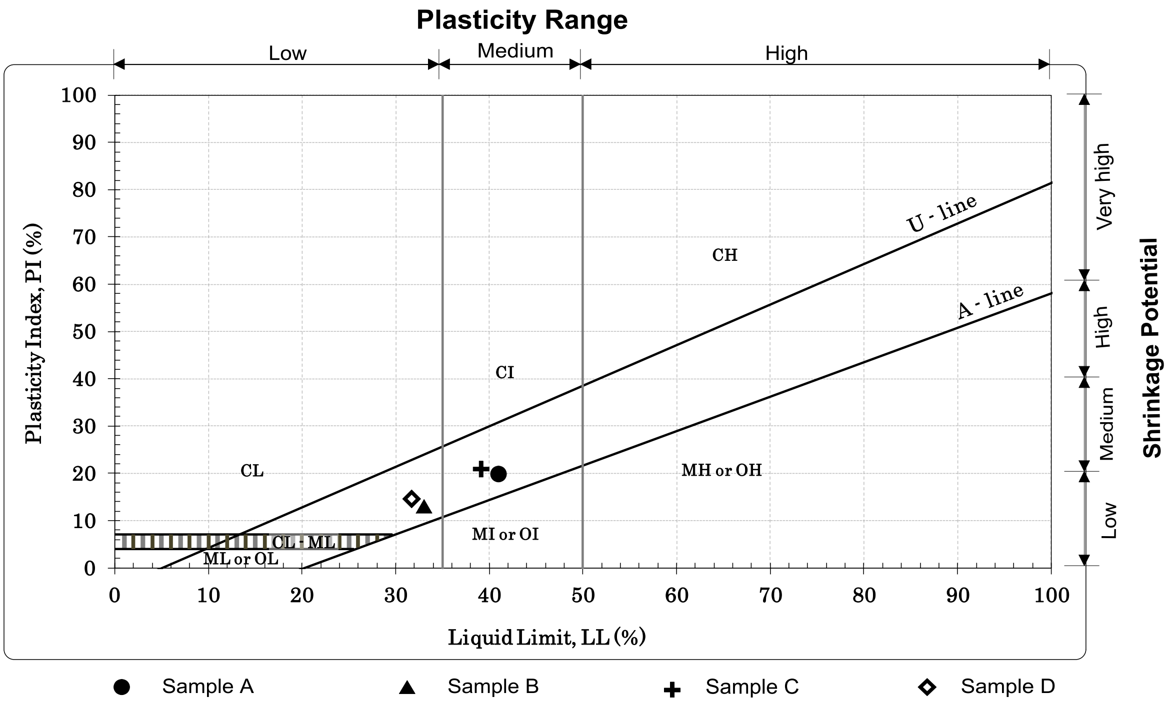

Figure 2. Plasticity chart for the soil samples (After Casagrande, 1948)

Table 3 Compaction, permeability and strength characteristics

Sample code	Compaction parameters		Coefficient of permeability, *k* (m/s)	Shear strength parameters		UCS (kPa)
	MDD (g/cm^3)	OMC (%)		c (KPa)	φ (°)	
A	1.67	22.9	4.272×10^{-10}	117.9	17	208.2
B	1.76	20.0	2.3159×10^{-9}	54.3	23.1	159.9
C	2.01	12.9	1.3942×10^{-8}	57.5	24.2	166.7
D	1.91	15.8	4.4284×10^{-8}	111.6	16.8	214.5

IV. Conclusion

From the foregoing, sample A meets all the requirements and is therefore potentially suitable for use as mineral seal in sanitary landfill. It combines the advantages of availability, abundance and lower construction cost than geosynthetic seals for contractors in the region. Samples B, C and D meet most of the recommended standard values with geotechnical test results comparing well with recommended values except for hydraulic conductivity (permeability) and UCS. Generally, compacting clayey soils at water content slightly higher than the OMC should give the lowest hydraulic conductivity (U.S. Environmental Protection Agency, 1989; Daniel and Benson, 1990). Therefore, the three soil samples (B, C and D) should be compacted at higher energies and water content slightly higher than their respective OMC for optimal performance.

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