2nd International Civil Engineering Conference (ICEC 2020)
Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

Free Swell Potential of Selected Lateritic Soils Exposed to Municipal Solid Waste Leachate: A Comparative Experimental Study

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ABSTRACT

Tests were conducted to investigate the effect of Municipal Solid Waste (MSW) leachates on free swell potential of lateritic soils. Series of experiments namely, particle size distribution analysis, Atterberg limits and compaction tests were performed for characterization of five selected soils and free swell tests conducted with tap water and MSW leachates; Leachate 1, Leachate 2 and Leachate 3 from active open dump landfills in Minna. The preliminary test results showed that the five selected soils designated as soil M1, M2, M3, M4 and M5 were classified as A-2-7, A-4, A-5, A-6 and A-7-5 respectively according to AASHTO classification method. Typical of lateritic soils, plasticity index of soils ranged from 9 – 15% while the maximum dry density varied from 1.6 – 1.8g/cm^3 with corresponding optimum moisture content of between 15 – 24%. For the free swell test, Soil M5 exhibited maximum free swell of about 20 and 12% when interacted with tap water and the leachates respectively. On the other hand, Soil M1 which swelled the least yielded swell values that reached 4.5 and 3.8% when hydrated with tap water and the leachates respectively. Intermediate amounts of swell were recorded for M2, M3, M4 soils exposed to both tap water and MSW leachates. Correlation between PI and free swell was established with R^2 of 72%. The outcome of this study is important for many applications, especially in the use of these soils in landfill liner applications.

Keywords: *Lateritic soils; Municipal solid waste leachate; Free swell; Landfills*

1 INTRODUCTION

Soil swelling is a term generally applied to the ability of a soil to undergo large changes in volume due to increased moisture content (Al-Rawas and Goosen, 2006; Yilmaz, 2009; Abbey *et al*., 2020). The swelling effect results from additional embedding of water/solution molecules into the soil matrix, remarkably into the interlayer of expansive minerals. Swelling of clays is a very common phenomenon which has long presented construction challenges with associated damages for engineering projects during construction and also in the operational life of the structure (Nagaraj *et al*., 2010; Moataz *et al*., 2019; Ahmed *et al*., 2020).

In terms of swelling tendency, lateritic soil which occurs in the tropical and sub-tropical regions and widely used in many civil engineering projects, either as foundation material to support the load exerted by structures, or as construction material itself, as in the cases of earth dams and highway embankments (Gidigasu, 1976; Ola, 1983; Osinubi and Nwaiwu, 2006; Salihu, 2017) generally exhibit moderate or no swelling on hydration. While such soils have beneficial applications in projects like highway and airfield embankments etc, the low swelling potential is a negative characteristic for some projects (such as core of earthdams and landfill liners) that needs to be addressed (Amadi and Gbadebo, 2014; Amadi and Odedede, 2019).

The most important factors which influence the swelling potential may be logically divided into two groups – factors that depend on the nature of the soil particles (type and amount of clay minerals) and factors determined by the placement as well as environmental conditions such as dry density, initial moisture content, compaction method, soil structure, thermal conditions, electrolyte concentration in pore water, fluid and fluid type etc.

For the mineralogical constitution, lateritic soils are rich in sesquioxides (iron oxides, aluminum oxides or both) and low silicates but contain kaolinite generated through the chemical weathering from aluminum silicate minerals like feldspar as the dominant clay mineral. The predominance of non-expanding kaolinite clay mineral results in a small degree of hydration and swelling potential (Gidigasu, 1976; Osinubi and Nwaiwu, 2006; Marschalko *et al*., 2013). Although, kaolinites and illites minerals are generally categorized as nonexpansive, they can cause volume change if their particle sizes are extremely fine (Al-Rawas and Goosen, 2006; Yilmaz, 2009; Malik and Priyadarshee, 2018; Makusidi, 2019).

Based on soil structure, lateritic soils can be divided into three major divisions viz. (i) coarse grained soils, (ii) fine grained soils, (iii) highly organic soils. The fine grained (concretionary) lateritic soil with high clay content becomes problematic specifically when moistened, resulting in swell values that can cause damage to structures, pavements etc.

Previous studies have shown that leachate contamination of soil causes alterations of its geotechnical properties including the swelling properties. The degree of alteration depends on the soil type and the type and concentration of the contaminant (Osinubi *et al*., 2012; Amadi, 2013); however, leachates from MSW landfills in particular have been found to have no significant detrimental impact on the hydraulic conductivity of lateritic soils (Osinubi *et al*., 2012). Similarly, clayey soil specimens contaminated with MSW leachates have been reported to exhibit considerably lower swelling and compressions than uncontaminated specimens in normal situations (Al-Rawas and Goosen, 2006; Amadi, 2009; Yilmaz, 2009). The knowledge of swelling properties of these soils with different leachates is important for many applications, especially in the use of these clays in barrier applications. This paper therefore reports the result of an investigation carried out to determine the influence of MSW leachates on free swell potential of selected lateritic soils.

2 MATERIALS AND METHODS

2.1 Lateritic soil samples

Bulk and fresh representative samples of lateritic soils were obtained from their respective deposits in different parts of Minna and environ by open excavation from depths of approximately 0.75 – 1.0 m after removing the top organic matter. Generally, they contained fragments of hard completely weathered materials. They were placed in labeled sample bags and transported to the laboratory for drying.

2.2 Municipal Solid Waste (MSW) leachates

The leachates used in this research were obtained from two active open dump landfills in Minna. The first leachate specimen (Leachate 1) was collected from Bosso waste disposal site, Minna. The waste composition in this landfill includes residential and domestic waste including waste from the university offices and laboratories. The leachate was collected from a leachate sump located at the centre of the landfill.

The second and third leachate specimens (Leachate 2 & Leachate 3) were obtained from different parts of Maikunkele, Minna waste dumpsite. In addition to the biodegradable wastes, Maikunkele dumpsite also accepts a wide range of waste such as general and hazardous household waste, car bodies, recyclables, batteries, paint and e-waste, including computers and mobile phones.

Generally, the three leachate samples contain organic and inorganic contaminants in relatively high concentrations that vary from one landfill to another. All of the leachate samples were stored in sealed plastic bottles and kept in the laboratory at regulated temperature.

The water used for the tests is potable tap water obtained from civil Engineering laboratories, Federal University of Technology, Minna.

2.3 Characterization of soil samples

These soils have a wide range of physical and chemical properties and come from a broad range of geological environments. The basic engineering properties of soil samples used in this study such as Liquid Limit LL, Plastic Limit PL and Plasticity Index PI determined by Atterberg tests together with particle size distribution analysis following procedures outlined in BS 1377 (1990). The compaction parameters (optimum water content w_{opt} and maximum dry density ρ_{dmax}) were obtained using the British Standard Light (BSL) test in accordance with BS 1377 (1990).

Air dried soil samples were pulverized sufficiently to run through No. 40 sieve (425µm) for Atterberg limit tests as well as swelling test and the No. 4 sieve (4.76 mm) for compaction test.

The mineral and elemental constituents of the lateritic soil samples were determined by XRD and XRF respectively.

2.4 Free Swell Test

Free-swell test is intended to provide a rapid indication of the swelling properties of the soil samples. A modified form of free swell test was conducted (Sivapullaiah *et al.*, 1987; Yilmaz, 2009) where 10cc of dry specimens passing BS 425µm was slowly poured into a 100cc graduated cylinder filled with hydrating liquid and noting the volume of the soil after it comes to rest at the bottom. Test codes call for recording of swell volume at 24 hours. However, in some cases, swelling continues at a significant rate at the 24 hour termination, thus a 48 hour swell time was adopted for all the tests (Amadi, 2009). From test data, free swell was calculated as follows:

$$\text{Free swell} = \frac{V_2 - V_1}{V_1} \tag{1}$$

where V_2 = soil volume after swelling, cc.
V_1 = soil volume before swelling (10cc)

3 RESULTS AND DISCUSSION

3.1 Properties of Soils and Leachates Used in the study

The natural water content of the five soil samples as obtained for the present study varied in the range 10 - 16%, whereas the basic characteristics of soil samples presented in Figs.1 and 2 show that the soils belong to five AASHTO groups. They presented different particle composition (Fig. 1) and Atterberg limits under natural conditions (Fig. 2). The five investigated soils were labeled as soil 1 (M1), soil 2 (M2), up to soil 5 (M5).

Soil M1 classified as A-2-7 following AASHTO classification system and identified as clayey sand is composed of 34.23% fines fraction (particle size less than 0.075 mm) and 11% sand. The Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) are 43, 32 and 11% respectively.

Soil M2 which contains 46% fines, 22% sand with LL = 36%, PL = 27% and PI = 9% is described as fine grained silty soil of low plasticity and classified as A-4 soil in accordance with AASHTO classification method.

Similarly soil M3 considered as fine grained inorganic silt of low plasticity contains about 53% fines and 7% sand with LL = 42%, PL = 32.47% and PI = 9.53%. It is categorized as A-5 in the AASHTO classification system.

For soil M4, the percentage of fines constitute about 71.5% while sand fraction is 20% with LL = 31.5%, PL = 17.69 and PI = 13.81%. The soil is defined as fine grained low plasticity clay and is classified as A-6 in the AASHTO classification scheme.

Lastly soil M5 which comprises of 60% fines and about 26.27% sand with LL = 42.0%, PL = 26.10 and PI = 15.9% is designated as inorganic clay of low plasticity (CL). These results allowed the classification of M5 soil sample in the A-7-5 subgroup in the aforementioned classification.

Generally, kaolinite clay mineral together with non-clay minerals namely quartz, feldspar and albite were recognized during XRD studies in the tested samples. The results are consistent with the previous baseline study on the lateritic soils from the area (Salihu, 2017; Maikusidi, 2019). The index properties are summarized in Table 1 while the main elemental components are silica, aluminum and iron oxides as shown in Table 2.

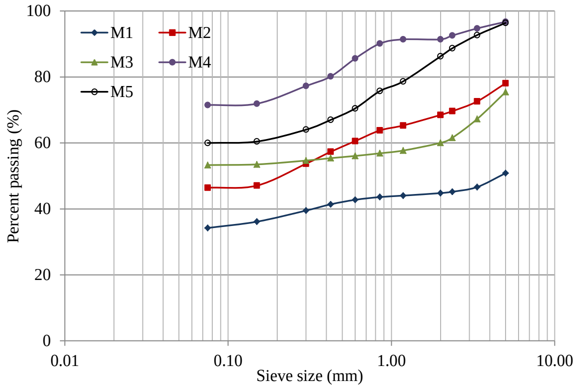

Fig. 1 Particle size distribution of soil samples

Table 1 Basic properties of soil samples

Property description	Value				
Soil	M1	M2	M3	M4	M5
%Passing 200	34.23	46	53	71.5	60
NMC (%)	10	12	15	16	13
LL (%)	43	36	42	31.5	42
PL (%)	32	27	32.47	17.69	26
PI (%)	11	9.0	9.53	13.81	15.9
AASHTO	A-2-7	A-4	A-5	A-6	A-2-7
Colour	Reddish Brown	Reddish Brown	Reddish Gray	Reddish Ash	Dark Brown

Table 2. Oxide Composition of soil samples used in the study

Soil	Oxide composition							
	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	K_2O	Na_2O	TiO_2	LOI
M1	76.56	15.09	2.30	2.66	0.89	2.10	0.33	0.07	0.82
M2	72.28	13.14	3.46	1.78	0.78	1.36	0.23	0.04	1.09
M3	75.69	16.88	1.44	4.22	0.20	0.87	0.08	*	1.20
M4	72.55	17.30	4.66	2.34	0.38	2.11	0.09	*	1.40
M5	68.60	27.40	0.82	2.50	0.42	1.67	*	*	1.40

*Not detected

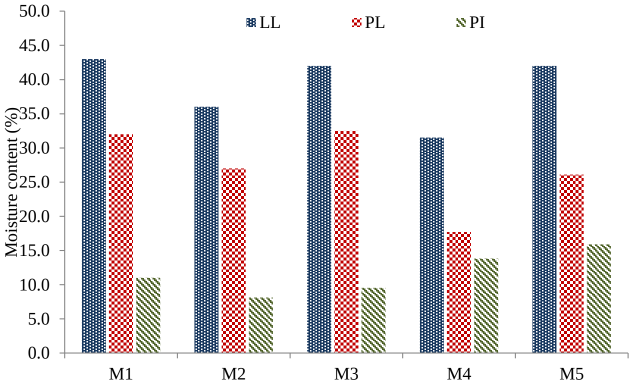

Fig. 2. Consistency limits of soil samples

Table 3 is a summary of the measured chemical parameters of the leachate samples used in the study. There are some observed similarities in some key characteristics between the leachate samples in this study and those of other tropical leachates reported in the literature (Amadi, 2013). Leachates (Leachate 1, Leachate 2 & Leachate 3) used in this study are indicated by pungent odour. While Leachates 1 & 2 have grey colour, leachate 3 is black in colour. The measured chemical oxygen demand (COD) values in the leachates ranged between 3812–6489 mg/L while the Biochemical oxygen demand (BOD) in leachate samples were between 216 - 288 mg/L. Ammonia contents were found in high concentrations (1200 - 2500 mg/L).

Table 3: Selected leachate parameters used for free swell test.

Parameters	Concentrations		
Leachate	1	2	3
EC	4600	5500	8000
TDS	7200	4000	9800
TH (as CaCO3)	2500	2056	1650
COD	5605	3812	6489
BOD	218	256	288
pH	8.5	8.1	8.4
Calcium, Ca	382	80	110
Potassium, K	436.05	754.52	1252
Sodium, Na	139.86	548.80	723.20
Iron, Fe	6.28	0.44	4.75
Lead (mg/l)	0.93	0.25	0.18
Chromium, Cr	0.85	0.32	0.24
Chloride, Cl	27.8	84.4	41.0
Sulphate, SO_4	265.0	38.0	410.0
Manganese, Mn	0.068	0.16	0.44
Ammonium, NH_4	2500	1200	2420
Magnesium, Mg	0.47	0.25	0.88
Nitrate, NO_3	7.2	8.5	12

Electrical Conductivity in µmhos/cm; All other values in mg/L except pH

Fig. 3 shows the compaction curves for the various soil samples based on British standard light (BSL) compaction effort. Plots of the maximum dry densities and optimum moisture contents are shown in comparison bar charts in Figs. 4 and 5. Maximum dry densities of 1.78, 1.63, 1.6, 1.72 and 1.8 g/cm^3 were obtained for soil M1, M2, M3, M4 and M5 respectively. Corresponding optimum moisture contents are 15.1, 20.6, 24, 18.3 and 17.1% respectively. The values of the compaction parameters for these soils are in agreement with the range obtained by Osinubi and Nwaiwu (2006) as well as Amadi and Osinubi (2018).

Compaction characteristics of lateritic soils are determined by their grading characteristics and plasticity of fines which are in turn traced to genetic and pedological factors. While gravels yield relatively high maximum dry densities with corresponding low optimum moisture contents, gravel-sand-clays and sand-clays achieved lower densities with higher optimum moisture contents. The maximum dry densities for clays are generally low with associated high optimum moisture content (Gidigasu, 1976; Ola, 1983; Marschalko *et al.*, 2013). The discrepancy in these parameters for the samples however, may be due to the different degree of laterization and the placement variables.

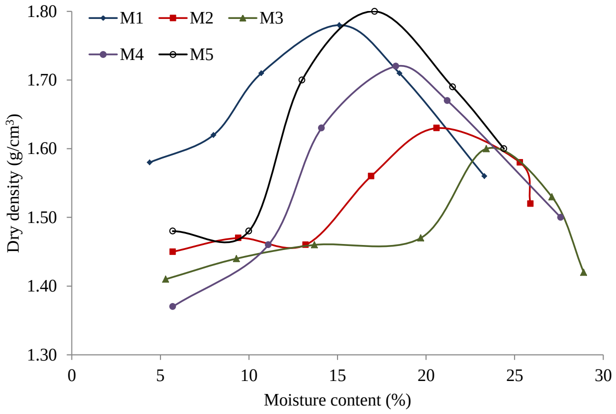

Fig. 3. Compaction curves of soil samples

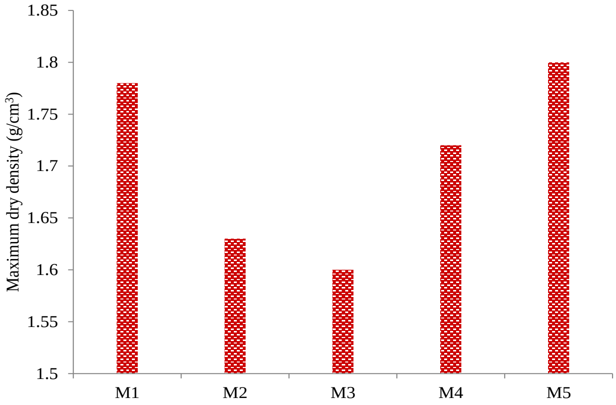

Fig. 4. Maximum dry density of soil samples

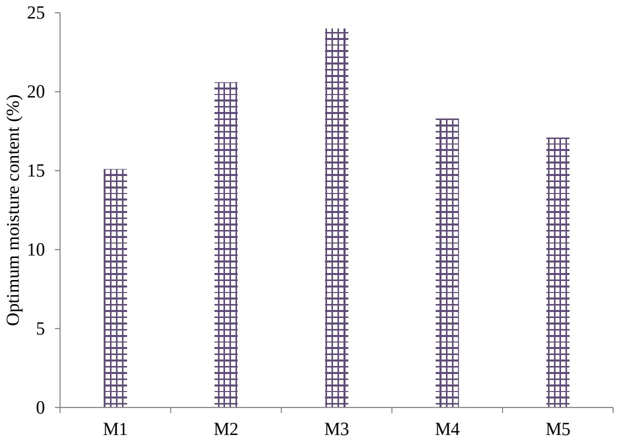

Fig. 5. Optimum moisture content of soil samples

3.2 Free swell of soil samples

The data in Fig. 6 contains the free-swell measurements made on the selected lateritic soils when hydrated with tap water and multispecies MSW leachates adopted in this study. While substantial free swell capacity was observed in some samples, others showed negligible swelling potential irrespective of the hydrating liquid.

When hydrated with tap water, soil M5 considered as low plasticity (CL) clay swelled the most recording free swell values of 20% whereas M1, a clayey gravely sand exhibited values as low as 4.5%. For Soil M2, M3, and M4, the amount of swell reached 7.5, 10 and 14% respectively. These results are in agreement with most research reports in the literature that soils whose dominant clay mineral is kaolinite results in a small degree of hydration and swelling potential (Gidigasu, 1976; Ola, 1983; Amadi and Gbadebo, 2014).

When the soils interacted with leachate solutions, the amounts of free swell decreased. The magnitude of the decrease varied with each leachate indicating that swelling of the soil samples were affected by the ionic strength of the leachates (ionic strength was measured by the electrical conductivity, EC of leachate solutions in the present study).

Similar to water hydration, the highest free swell was obtained from soil M5 which was determined as 12, 12, 10% for Leachates 1, 2 and 3 respectively. On the other hand, soil M1 swelled the least recording swell values as low as 3.8, 3.5 and 2.5% respectively for Leachates 1, 2 and 3. Intermediate swell values were obtained for the other soils. For example, the amount of swell for soils M2, M3 and M4 were 5, 6.8 and 8.6% when hydrated with Leachate 1; 5, 5.6 and 10% for leachate 2; 3.4, 5 and 8.5% in leachate 3. Similar to the effect of MSW leachate on the hydraulic conductivity of lateritic soils reported by Osinubi *et al*. (2012), the free swell values of samples were negligible and appeared to exhibit an inversely relationship with the ionic strength.

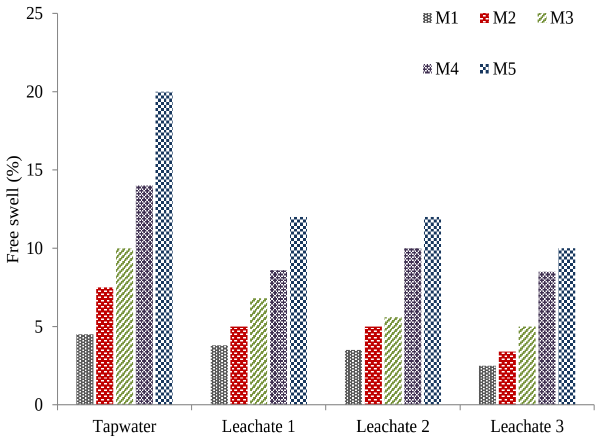

Fig. 6. Free swell at 48 hours for specimens hydrated with tap water and three leachate samples

The results also agree with the outcome of many research works reported in the literature for clays and bentonitic clays (Osinubi *et al*., 2012; Amadi and Odedede, 2019).

The thickness of the double layer i.e., the immobile water layer and absorbed ions formed by dissolved cations and water molecules attracted to the surface of a clay particle is significantly related to the swelling capacity of the soil. When water comes in contact with a soil mineral, the double layer becomes thick by attracting the water molecules to the clay particles, then the soil swells. However, when leachate or any other electrolyte solution comes in contact with soil, the double layer shrinks, becomes thin and the swelling capacity of the soil deteriorates.

The amount of swelling is also known to be dependent on the clay mineralogy of the soil (Sivapullaiah *et al*., 1987; Nagaraj *et al*., 2010; Moataz *et al*., 2019; Abbey *et al*., 2020). Fig. 7 shows the relationship between free swell for specimens hydrated with tap water and plasticity index (PI) of specimens. A proportional relationship between free swell and plasticity index is observed with coefficient of determination r^2 of 72%.

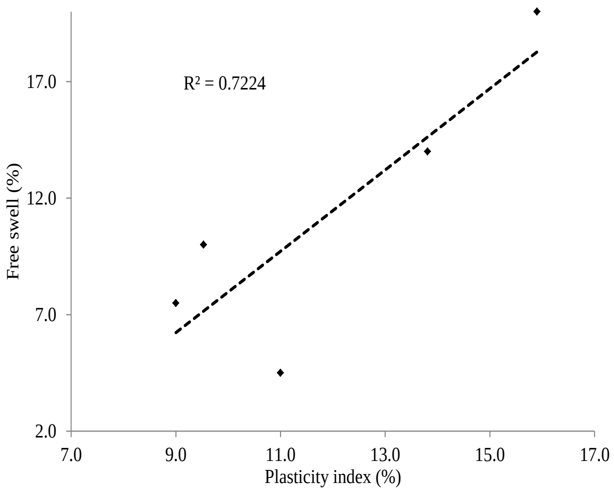

Fig. 7. Relation between the free swell at 48 hours for specimens hydrated with tap water and plasticity index (PI) of specimens

4 CONCLUSION

This paper presents results of a laboratory investigation aimed at evaluating the influence of municipal solid waste (MSW) leachate on free swell potential of lateritic soils. The selected lateritic soils labeled soil M1, M2, M3, M4 and M5 were tested for characterization. Free swell tests were conducted with tap water and three MSW leachate samples designated as Leachates 1, 2 and 3 collected from landfills in Minna. The results of Atterberg's limit tests together with that of particle size distribution allowed the classification of soil M1, M2, M3, M4 and M5 samples respectively in the A-2-7, A-4, A-5, A-6 and A-7-5 subgroups of American Association of State Highway and Transportation Officials (AASHTO) classification scheme. The results of consistency tests indicate that; the liquid limit of samples ranged from 31.5 – 43%, the plastic limit from 17.69 – 32.47%, the plasticity index from 9 – 15% while the maximum dry density varied from 1.6 – 1.8g/cm^3 with corresponding optimum moisture content of between 15 – 24%.

While substantial free swell capacity was observed in soil M4 and M5, others namely M1, M2 and M3 showed negligible swelling potential irrespective of the hydrating liquid.

REFERENCES

Abbey, S.J.; Eyo, E.U. and Ng'ambi, S. (2020). Swell and microstructural characteristics of high-plasticity clay blended with cement. *Bull Eng Geol Environ* 79, 2119–2130. https://doi.org/10.1007/s10064-019-01621-z

Ahmed, A.H.; Hassan, A.M. and Lotfi, H.A. (2020). Stabilization of Expansive Sub-grade Soil Using Hydrated Lime and Dolomitic-Limestone By-Product (DLP). *Geotech Geol Eng* 38, 1605–1617. https://doi.org/10.1007/s10706-019-01115-5

Al-Rawas, A. A. and Goosen, M. F. A. (2006). Expansive Soils: Recent Advances in Characterization and Treatment. Taylor and Francis, New York, 526.

Amadi, A. A. (2009). Free Swell as a compatibility test for lateritic soil-bentonite mixtures as landfill liner materials. *Nigerian Society of Engineers* (*NSE*) *Technical Transaction*, Vol. 42, No. 2, 31 - 44.

Amadi, A. A. (2013). Swelling Characteristics of Lateritic Soil – Bentonite Mixtures Subjected to Municipal Waste Leachate Contamination. *Journal of Environmental Earth Sciences*, Springer-Verlag Berlin Heidelberg, Vol. 70, No. 6, 2437 – 2442. doi:10.1007/s12665-013-2286-2.

Amadi, A. A. and A. O. Gbadebo (2014). Analysis of Swelling Behaviour of Lateritic Soil Treated with bentonite. *Nigeria Journal of Engineering and Applied Sciences*, Vol. 1, 1, 55 – 61.

Amadi, A. A. and Osinubi, K. J. (2018). Transport Parameters of Lead (Pb) Ions Migrating Through Saturated Lateritic soil – Bentonite Column. *International Journal of Geotechnical Engineering*. Taylor and Francis Publishers, UK. Vol. 12, Issue 3, 302 – 308. http`s://doi.org/10.1080/19386362.2016.1277620

Amadi A. A. and Odedede, O. (2019). Attenuation of Contaminants in Landfill Leachate by Lateritic Soil Enhanced with Bentonite. Geomechanics and Geoengineering: An International Journal, Taylor and Francis Publishers, UK. https://doi.org/10.1080/17486025.2019.1670872

BS 1377 (1990). Methods of testing soil for Civil Engineering Purposes. British standards Institute London.

Gidigasu M.D. (1976). Laterite Soil Engineering, Elsevier Scientific Publishing Co. New York.

Malik, V. and Priyadarshee, A. (2018). Compaction and swelling behavior of black cotton soil mixed with different non-cementitious materials, International Journal of Geotechnical Engineering, 12:4, 413-419, DOI: 10.1080/19386362.2017.1288355

Makusidi, M. A. (2019). Durability Characteristics of Lateritic Soil Treated with Iron Ore Tailings and Lime for Pavement Construction in Areas Exposed to Severe Moisture Fluctuation Unpublished M.Eng. Thesis submitted to the Department of Civil Engineering, Federal University of Technology, Minna.

Marschalko, M.; Yilmaz, I.; Fojtová, L.; Karel, K.; Bouchal, T. and Bednárik, M. (2013). Influence of the Soil Genesis on Physical and Mechanical Properties. TheScientificWorldJournal. 2013. 454710. 10.1155/2013/454710.

Moataz, A. Al-Obaydi; Ibrahim, M. Al-Kiki and Abdulrahman, H. Aldaood (2019). Effect of swelling on the shear strength behaviour of expansive soil, International Journal of Geotechnical Engineering, DOI: 10.1080/19386362.2019.1651043

Nagaraj, H.; Munnas, M. and Sridharan, A. (2010). Swelling behavior of expansive soils, International Journal of Geotechnical Engineering, 4:1, 99-110, DOI: 10.3328/IJGE.2010.04.01.99-110

Ola S.A. (1983). Geotechnical Properties and Behavior of some Nigerian Lateritic soils. In: Tropical Soils of Nigeria in Engineering Practice, A. Ola (Ed.), Balkema, Rotterdam.

Osinubi, K. J. and Nwaiwu, C. O. (2006). Design of Compacted Lateritic Soil Liners and Covers. J. Geotech. and Geoenviron. Eng., Vol. 132, Issue 2, 203 – 213. https://doi.org/10.1061/(ASCE)1090-0241(2006)132:2(203)

Osinubi, K. J.; Eberemu, A. O. and Amadi, A. A. (2012). Compatibility of compacted lateritic soil – bagasse ash mixtures with municipal solid waste leachate. *International Journal of Environment and Waste Management, Vol. 10, No. 4, 365 – 376.* Inderscience Publishers Enterprises Ltd, United Kingdom. ISSN 1478-9876. doi: 10.1504/IJEWM.2012.049841.

Salihu, U. (2017). Effect of Cement Type on Strength Properties of Lateritic Soil. Unpublished M.Eng. Thesis submitted to the Department of Civil Engineering, Federal University of Technology, Minna.

Sivapullaiah, P. Sitharam, T. and Subba Rao, K. (1987). Modified Free Swell Index for Clays," *Geotechnical Testing Journal* 10, no. 2: 80-85. https://doi.org/10.1520/GTJ10936J

Yilmaz, I. (2009). Swell potential and shear strength estimation of clays. *Applied Clay Science*, Vol. 46, No. 4, 376-384. https://doi.org/10.1016/j.clay.2009.09.011