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REVIEW PAPER

HYDRAULIC CONDUCTIVITY AND VOLUMETRIC SHRINKAGE PROPERTIES REVIEW ON GRADATION EFFECT OF COMPACTED LATERITE SOIL LINER

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Abstract: This paper reviews the effects of gradation on hydraulic conductivity and volumetric shrinkage properties of compacted laterite soil liner. The distribution of different grain sizes affects the engineering properties of soil such as compressibility, swelling and shrinkage, shear strength, and hydraulic conductivity. It is observed that there are dissimilarities of values in laterite soils from various researches around tropical countries of the world in terms of hydraulic conductivity and volumetric shrinkage. Hydraulic conductivity varies from 4.36×10^{-3} m/s to 4.7×10^{-11} m/s and volumetric shrinkage of $\leq$ 4%relative to fine contents ranging from 1.3% to 69% and coarse contents ranging from 31% to 98.7%.Generally, there is no clear trend established for effects of gradation on hydraulic conductivity and volumetric shrinkage properties of compacted laterite soil liners. This is because laterite soils with less than 50% fines content might not be used as liner or hydraulic barriers because their hydraulic conductivities are less than the minimum requirement of 1×10^{-9} m/s. At times researchers usually left out volumetric shrinkage in their study, but field studies have shown that desiccation can induce severe cracking of unprotected soil barriers. When fine grained soils lose moisture they tend to shrink, which result to cracking that can adversely affect the engineering properties and performance of the soils. The adversative influence includes reduced strength of the cracked soils and increased hydraulic conductivity. It is expected that with logical understanding of the effects of gradation on hydraulic conductivity and volumetric shrinkage properties of compacted laterite soil it will serve as a guide in the design of hydraulic barriers for engineered sanitary landfills in tropical countries around the world.

Keywords: *Gradation, hydraulic conductivity, laterite, liner, volumetric shrinkage*

1.0 Introduction

Municipal, non-hazardous and hazardous wastes have become a major concern in all aspects of urban development. Their generation gradually increased despite all waste minimisation efforts, and therefore its management gets tougher subsequently by years. In general, waste will eventually be exposed to soil no matter what disposal or containment measures are taken. Thus, an understanding of soil-waste interaction is important so that geotechnical and geoenvironmental structures could be constructed safely and reliably (Taha *et al.*, 2004). Establishment of good sanitary landfill system would help us to achieve an objective of a clean and healthy society in which we live in. Also, the criteria for this sanitary landfill design would be heading towards a cost-effective design making use of readily available materials in the final chosen site of the project or locally generated materials. This would help in creating more economical sanitary landfill construction (Oluwapelumi, 2015).

Landfills are the final repositories for unwanted or unusable wastes (Daniel, 2012). In most undeveloped countries and some developing countries, nearly all wastes are discarded in open, unengineered dumps as shown in Figure 1. Sometimes wastes are often burn to conserve space. A sanitary landfill consists of a refuse disposal area in which the waste is disposed of in cells that range in thickness. Not all sanitary landfills have liners. The sanitary landfill represented a dramatic improvement over the open dumping because of controlled placement of waste in sanitary landfills greatly reduced the number of rodents and insects, dramatically reduced public health risks, and generally contributed to major aesthetic improvements in waste disposal (Daniel, 2012). However, engineered sanitary landfills have all the aforementioned qualities and also have liners to contain the migration of leachate from the wastes against groundwater contamination in a manner that is protective of human health and the environment. Municipal solid waste landfill with liner system is shown in Figure 2.

Landfill liners provide an economical and environmentally safe disposal of municipal solid waste. The primary purpose of liner system for waste containment facility is to prevent or minimize infiltration of leachate through the hydraulic barrier. Liners provide the final line of defence against groundwater contamination. A liner serves as a hydraulic barrier to flow of fluids. Liners for waste containment may be classified into three (Daniel, 2012):

- Geosynthetic clay liners.
- Composite liners.
- Soil liners.

Soil liners can be divided into naturally occurring clay liners and compacted clay liners. Natural clay liners are naturally occurring formations of low hydraulic conductivity clay rich soils. They normally contain significant amounts of clay minerals. Compacted clay liners are constructed primarily from naturally occurring soil materials containing significant quantity of clay obtained from borrow pits. Other processed materials used in constructing compacted clay liners include bentonite-soil blends, pozzolanic fly ash, etc. Compacted soil liners have been used for many years as engineered hydraulic barriers for waste containment facilities. In recent years, improved understandings of how compacted soil liners should be constructed and tested are evolving.

Demand of common landfill liner materials will significantly increase due to construction of larger capacity landfills sites. When demand is more than supply, the cost of the material will certainly rise. With regard to this, it is clear that provision of material for liner construction is becoming less economical, because these materials are composed of clayey or mixed (with Bentonite) soils due to their low hydraulic conductivity (Daniel, 2012). In addition, these materials may not be locally available and may have to be imported from somewhere else, and could significantly increase the cost of construction. Therefore, it is very essential to search for local materials available for the construction of compacted soil liners. For a project to be viable, the materials to be used should be relatively abundant. Thus, laterite soil which is commonly available is investigated. Likewise, much of the current practices in conventional geotechnical engineering have relied mainly on experience with soils from temperate regions.

However, laterite soils are different in various characteristics that lead to differences in general properties and behaviour compared to non-laterite soils. This research explores the effects of gradation on hydraulic conductivity and shear strength properties of compacted laterite soil to be used in the design of engineered sanitary landfill liner.

Figure 1: Open Dump Landfill

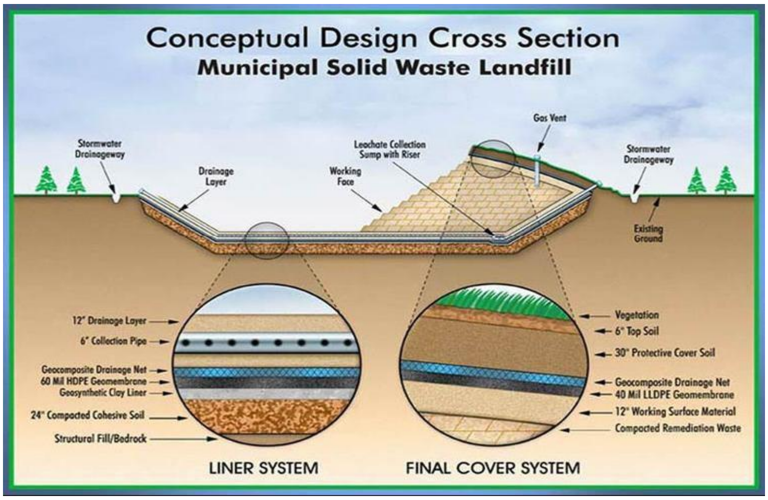

Figure 2: Engineered Sanitary Landfill

2.0 Laterite Soils

Laterite soils are different in general properties and behaviour from temperate regions soils. A laterite soil is a residual of rock decay that is reddish in colour and has a high content of iron and aluminum oxides, and low proportion of silica. These soils are pedogenic materials, the formation of which requires conditions of temperature and rainfall that characterize the humid tropical and subtropical zones of the world (Gidigasu, 2012). A laterite is a soil whose ratio of iron to aluminum oxides is less than 1.33, whereas a lateritic soil has a ratio between 1.33 and 2.00 (Bawa, 1957).

Laterites occur in six main regions of the world which are Africa, Australasia, Central and South America, India, Southeast Asia. Lateritic materials constitute the major surfacial deposit of engineering materials in many parts of tropical regions (Osinubi and Nwaiwu, 2006). Lateritic soils are residually formed from a variety of parent rocks. All laterite soils possess a permanent feature of high content of iron, aluminum, or titanium oxides in relation to other constituents (Gidigasu, 2012). They are formed under weathering systems productive of the process of laterization, the important characteristics of which is the decomposition of ferro-alumino silicate minerals and the permanent deposition of sesquioxides within the profile to form the horizon of material known as laterite (Gidigasu, 2012). They occur mostly as the toppings of soil and therefore provide excellent borrow spaces for wide use in several construction activities.
According to Mustapha and Alhassan (2012), the geotechnical characteristics and field performance of laterites are influenced considerably by their pedogenesis, degree of weathering, morphological characteristics, chemical and mineral compositions as well as prevailing environmental conditions. They categorized lateritic weathering profile derived from granite basement into three major horizons below the humus stained top

soil: (i) the sesquioxide rich lateritic horizon with sometimes gravelly or hardened in-situ as crust, (ii) the mottled zone with evidence of enrichment of sesquioxide sand and (iii) the pallid or leached zone which overlies the parent rock and contain rocks suffering from chemical and mineralogical changes, but retaining their physical appearance.

For instance, Malaysia has a wide variety of soils. These soils have been mapped on mountainous, hilly, rolling, undulating, level and swampy terrain. They occur at high and at low altitudes. Both shallow moderately deep and deep soils have been recognized and mapped. Some of these soils are organic in origin while most of them are made-up of mineral soil materials. These soils can be well drained or poorly drained or can even be under water for long periods of time. Malaysian soils have a variety of colours ranging from blue, to white, from yellow to brown and to red. They can be sandy in texture without any clay or have a range of clay contents giving rise to sandy loam, sandy clay loam, sandy clay and clay textures. These soils can be developed over a range of parent materials. Shallow lateritic soils and their associated soils occupy 0.6 million hectares in Peninsular Malaysia (Paramananthan, 2012).

3.0 Gradation of Compacted Laterite Soil Meant for Liner

3.1 Percentage Fines

The traditional selection and performance criteria for assessing the technical suitability of materials meant for hydraulic barriers in waste disposal facilities are low hydraulic conductivity, adequate shear strength and low volumetric shrinkage (Bello, 2015, Mosesl *et al*., 2013, Osinubi and Nwaiwu, 2006, Daniel and Wu, 1993). These criteria in most regulatory agencies (guidelines) and researches specified a minimum of 20% fines with respect to gradation. A minimum of 200 kN/m^2 shear strength, maximum hydraulic conductivity of 1×10^{-9} m/s and less than or equal to 4% volumetric shrinkage are required for hydraulic barrier systems. But these guidelines seem to be different from laterite soil with respect to the gradation of 20% fines content. From this review, it was found that laterite soils with less than 50% fines content cannot be used as liner or hydraulic barriers because their hydraulic conductivities are less than the minimum requirement of 1×10^{-9} m/s. The Percentage grain sizes of compacted laterite soil from various researchers around some tropical countries are presented in Table 1. Other researchers like (Bello, 2015, Osinubi *et al*., 2015, Osinubi and Nwaiwu, 2006) also investigate the geotechnical properties of laterite soil as liner material.

In the following, the effects of gradation on hydraulic conductivity and volumetric shrinkage properties of compacted laterite soil for engineered sanitary landfill liner are compared with those from studies in the literatures and discussed.

Table 1: Percentage grain sizes of compacted laterite soil

Author	*Gravel (%)*	*Sand (%)*	*Fines (%)*	*Hydraulic Conductivity (m/s)*	*Volumetric Shrinkage (%)*	*Country*
(Prakash and Poulose, 2016)	0	60.9	39.1	9.19×10^{-7}	-	India
(Ab Aziz *et al*., 2015)	0.88	77.48	21.64	4.69×10^{-6}	-	Malaysia
(Adeyemi *et al*., 2015)	3	32	65	4.75×10^{-9}	-	Nigeria
(Omoniyi *et al*., 2014)	0	54	46	2.06×10^{-8}	-	Nigeria
(Amadi and Eberemu, 2013)	31	12	57	7.91×10^{-9}	< 4	Nigeria
(Mustapha and Alhassan, 2012)	-	63	37	4.36×10^{-3}	-	Nigeria
(Sree *et al*., 2010)	16.8	81.9	1.3	2.06×10^{-7}	-	India
(Frempong and Yanful, 2008)	0	33	67	4.7×10^{-11}	< 4	Ghana
(Eberemu, 2008)	2.98	40.31	56.71	3.93×10^{-10}	< 4	Nigeria
(Taha and Kabir, 2004)	0	34	66	1.9×10^{-10}	< 4	Malaysia
(Yangsheng LIU; BAI Qingzhong, 2004)	0	76	24	1.0×10^{-7}	-	China
(de Brito Galvão *et al*., 2004)	0	31	69	1.3×10^{-9}	-	Brazil

3.2 Hydraulic Conductivity

Hydraulic conductivity which refers to the degree of ease with which a fluid can flow through a material should have a maximum value of 1×10^{-9} m/s for engineered sanitary landfill liners (MHLG, 2005, USEPA, 1991). Hydraulic conductivity is the major factor affecting the performance of hydraulic barriers (Daniel, 2012). Soils with high permeability are considered undesirable for landfills. The infiltration of water through this soil is high and the possibility of groundwater pollution may increase. To protect the groundwater, it is preferable that the soil content is clayey that has very low permeability (Ahmad *et al*., 2014).

A few numbers of experimental studies dealing with the gradation effects on hydraulic conductivity of laterite soil are available in the literatures. Studies by numerous investigators (Benson *et al*., 1994, Benson and Trast, 1995, Afolayan *et al*., 2005) indicate that hydraulic conductivity of compacted natural soils depend on soil composition such as particle size distribution, soil structure as determined by moulding water content and compactive effort, among other factors. Moreover, current recommendations for construction quality control of soil liners suggest that soft data (plasticity index, clay content, gravel content, water content, and dry unit weight) be used as the primary means to control construction. Trial sections or test pads should be used prior to construction to verify that construction methods to be used yield acceptably low hydraulic conductivity at field scale (Daniel and Benson, 1990). The particle-size distribution of compacted clay affects hydraulic conductivity because the size of voids conducting flow is affected by the relative proportions of large and small particle sizes. Low hydraulic conductivity is likely to be achieved when the soil is well graded and the clay fraction governs the hydraulic behaviour of the matrix (Daniel and Benson, 1990). The fines in a soil have a higher impermeabilizing effect if they are well distributed so they can most effectively plug voids among the larger particles. Mechanical mixing distributes fines and breaks down some of the soil aggregates thereby supplying fines for void-plugging and destroying large voids (Benson and Trast, 1995).

Bello (2013) presents the effect of particle size distribution on hydraulic conductivity of three compacted reddish brown tropical soils from Nigeria. The hydraulic conductivities for specimens with fines content of 66.4% were more sensitive to moulding water content for all compactive efforts than the remaining specimens with lower fine contents. According to (Benson and Trast, 1995), grading modulus can be used to explain the changes observed. The grading modulus captures the fines to medium sand fraction of the soils which contribute to changes in hydraulic conductivity especially on the wet side of the optimum water content. However, hydraulic conductivities of all the specimens at energy level of Reduced Proctor compaction effort are generally higher than 1×10^{-7} cm/s. By this, it can be understood that compaction of reddish brown tropical soils in the field using compaction energies equivalent to that of the Reduced Proctor will produce unacceptable hydraulic conductivity values for liners. Compaction of soil samples at the energy of Standard Proctor used on his study gave hydraulic conductivity values that were lower than 1×10^{-7} cm/s.

Osinubi and Nwaiwu (2005) describe research on three lateritic soil samples with differences in fines contents that ranged from 64 to 72%. The values of hydraulic conductivity for the soils decreased with higher molding water contents and compactive efforts. Soil sample specimens with the lowest grading modulus value of 0.45 had hydraulic conductivity values that were less than 1 × 10^{-9} m/s than did specimens of soil samples with higher grading modulus, at molding water contents ranging from 12.5 to 22.5%.

Adeyemi *et al*. (2015) performed a study on a well graded lateritic soil. The lateritic soils contained 60% – 65% fines, 2% - 3% gravel and 31% to 38% sand. Coefficient of permeability was observed to reduce with higher compaction energy. This may be attributed to the reduction in the pores as compaction energy increases, and this removes or reduces the large pores through which fluid flows. The soils can be classified as practically impermeable soils based on the permeability values (Adeyemi *et al*., 2015). From this review, it was found that laterite soils with less than 50% fines content might not be used as liner or hydraulic barriers because their hydraulic conductivities are less than the minimum requirement of 1 × 10-9 m/s (see Table1). Therefore, laterite soil can only be used when it contains a minimum of 50% fines, because that is when it satisfies the criteria or guideline of liner design. But this contradicts the minimum 20% fines content specifies by researchers and agencies. Hence, an investigation into the gradation aspect of tropical laterite soil is paramount in the design of liners or hydraulic barriers for sanitary landfills.

3.3 Volumetric Shrinkage

In geoenvironmental practice, volumetric shrinkage of geomaterials for the construction of liners and covers is limited to 4% based on the outcome of researches which established that it required more than 4% volumetric shrinkage strain to cause significant cracking in mineral liners (Daniel and Wu, 1993). Thus, to ensure good control over the quality of compacted soils as well as compliance with the requirement of ≤ 4% normally specified by most regulatory agencies for desiccation shrinkage, ranges of water contents within which the compacted soil will exhibit specification requirements of volumetric shrinkage ≤ 4% must be determined.

Field studies have also shown that compacted clay barriers in earthen covers undergo seasonal variations in water content, even at significant depth, due to seasonal variations in precipitation and evapotranspiration (Osinubi and Bello, 2009). Field studies have also shown that desiccation can induce severe cracking of unprotected clay barriers (Daniel and Wu, 1993, Sims *et al*., 1996, Day, 1997, Stewart *et al.*, 1999). When fine grained soils lose moisture they tend to shrink, which result to cracking that can adversely affect the engineering properties and performance of the soils. The adversative influence includes reduced strength of the cracked soils and increased hydraulic conductivity. Taha and Taha, 2011 (Taha and Taha, 2011) explained that when there is an increase in soil density, there is a decrease in the volume of the voids in the soil, and this comes with an attendant reduction in volume shrinkage, which in turn causes a decrease in cracks in the soil. A study by Albrecht and Benson, 2001 (Albrecht and Benson, 2001) showed that the volumetric shrinkage occurring in compacted natural clays during desiccation is a direct function of the volume of water to volume of soil when saturated. This soils with higher clay content and higher plasticity index generally are more prone to large volumetric shrinkage during drying. Amadi, 2012 (Amadi, 2012) describes that often, part or the entire barrier systems in landfill facilities are constructed exclusively with fine grained soils such as residual lateritic soil. Long term integrity of such barrier systems is however a critical issue especially in tropical latitudes due to variations in climatic and environmental conditions associated with wetting and drying. These variations often cause severe volume change leading to the formation of vertical and horizontal cracks and eventual failure associated with increased hydraulic conductivity resulting from pathways created for moisture migration. Fine grained soils possess larger surface areas than coarse grained soils and exhibit dramatically different engineering properties when compacted. Notably, such soils require higher moisture content for compaction purposes that consequently lead to higher drying shrinkage.

Although soil samples having high fines contents are known to yield low hydraulic conductivity values. Care has to be taken so as to ensure lateritic soils with fines content greater than 70% are not used as liners or as covers in particular. This is because of the tendency of a lateritic soil with high fines content to undergo high volumetric shrinkage (Osinubi and Nwaiwu, 2006). Lateritic soils have relatively high free iron oxide. The free iron oxide contained in lateritic soils have the tendency to coat clay, silt, and sand particles to form larger soil particle sizes when desiccation has taken place, and this may lead to cracking and the attendant high hydraulic conductivities (Osinubi and Nwaiwu, 2006).

A study on compacted fine grained lateritic soils by Osinubi and Nwaiwu (Osinubi and Nwaiwu, 2008) showed that volumetric shrinkage strains for these soils are sensitive to variations in compaction water content, compactive effort, dry unit weight as well as to initial degree of saturation. They found that the variations in compaction water content and soil composition have significant influences on volumetric shrinkage as indicated by the two-way analyses of variance.

Sand and silt particles reduce total shrinkage because they decrease the volume of water held by the clay soil (Daniel and Wu, 1993). The use of clayey sands for liners and covers has been encouraged as they combine the attributes of low hydraulic conductivity and low compressibility to minimize the amount of shrinkage that takes place upon drying. It is pertinent to note that shrinkage cracks can occur locally when the capillary pressures exceed the cohesion or the tensile strength of the soil (Daniel and Wu, 1993). Cracks cause rapid infiltration of water and other fluids into the soils and for impermeable soils such as compacted clayey soils, hydraulic conductivity is increased. It has been shown that desiccation cracks formed in a hydraulic barrier soil resulted in preferential flow paths thus increasing the overall hydraulic conductivity of the soil. Induced volumetric shrinkage problem can be addressed by one of the measures outlined in the use of soils that are rich in sand that combine the attributes of low hydraulic conductivity and low desiccation upon drying (Drumm, 1997). The amount of volumetric shrinkage depends on the structure and strength of the soil.

From this review, it was found that laterite soils with coarse contents ranging from 33% to 43.29% can be used as liner or hydraulic barriers because of their low potential for desiccation cracks that give volumetric shrinkage of less than 4% (Table 1) (Amadi and Eberemu, 2013, Frempong and Yanful, 2008, Eberemu, 2008, Taha and Kabir, 2004). This is in line with Daniel and Wu (Daniel and Wu, 1993) which explains that it is likely to compact clayey sand to a low hydraulic conductivity and concurrently gets a compacted soil with negligible potential to shrink and crack when desiccated.

4.0 Conclusions

There is no information in published literature on the minimum percentage of fines required to be adopted in the design of compacted laterite soils as landfill liners and covers in waste containment applications. Likewise, clear trend has not been established for effects of gradation on compacted laterite soil. Therefore, there is need to find soil indices that better describe the effect of particle size and grading characteristics of these soil. With abundance of laterite soil in the tropics, it is expected that with an adequate understanding of gradation effects it will become very useful material for hydraulic barriers in waste containment facilities.

References

Ab Aziz, N. N. S. N., Mukri, M., Hashim, S. & Khalid, N. 2015. Influence of Compaction Effort for Laterite Soil Mix With Geopolymer in Designing Soil Liner. *EJGE,* 20**,** 12353-12364.

Adeyemi, G. O., Afolagboye, L. O. & Chinwenwa Chukwuemeka, A. 2015. Geotechnical properties of non-crystalline coastal plain sand derived lateritic soils from Ogua, Niger Delta, Nigeria. *African Journal of Science, Technology, Innovation and Development,* 7**,** 230-235.

Afolayan, J. O., Nwaiwu, C. M. O. & Osinubi, K. J. 2005. Comparative reliability evaluation of lateritic soils as hydraulic barriers. *Geotechnical and Geological Engineering,* 23**,** 561-581.

Ahmad, S. Z., Ahamad, M. S. & Yusoff, M. S. 2014. Spatial effect of new municipal solid waste landfill siting using different guidelines. *Waste Manag Res,* 32**,** 24-33.

Albrecht, B. A. & Benson, C. H. 2001. Effect of desiccation on compacted natural clays. *Journal of Geotechnical and Geoenvironmental Engineering,* 127**,** 67-75.

Amadi, A. & Eberemu, A. 2013. Characterization of geotechnical properties of lateritic soil-bentonite mixtures relevant to their use as barrier in engineered waste landfills. *Nigerian J Technol,* 32**,** 93-100.

Amadi, A. A. 2012. Improvement of Barrier Soil Properties with Fly Ash to Minimize Desiccation Shrinkage. *International Journal of Engineering Research in Africa,* 7**,** 1-11.

Bawa, K. S. 1957. Laterite Soils and Their Engineering Characteristics, 1957. *Journal of Soil Mechanics and Foundation Division, ASCE, 83, 1 – 15.*

Bello, A. 2015. Acceptable Zone for Reddish Brown Tropical Soil as Liner Material. *The Pacific Journal of Science and Technology,* 16.

Bello, A. A. 2013. Hydraulic conductivity of three compacted reddish brown tropical soils. *KSCE Journal of Civil Engineering,* 17**,** 939-948.

Benson, C. H. & Trast, J. M. 1995. Hydraulic conductivity of thirteen compacted clays. *Clays and clay minerals,* 43**,** 669-681.

Benson, C. H., Zhai, H. & Wang, X. 1994. Estimating hydraulic conductivity of compacted clay liners. *Journal of Geotechnical Engineering,* 120**,** 366-387.

Daniel, D. E. 2012. *Geotechnical practice for waste disposal*, Springer Science & Business Media.

Daniel, D. E. & BENSON, C. H. 1990. Water content-density criteria for compacted soil liners. *Journal of Geotechnical Engineering,* 116**,** 1811-1830.

Daniel, D. E. & Wu, Y.-K. 1993. Compacted clay liners and covers for arid sites. *Journal of Geotechnical Engineering,* 119**,** 223-237.

Day, R. W. 1997. Discussion of "Hydraulic Conductivity of Desiccated Geosynthetic Clay Liners" by Tom Boardman and David E. Daniel. *Journal of Geotechnical and Geoenvironmental Engineering,* 123**,** 484-486.

De Brito Galvão, T. C., Elsharief, A. & Simões, G. F. 2004. Effects of lime on permeability and compressibility of two tropical residual soils. *Journal of environmental engineering,* 130**,** 881-885.

Drumm, E. C., Boles, D. R. And Wilson, G. V. 1997. Desiccation cracks result in preferential flow. *Geotechnical News,* 15**,** 22-25.

Eberemu, O. A. 2008. *Evaluation of bagasse ash treated lateritic soil as a suitable material for waste landfill barrier (liner and cover).* PhD, Ahmadu Bello University, Zaria, Nigeria.

Frempong, E. M. & Yanful, E. K. 2008. Interactions between three tropical soils and municipal solid waste landfill leachate. *Journal of geotechnical and geoenvironmental engineering,* 134**,** 379-396.

Gidigasu, M. 2012. *Laterite soil engineering: pedogenesis and engineering principles*, Elsevier.

MHLG 2005. Ministry of Housing and Local Government, Criteria for Siting Sanitary Landfills: National Strategic Plan for Solid Waste Management, Vol. 3, Appendix 6B, Kuala Lumpur, Malaysia.

Mosesl, G., Oriola, F. & Afolayan, J. 2013. The impact of compactive effort on the long term hydraulic conductivity of compacted foundry sand treated with bagasse ash and permeated with municipal solid waste landfill leachate. *Front. Geotech. Eng,* 2**,** 7-15.

Mustapha, A. & Alhassan, M. 2012. Chemical, Physico-chemical and Geotechnical Properties of Lateritic Weathering Profile Derived from Granite Basement. *Electronic Journal of Geotechnical Engineering (EJGE),* 17**,** 1885-1894.

OluwapeLUMI, O. O. 2015. Geotechnical Characterization of some Clayey Soils for Use as Landfill Liner. *Journal of Applied Sciences and Environmental Management,* 19**,** 211-217.

Omoniyi, I. O., Olufemi, O. & Abdulwahid, A. K. 2014. Geotechnical and Mineralogical Evaluation of Some Lateritic Soils from Southwestern Nigeria. *EJGE*, Vol. 19.

Osinubi, K. J. & Bello, A. A. 2009. Desiccation-induced shrinkage in compacted abandoned dumpsite soil. researchgate.net/publication/282325487: researchgate publication.

Osinubi, K. J., Moses, G., Oriola, F. O. P. & Liman, A. S. 2015. Influence of Molding Water Content on Shear Strength Characteristic of Compacted Cement Kiln Dust Treated Lateritic Soils for Liners and Covers. *Nigerian Journal of Technology,* 34**,** 266.

Osinubi, K. J. & Nwaiwu, C. M. 2005. Hydraulic conductivity of compacted lateritic soil. *Journal of geotechnical and geoenvironmental engineering,* 131**,** 1034-1041.

Osinubi, K. J. & Nwaiwu, C. M. 2006. Design of compacted lateritic soil liners and covers. *Journal of geotechnical and geoenvironmental engineering,* 132**,** 203-213.

Osinubi, K. J. & Nwaiwu, C. M. O. 2008. Desiccation-induced Shrinkage in Compacted Lateritic Soils. *Geotechnical and Geological Engineering,* 26**,** 603-611.

ParamananthaN, S. 2012. Keys to the identification of Malaysian soils using parent materials, 2rd Edn Param Agricultural Soil Surveys (M) Sdn. *BHD Malaysia***,** 2-20.

Prakash, A. & Poulose, E. 2016. Kuttanad Clay Amended Laterite as a Landfill Liner for Waste Disposal Facilities. *International Journal of Scientific Engineering and Research (IJSER),* 4 75-78.

Sims, J. E., Elsworth, D. & Cherry, J. A. 1996. Stress-dependent flow through fractured clay till: A laboratory study. *Canadian geotechnical journal,* 33**,** 449-457.

Sree, D., Ajitha, A. & Evangeline, Y. S. 2010. Study on Amended Soil Liner Using Lateritic Soil. *Indian Geotechnical Conference – 2010, GEOtrendz, December 16–18, 2010. IGS Mumbai Chapter & IIT Bombay.*

Stewart, D., Cousens, T., Studds, P. & Tay, Y. 1999. Design parameters for bentonite-enhanced sand as a landfill liner. *Proceedings of the Institution of Civil Engineers-Geotechnical Engineering,* 137**,** 189-195.

Taha, M. R., Ahmad, K., Aziz, A. A., Chik, Z., Huat, B., Sew, G. & Ali, F. 2004. Geoenvironmental aspects of tropical residual soils. *Tropical residual soils engineering***,** 213-229.

Taha, M. R. & Kabir, M. H. 2004. Tropical residual soil as compacted soil liners. *Environmental Geology,* 47**,** 375-381.

Taha, O. M. E. & Taha, M. R. 2011. Cracks in soils related to desiccation and treatment. *Australian Journal of Basic and Applied Sciences,* 5**,** 1080-1089.

USEPA 1991. Design and construction of RCRA/CERCLA final covers. *Soils Used in Cover Systems, EPA/625/4-91/025. United States Environmental Protection Agency*.

Yangsheng L.; Bai Qingzhong, N. Y. 2004. Properties of bentonite enhanced loess and laterite. *Chinese J. Chem. Eng.,* 12**,** 37-41.