2^{nd}International Civil Engineering Conference (ICEC2020)
Department of Civil Engineering
Federal University of Technology, Minna, Nigeria

Changes in Hydraulic Conductivity of Compacted Lateritic Soil in Response to Ceramic Dust Treatment

Garba, S.; Amadi, A. A. & Adejumo, T. W. E.
Department of Civil Engineering Federal University of Technology, Minna
Email: garba.saidu@yahoo.com

ABSTRACT
This study investigates the potential of using up to 12% ceramic dust (CD) to improve the hydraulic conductivity of compacted lateritic soil for landfill liner application. To achieve this objective, the following tests; natural moisture content, Atterberg limits, specific gravity and sieve analysis, compaction as well as hydraulic conductivity tests were conducted, compaction test was carried out using three energy levels namely: British Standard Light (BSL), West African Standard (WAS)i.e. "Intermediate effort" and British Standard Heavy (BSH) efforts. Hydraulic conductivity tests were carried out under dry of optimum, optimum and wet of optimum compaction conditions. The results obtained shows that the soil is classified according to American Association of State Highway and Transport Officials (AASHTO) as A-2-6 and OL by Unified Soil Classification System (USCS).Test results indicate that liquid limit (LL) ranged from 54.0 to 54.2%, Plastic limit (PL) from33.18 to 41.89% and Plasticity index (PI) from 2.31% to 20.82% for CD content adopted in this study. The compaction test results shows that MDD is in the range of 1.29kg/cm^{3}to 1.67kg/cm^3, with corresponding OMC which decreased from 24 to 16%.The hydraulic conductivity result decreased from 1.49 x 10^{-8}m/s to 8.143x10^{-10} m/s for CD content of 0 – 6%. Clay liners in landfills are expected to have a hydraulic conductivity of1x10^{-9} m/sec. or less. Consequently, only mixture with 6% treatment corresponding to 1.67kg/cm^3 MDD met the requirement (i.e. ≤1 x 10^{-9} m/s)for construction of liner and cover systems for MSW containment.

Keywords: *Atterberg limit, Ceramic Dust, Compaction energy, Distilled water, Hydraulic conductivity, Unconfined Compression strength.*

1.0 INTRODUCTION

Waste management has been one of the greatest challenge facing the Federal, State and Local governments in Nigeria. It comprises of wastes of different characteristics including industrial, chemical, biological, bio-medicals, E-waste, e.t.c. Hoornweg and Bhada, (2012). Many of them have the presence of heavy metals like chromium, nickel, zinc, lead, cadmium etc which pose danger to human health. (Raghab *et al.* 2013). More than 250MT of wastes are found disposed of in many dump sites in Nigeria. In Minna, like other cities in Nigeria open dumping is the most practiced method of municipal solid waste (MSW) disposal (Ahsan *et al.* 2014), most open pits are located near residential quarters and therefore pose a threat to public health and the environment. In addition the leachates generated from the dump sites are released into the geo-environment which contaminate the ground water. According to USEPA (1988) contamination of groundwater by municipal solid waste (MSW) leachate renders the groundwater to be unusable for domestic purposes. Similarly, world Health Organization (WHO) stated that a long-term exposure to the contaminated environment can affect 1/4th of the total population exposed to it adversely, (Keldsen *et al.* (2002). In addition, the methane gas generated at such dump sites as a result of bacterial degradation of waste is not properly disposed off and therefore poses a potential fire hazard.

To maintain the ecological environment and to contain the generated leachate as well as to prevent the contamination of ground water, it is necessary to construct engineered landfills, whose main components are a barrier called liner, and a cover. Other components include leachate collection systems, leachate treatment, gas collection, gas treatment, air and water monitoring systems (Benson and Trast, 1995).

Hydraulic conductivity tests are often conducted on the soil barrier material intended for containment of wastes using liquid with representative properties of the leachate to be contained (Lee *et al;* 2005). The hydraulic conductivity determines the ability of leachate to flow through compacted soil matrix system under hydraulic gradient. Borgadi *et al.* (1993) stated that hydraulic conductivity is considered as the basic parameter for the design of hydraulic barrier systems and for characterizing liner performance and reliability. The primary function of a clay liner is to prevent the release of contaminants from the landfill into underlying aquifer, hence the hydraulic conductivity of clay liner should be low to prevent advective transport (Cho *et al.* 2002). Hence the engineering specifications for a compacted clay liner usually consist of a hydraulic conductivity of ≤ $1x10^{-9}$ m/s or less (Daniel and benson 1990; Benson *et al.* 1994; Mollins *et al*. 1996; Umar *et al*., 2015). Recently, compacted soil liners are frequently used in conjunction with geomembranes to form a composite liner, which usually consists of a geomembrane placed directly on the surface of a compacted soil liner. Shackelford *et al.* (2000) evaluated the hydraulic conductivity of geosynthetic clay liners (GCLs) permeated with non-standard liquids. They found that the hydraulic performance of GCLs depends to a large extent on the hydraulic conductivity of the bentonite. Daniel and koerner (1993), showed that bentonite clay materials are the preferred hydraulic barriers because of their low hydraulic conductivity and good adsorption or retention capacity. Application of clay-bentonite mixtures and GCLs may however, become very expensive because of the high cost of synthetic liners (Cokca and Yilmaz 2004). According to Yeheyis et al.(2010), reuse of industrial waste products and by-products, such as ceramic dust, can be a viable alternative for barrier construction which will translate to adequate utilization of lateritic soil as well as an important step towards sustainability and economy.

In the laterization processes, sesquioxides of iron and aluminum are absorbed onto the surfaces of the clayey constituents through the interaction of the positively charged sesquioxides and the negatively charged clay particles. The sesquioxides cause a physical cementation of fine particles into coarser aggregations resulting in a granular structure Townsendet al. (1971). The consequences of these processes on the engineering characteristics of lateritic soils include low plasticity, high permeability, low swelling potential etc. Therefore, the relative high hydraulic conductivity of laterite soil resulting from mineralogy makes it not suitable for the construction of landfill liners alone.

Ceramic wastes are generated as waste during the process of dressing and polishing of ceramic tiles. It is estimated that 15 to 30% wastes are produced of total raw material used. The disposal of this ceramic waste creates soil, water and air pollution Bidula and Akshaya, (2013). The potential of this ceramic dust to reduce the hydraulic conductivity and improve its sorption capacity when blended with lateritic soils in land fill liner application.

This paper therefore, reports the results of hydraulic conductivity test conducted on specimens of lateritic soil stabilized with ceramic dust. The specimens were prepared and tested for hydraulic conductivity in the laboratory under controlled conditions.

2.0 MATERIALS AND METHODS

Soil: The soil used in this study is a natural red-dish brown lateritic soil collected in Minna, Nigeria while, waste ceramic dust was obtain from a fresh dump in West African Ceramic Company, Ajaokuta, Kogi State, Nigeria.

2.1 **Materials Preparation and Methodology**:

The soil was air dried and pulverized sufficiently to run through the BS No. 4 (4.76 mm aperture) sieve for compaction and permeability tests and BS 4.25μm sieve for Atterberg limit tests. For samples containing ceramic dust, the relevant quantities of dry soil and ceramic dust (0, 3, 6, 9, and 12%) by dry weight of soil were mixed.

The following experiments were performed: particle size distribution; moisture content test; Atterberg's limit tests; compaction test and permeability test in accordance with B.S. 1377: 2003

2.2 Hydraulic conductivity test

The hydraulic conductivity of compacted mixtures were evaluated using the rigid wall permeameter under falling head condition after soaking for 24 hours in accordance with procedures outlined in BS 1377 (2003). Processed soil mixtures were compacted at the following moisture condition: wet of optimum, optimum and dry of optimum for BSH BSL and WAS compaction effort. The permeant liquid was tap water and permeation was terminated after a steady flow was established (i.e., when there was no statistically significant trend in hydraulic conductivity over time in agreement with (Lee,et. al.2005) as well as (Osinubi and Amadi, 2008)

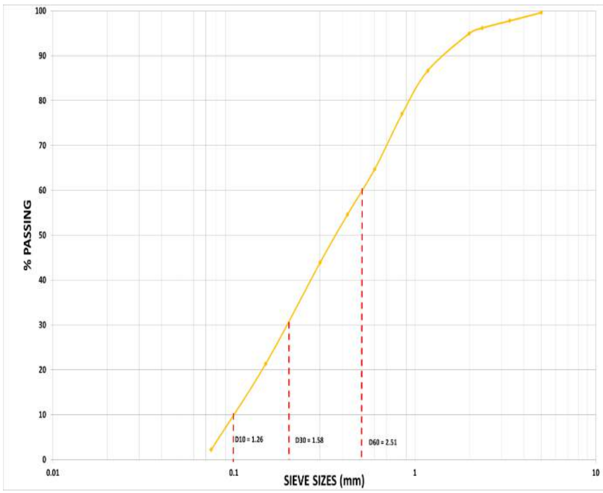

Figure 1: Particle Size Distribution Curve of Lateritic Soil.

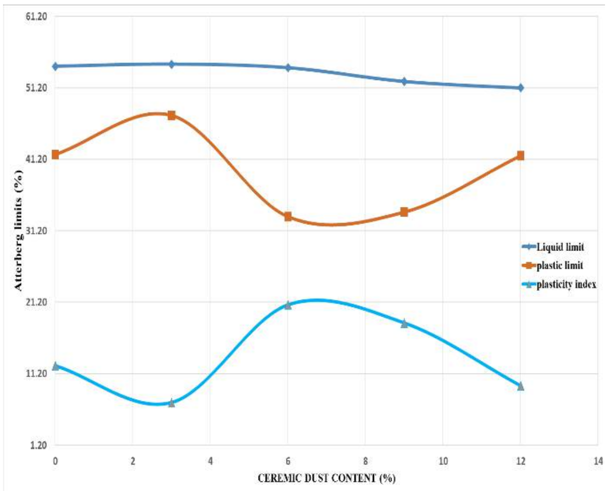

Fig. 2: Variation of Atterberg limits with ceramic dust content

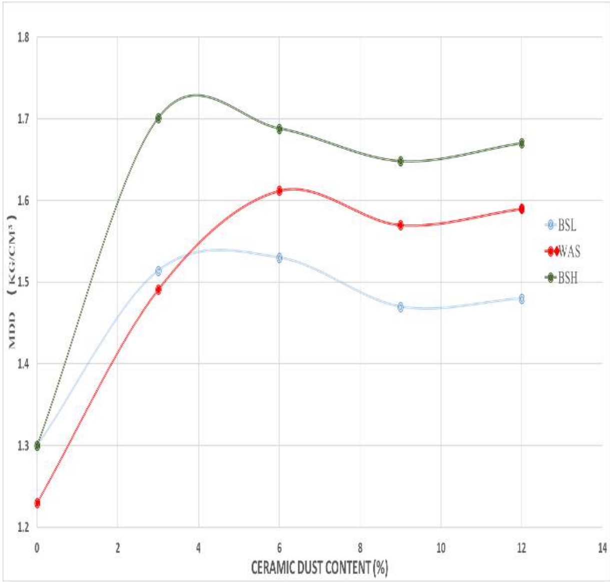

Fig. 3: Variation of MDD with ceramic dust content for BSL, WAS, BSH)

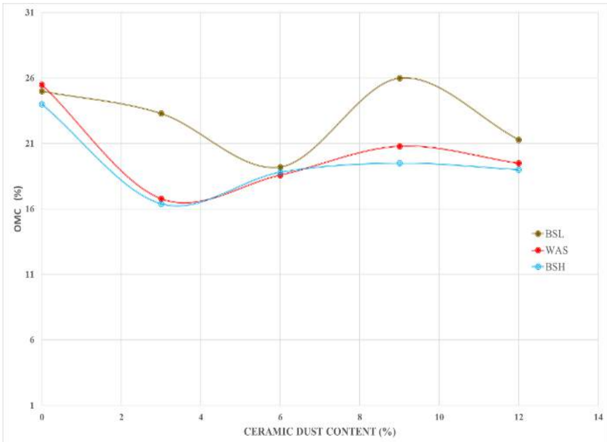

Fig. 4 Variation of OMC with ceramic dust content for BSL, WAS, BSH effort

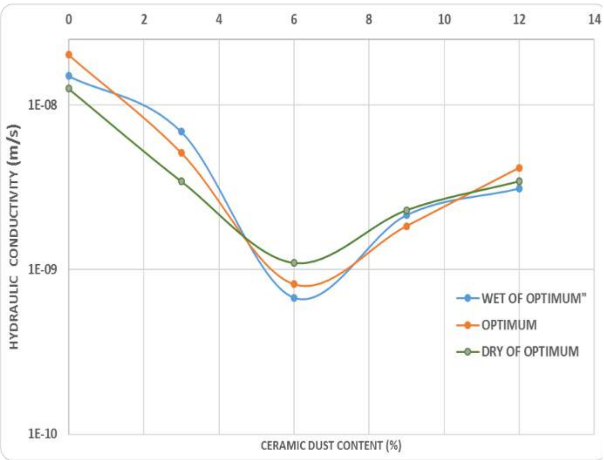

Fig. 5 Variation of hydraulic conductivity with ceramic dust content for BSH at the various compaction conditions

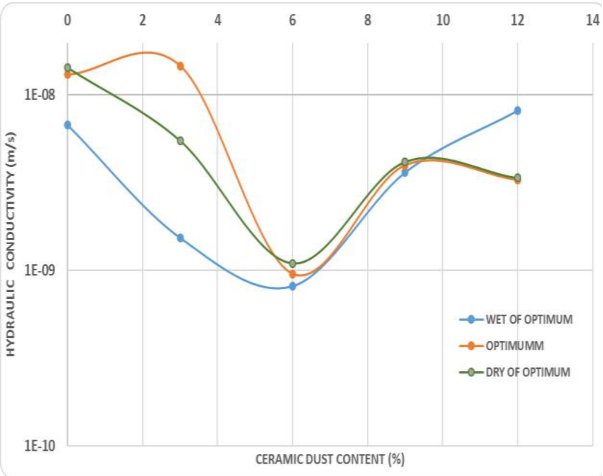

Fig. 6 Variation of hydraulic conductivity with ceramic dust content for BSL at the various compaction conditions

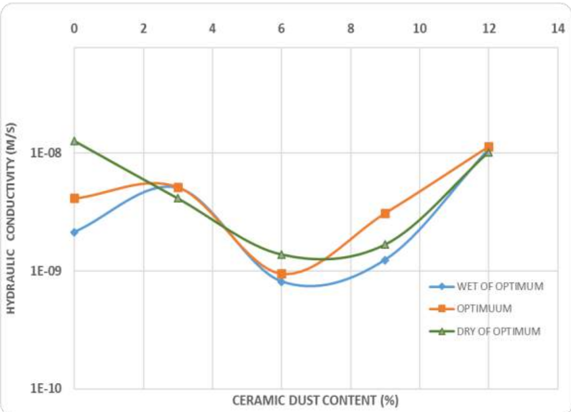

Fig. 7 Variation of hydraulic conductivity with ceramic dust content for WAS at the various compaction conditions

TABLE 1. PHYSICAL PROPERTIES OF THE SOIL

Property	Quantity
Percentage Passing BS No. 200 Sieve	2.2
Natural Moisture Content, %	29.35
Liquid Limit, %	54.2
Plasticity Index, %	12.31
Specific gravity	1.84
AASHTO Classification	A-2- 6
USCS	OL,ML

TABLE 2. OXIDE COMPOSITION OF LATERITIC SOIL DETERMINED BY X-RAY DIFFRACTION (XRD) COMPOUND ANALYSER

Property	Concentration (%)
Al2O3	24.8839
SiO2	54.3376
K2O	0.2574
CaO	0.946
MnO	0.0313
Fe2O3	2.9354
SO_3	0.0331
P_2O_5	-8493.4751
Cl	-15104.6417 Kcps
MgO	9.342 Kcps
NaO_2	1.0697 Kcps

TABLE 3. OXIDE COMPOSITION OF CERAMIC DUST (CD) DETERMINED BY X-RAY DIFFRACTION (XRD) COMPOUND ANALYSER

Property	Concentration (%)
SiO_2	68.15
Al_2O_3	17.39
Fe_2O_3	1.59
CaO	0.70
MgO	0.81
MnO	0.02
P_2O_5	-8365.40
K_2O	1.31

Na_2O	1.51
SO_3	0.06
	Total 100

TABLE 4. MINERALOGY COMPOSITION OF CERAMIC DUST (CD) DETERMINED BY X-RAY DIFFRACTION (XRD) MINERALOGY ANALYSER

Minerals Materials	**Chemical Compound**	**Concentration (%)**
White Clay		4.24
Black Clay		25.35
Kaolin Clay	$Al_2Si_2O_5(OH)$	30.37
Red Feldspar	$K(Al,Si)_4O_8$	20.59
White Feldspar	$NaAlSi_3O_8$	14.03
Talc	$Mg_3Si_4O_{10}(OH)_2$	2.84
Limestone	$CaCO_3$	0.93
Reddish brown clay		1.66

3.0 RESULTS AND DISCUSSION

3.1. Characterization of study soil mixtures

Particle size distribution curve (Fig. 1) showed that the soil comprised of about 54.64% sand fraction (0.063-2mm), and 2.2% fines content (percentage passing no. 200 sieve). Also from the Fig. 1 it was observed that coefficient of curvature is 1.99 while coefficient of uniformity is 0.79. The plasticity Index (PI) of the ceramic dust is relatively higher (i.e. 14.7%) than that of lateritic soil and has a high swelling potential. The soil-ceramic dust mixtures demonstrated slight decrease in liquid limit (LL) from 54.2 to 54.0%, and substantial increase in plasticity index (PI) from 12.31% to 20.82% at a range of 0 – 6% CD treatment. (Fig. 2). Higher liquid limit and plasticity index are associated with soils having a greater quantity of clay particles (Grim and Guven, 1978) which in turn manipulates the hydraulic conductivity. The physical Properties of lateritic Soil are tabulated in Table 1, oxide composition of lateritic soil are listed in Table 2 while oxide composition and Mineralogy composition of ceramic dust (CD) are tabulated in Table 3 and 4 respectively.

3.2 Compaction characteristics

The variation of dry density with ceramic dust content for the various soil mixtures (0, 3, 6, 9 and 12% ceramic dust content) is reported in Fig. 3.From the figure it shows that the addition of ceramic dust resulted in increase in maximum dry density up to 4% and decreased at 12% ceramic dust content thereafter, similar trend was observed for all compaction effort. The maximum dry density for BSH effort increases from 1.30kg/cm^3 to 1.66kg/cm^3 for 0-6% treatment, thereafter, it reduced, reaching 1.64kg/cm^3 at 12% treatment. In the case WAS the maximum dry density increased from 1.22kg/cm^3 to 1.61kg/cm^3 for 0-6% stabilization and decreased to 1.58 kg/cm^3 at 12% treatment. While for BSL the maximum density increases from 1.19kg/cm^3 to 1.53kg/cm^3 for 0-6% modification and then decreased to 1.43kg/cm^3 at 12% treatment. Similarly, the variation of optimum moisture content with ceramic dust content presented in (Fig. 4) indicate that for BSL, the OMC decreased from 25.0% to 19.2% for 0 to 6% treatment and further increased to 21.3% at 12% treatment, for WAS the OMC decreases from 25.5% to 18.6% for 0 to 6% stabilization and further increased to 19.5% at 12% CD content, while for BSH the OMC decreased from 24.0% to 18.8% for 0 to 6% modification and further increased to 19.0% at 12% CD content. This was due to the increase in fines content because of inclusion of ceramic dust with larger surface area that required more water to react. It could also be due to the demand for water required for the hydration of the CD in the mixture. (Kumar, and Sharma 2004)

3.3 Variation of hydraulic conductivity with ceramic dust content

The variation of hydraulic conductivity with ceramic dust content for BSH, BSL and WAS compaction energies are shown in Figs.5, 6 and 7 respectively. The hydraulic conductivity of compacted samples decreased with increase in ceramic dust contents up to 6% treatment and thereafter increased for the three compaction energy methods at wet of optimum, optimum, and dry of optimum conditions. Specifically, for BSH compaction effort at wet of optimum condition, the hydraulic conductivity reached values as low as 6.75X10^{-10} m/s at 20.8% OMC, while BSL effort yielded 8.14X10-^{10}m/s at 21.2% OMC and WAS achieved 8.14X10^{-10} m/s at 20.6% OMC. Similarly for optimum condition, the hydraulic conductivity values for BSH, BSL and WAS, are 8.14x10^{-10}, 9.55 x10^{-10} and 9.55 x10^{-10} at 6% treatment respectively, and for dry of optimum condition, the hydraulic conductivity values for BSH, BSL and WAS, are 1.09 x10^{-9}, 1.09 x10^{-9} and 1.39 x10^{-9} at 6% treatment respectively. Largely, the recorded values for the three energies levels at 6% stabilization for optimum and wet of optimum conditions met the general specification of 1.0X10^{-9} m/sec. or less required for performance in waste repositories (USEPA 1994; CGRM, 2007; Amadi and Eberemu, 2013). The reduction in hydraulic conductivity was observed due to the potential of ceramic dust to fill the voids in the matrix of lateritic soil. This is consistent with the findings of Yeheyis *et. al* (2010). Generally, soils compacted at water contents less than optimum tend to have a relatively high hydraulic conductivity while soils compacted at water contents greater than optimum tend to have low hydraulic conductivity (USEPA, 1989).

2.0 CONCLUSION

Hydraulic conductivity test was conducted to evaluate suitability of lateritic soil-ceramic dust mixtures as barrier material in waste repositories. Analysis of preliminary data obtained from the study indicates that the Atterberg limits (liquid limit, plastic limit and plasticity index), compaction properties of the natural soil were substantially enhanced by the introduction of ceramic dust. Expectedly, soil mixtures developed higher Atterberg limits, but exhibited lowest hydraulic conductivities at 6% treatment. The recorded k values for optimum and wet of optimum conditions for the three energies levels at 6% stabilization met the general specification i.e., 1.0X10^{-9} m/sec. or less required in the selection of barrier material in waste repositories (USEPA, 1994; CGRM, 2007; Amadi and Eberemu, 2012).

In view of the preliminary nature of this study, more work is therefore required especially on the long term hydraulic conductivity.

REFERENCES

AASHTO (1986), Standard Specifications for Transportation Materials and Methods of Sampling and Testing, 14th Edition, *American Association of State Highway and Transportation Officials, Washington, D.C.*

Ahsen, A, M., Alamgir, M. M. EL-Sergary, S., Shams, M. K., Rowshon, and NNNK Dauud (2014) Assessment of municipal solid waste management system in adevelopingcomtry" *chines journal of Engineering* Article ID 56935,

Amadi, A. A. and Eberemu, A. O. (2012) Delineation of compaction criteria for acceptable hydraulic conductivity of lateritic soil-bentonite mixtures designed as landfill liners. *Journal of Environmental Earth Sciences, Vol. 67, No.4 pp 999{1006..*

Amadi, A. A. and Osinubi, K. J. (*2008*) Laboratory measurement of hydraulic conductivity of compacted lateritic soil treated with bentonite for geotechnical structures. *Proc. of Bimonthly Meeting/Workshop Material Society of Nigeria (MSN), Zaria Chapter, Jan. { Dec., , pp. 43{51.*

Amadi, A.A.andEberemu, A.O. (2013) Characterization of Geotechnical Properties of Lateritic Soil Bentonite Mixtures Relevant to their use as Barrier in Engineered Waste Landfills *Nigerian Journal of Technology (NIJOTECH) Vol. 32, No. 1, 93{100. ISSN 1115-8443*

Benson, C. H.;Zhai, H. and Wang, (*1994)* X. Estimating hydraulic conductivity of compacted clay liners. *J. GeotechEngrg ASCE, Vol. 120, No. 2, pp 366387.*

Benson, C.H. &Trast, J.M. (1995), Hydraulic Conductivity of Thirteen Compacted Clays. *Clay and Clay Minerals,Vol 43(6), 669-681.*

Bidula B. and Akshaya K. S. (2013) "Improvement in Geotechnical Properties of an Expansive Soil using Fly Ash - Quarry Dust Mixes", *Electronic Journal of Geotechnical Engineering, Vol. 18, 3487- 3500.*

Borgadi, I; Kelly, W.E. & Wang, X. (1993), Reliability Model for Soil Liners, *Journal of Geotechnical and Geoenvironmental Engineering, ASCE, **115**(5), 658-669.*

BS 1377 (1990), Methods of Testing Soils for Civil Engineering Purposes, *British Standard Institution, London. 2003*

CGRM,Canadian Government Report, Manitoba,(2007)Technical Reference Document for Liquid Manure Storage Structures*,"Compacted Clay Liners", February,.*

Cho, W. J., Lee, J. O.& Kang, C. H. (2002).Hydraulic Conductivity of Compacted Soil-Bentonite Mixture for a Liner Material in Landfill Facilities, *Env. Eng. Res., Korean Society of Civil Engineers, 7(3), 121-127.*

Cokca, E. and Yilmaz, Z. (2004). Use of Rubber and Bentonite added Fly Ash as liner material, *Waste Management, 24(2), 153-164.*

Daniel D. E., and koerner R. M., (1993) Quality assurance and quality control for waste containment facility, Risk reduction Engineering Laboratory, USEPA Retrieved from *htt:/nepis.epa.gov/adobe/PDF/30002Z07pdf*

Daniel, D.E. & Benson, C.H. (1990), "Water-Content Density Criteria for Compacted Soil Liners", *Journal of Geotechnical Engineering, ASCE,* ***116*** *(12), 1811-1830.*

Grim, R. and Guven, N.(1978)Bentonite: Geology, Mineralogy, Properties and Uses. *Elsevier Science Publishing, N.Y.*

Hoornwag D., and Bhada ., (2012) what a waste: a global revie o solid waste management *No. 15 www.worldbank.org/Urban*

Kjeldsen P., Berlarz, M. A., Rooker A. P., Beun A., Ledin A., and Christensen T. H., (2002): Present and long-term composition of MSW leachate: *A review, critical Review in Environmental Science and Technology 32 (), (297-336)*

Lee, J-M., Shackelford, C.D., Benson, C.H., Jo, H-Y.&Edil, T.B. (2005), Correlating Index Properties and Hydraulic Conductivity of Geosynthetic Clay Liners *Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 131(11), 1319-1329.*

Mollins, L.H;Stewart D.I. &Cousens, T.W. (1996). *Predicting the Properties of Bentonite Sand Mixtures, Clay Minerals, 31, 243-252.*

Raghab S. M., Abd EL Meguid A. M., and Hegazi A. A., (2013): Treatment of leachate from municipal solid waste landfill *HBRC jurnal 9 (2), 1877-192*

Shackelford, C.D; Benson, C.H; Katsumi, T;Edil, T.B. & Lin, L. (2000). Evaluating the Hydraulic Conductivity of GCLs *Permeated with Non-standard Liquids Geotextiles and Geomembranes, Elsevier Science Ltd, 18, 133-161.*

Townsend, F. C., Manke, G. P. and Parcher, J. V. (1971) The Inuence of Sesquioxides Laterite Soils Properties. *Highway Research Records No. 374, HighwayResearch Board, Washington DC, USA.*

Umar, S. Y.; A. U.Elinwa, A. U and Matawal, D. S(2015) Hydraulic Conductivity of Compacted Lateritic Soil partially replaced with Metakaolin *Journal of Environment and Earth Science www.iiste.org ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) Vol.5, No.4, 5*3–64

USEPA (1988), Criteria for Municipal Solid Waste Landfills, *United States Environmental Protection Agency, Washington D.C.*

USEPA (1989), Requirements for Hazardous Waste Landfills, Design, Construction and Closure, Publication*No.EPA-125/4-89. 022. EPA, Cincinnati.*

USEPA US Environmental Protection Agency: (1994) from *http/nepsi.epa.gov/sitesproduction/files/2016-06documents/wqs-handbook-1994.df&ved=2ahukEwjq"mhkrsAhxiAzmBHbcDHMQfjABegQiCRAH&USg=AvVaw1HZWthYYt_PBgp6rOuVGLr.*

Yeheyis, M.B., Shang, J.Q. &Yanful, E.K. (2010)."Feasibility of Using Coal Fly Ash for Mine Waste Containment*".Journal of Environmental Engineering, ASCE, 136 (7), 682- 690.*

Kumar BRP, Sharma RS (2004) Effect of flyash on engineering properties of expansive soils. *J Geotech Geoenviron ASCE130(7):764–767*