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Hydraulic Conductivity of Compacted Lateritic Soil Partially Replaced with Metakaolin

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Abstract
The study investigates the potentials of using metakaolin (MK) to improve the properties of compacted lateritic soil for hydraulic barrier system for containment of municipal solid waste (MSW). Oxide compositions determined by the X-ray fluorescence (XRF) show that MK contains Silicon oxide, SiO_2 (53.4 %), Aluminium oxide Al_2O_3 (34.2 %), Titanium oxide, TiO_2 (5.97 %) and Iron oxide, Fe_2O_3 (3.84 %) in high proportion. The soil was replaced with 0 %, 5 %, 10 %, 15 % and 20 % MK and compacted using four compaction energy levels namely: the Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS) or "Intermediate" and British Standard Heavy (BSH) over a range of molding water contents (10 - 25 %). Unconfined compressive strength (UCS) and hydraulic conductivity tests were conducted and the results obtained were used to evaluate whether the lateritic soil partially replaced with MK conforms with the specifications for barrier systems for MSW containment. The results of this study show a general improvement in UCS of the soil specimens with increase in the percentage replacement of MK. Results of the study also show that hydraulic conductivity values of the specimens permeated with leachate are better than the results of hydraulic conductivities obtained when de-ionized water (DIW) was used as the permeant fluid. The specimens replaced with 5-20 % MK and compacted using the BSH compaction energy yielded hydraulic conductivities on the orders of 6.3 x 10^{-10} m/s to 2.2 x 10^{-10} m/s when DIW was used as the permeant fluid. On the other hand, the specimens compacted using the WAS and BSH compaction energies and permeated with leachate yielded hydraulic conductivity values in ranging from 6.8 x 10^{-10} m/s to 3.6 x 10^{-11} m/s. These hydraulic conductivity values met the regulatory maximum hydraulic conductivity (i.e. < 1 x 10^{-9} m/s) for construction of liner and cover systems for MSW containment.
Keywords: Compaction energy, Metakaolin, Hydraulic conductivity, Unconfined compressive strength, Municipal solid waste leachate, De-ionized water

1. Introduction

In Nigeria, solid waste management is characterized by insufficient collection methods, insufficient coverage of collection systems and improper disposal (Ogwueleka 2009). Waste management has been one of the greatest challenges facing the Federal, State and Local governments in Nigeria. Municipal solid waste (MSW) containment is one of the most troublesome and most urgent problems facing the industrial community. According to (EPA 1988) contamination of groundwater by MSW leachate renders the groundwater and the area of contamination of aquifer unusable to domestic purposes. Hydraulic conductivity tests are often conducted on the soil barrier material intended for containment of MSW using the actual liquid to be contained or a liquid with representative properties (Lee *et al.* 2005). The hydraulic conductivity determines the ability of MSW 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 of the design of hydraulic barrier systems and for characterizing liner performance and reliability. Results of laboratory hydraulic conductivity tests on compacted specimens are often used to determine compaction criterion for each soil. Such a compaction criterion can, in turn, be used as a guide for suitable construction of soil liners and covers in the field (Nwaiwu *et al.* 2005).

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). The engineering specifications for a compacted clay liner usually consist of a hydraulic conductivity of < 1 x10^{-9} m/s (Daniel 1990; Benson *et al.* 1994a; Mollins *et al*. 1996; Umar *et al*. 2015). According to Benson and Trast (1995), most regulatory agencies in the United States require that the hydraulic conductivity of clay liners be ≤ 1 x 10^{-9} m/s. 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 that do not contain geomembrane depends on the hydraulic conductivity of the bentonite. Daniel (1993) showed that bentonite clay materials are the preferred hydraulic barriers because of their low hydraulic conductivity and good adsorption or retention capacity. Shackelford *et al.* (2000) indicate that the characteristically low hydraulic conductivities of (< 10^{-8} cm/s) often reported for bentonites are primarily due to restriction of the pore spaces effective in flow by adsorbed cations and water molecules associated with montmorillonite in the bentonite. 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), reusing of industrial waste products and by-products, such as coal fly ash, can be a viable alternative for barrier construction and an important step toward sustainability.

Several investigators have studied the use of materials such as foundry green sand, blast furnace slag, fly ash, tire waste, volcanic ash and bentonite as additives to clay soil for design and construction of liners and covers for municipal solid waste containment (Haug and Wong 1993; Freber 1996; Kraus *et al*. 1997; Kumar and Singh 2004; Olawuyi and Olusola 2010; Yeheyis *et al*. 2010; Amu *et al*. 2011; Kolovos *et-al*. 2013). In contrast, the beneficial use of MK in construction of landfill liners and covers has not been reported in published literature. Kolovos *et al.* (2013) studied the mechanical properties of soilcrete mixtures modified with metakaolin, having reported that in soilcrete samples with 50% w/w of modified binder, MK exhibits a pronounced pozzolanic reactivity leading to improved compressive strength, even though moderate influence on the compressive strength was observed in the case of soilcrete samples with 30 % w/w binder, where the dilution effect of the soil seemed to be prominent.

This paper discusses the results of hydraulic conductivity and unconfined compressive strength (UCS) tests conducted on specimens of lateritic soil partially replaced with MK. The specimens were prepared and tested for UCS and hydraulic conductivity in the laboratory under controlled conditions. Results of the UCS and hydraulic conductivity tests are used to evaluate the influence of compaction energies and the efficacy of MK as a material for use with lateritic soil in the construction of hydraulic barrier systems for containment of MSW.

2. Materials and Methodology

The soil used in this study is a natural occurring laterite and is reddish brown in colour. The soil sample was obtained from Bauchi, Bauchi State, Nigeria (latitude 10^o 18' N and longitude 9^o 49' E), at a depth of at least 500 mm below the ground level using the method of disturbed sampling. The particle size distribution test on the soil was conducted in accordance with specifications outlined in BS 1377 (1990). The physical properties and the X-ray fluorescence (XRF) results of the soil are summarized in Tables 1 and 2, respectively. Chemical analyses were carried out at the National Steel Raw Material Exploration Agency (NSRMEA), Kaduna using X-ray fluorescence (XRF), to determine the oxide composition of the soil and MK. As shown in Table 1, the soil was classified as A-6 using the American Association of State Highway Transportation Officials (AASHTO 1986) soil classification system and CL using the Unified Soil Classification System (ASTM, 1992). The liquid limit and plastic limit of the soil were 38 % and 16 %, respectively. The liquid limit and plastic limit of a type of soil can be correlated with various engineering properties, such as permeability, shrinkage and swelling behavior, shear strength and compressibility (Sharma and Lewis 1994; Abdullah *et al.* 1999). The gravel content of the soil (defined as soil fraction retained on sieve 4.76 mm sieve size) was 1.5 % which is less than 10 % recommended for soil liners by EPA (1988), the sand and clay contents were 33 % and 38 %, respectively. Sixty - two percent (62 %) of the soil passed the number 200 sieve and 28 % finer than 0.005 mm. Therefore, the soil is clayey sand and is ideal for compacted barrier systems for effective containment of MSW. Such soils have adequate plasticity to yield low hydraulic conductivity, and high percentage of sand to minimize volumetric shrinkage upon drying (Daniel 1993). As shown in Table 2, the lateritic soil consists majorly of Aluminium oxide (Al_2O_3), 12.5 %; Silicon oxide (S_iO_2), 44.7 %; Iron oxide (Fe_2O_3), 24.4 %; and Potassium oxide (K_2O), 8.08 %. Kaolin was obtained from Alkaleri, Alkaleri Local Government Area of Bauchi State and burnt at a temperature of 650^oc to obtain the metakaolin used in this study. This temperature is high enough to allow for loss of hydroxyls but below temperatures that cause the formation of a vitreous phase and crystallization of other phases such as mullite (Velosa et al. 2009). The MK has a moisture content of 0.18 %, specific gravity of 2.6, bulk density of 700 kg/m^3 and pH of 7.0. As shown in Table 3, MK consists majorly of S_iO_2, Al_2O_3, and Fe_2O_3 contributing 53.7 %, 34.2 %, 3.84 %, of the total. The next most abundant component is titanium oxide, T_iO_2 (5.97 %). According to ASTM standard specification (C 618 – 2012), the sum of S_iO_2, Al_2O_3, Fe_2O_3 be $\geq$ 70 % for any material to be used as a pozzolana.

Table 1. Physical properties of the soil

Percentage Passing BS No. 200 Sieve	62
Natural Moisture Content, %	5
Liquid Limit, %	38
Plastic Limit, %	22
Plasticity Index, %	16
Specific gravity	2.4
Linear Shrinkage, %	12
Gravel, (<4.76mm),%	1.5
Sand, (0.075 – 4.76mm), %	33
Fines, (<0.075mm),%	57
Clay, (<2µm),%	38
Plasticity Product	143
Color	Reddish Brown
AASHTO Classification	A- 6
USCS	CL

Table 2. Oxide composition of lateritic soil determined by X-ray fluorescence (XRF) spectroscopy

Property	**Concentration (%)**
Al_2O_3	12.5
S_iO_2	44.7
K_2O	8.1
CaO	2.3
T_iO_2	2.2
V_2O_3	0.1
MnO	0.2
Fe_2O_3	24.4
CuO	0.1
ZnO	0.1
Au_2O_3	3.6
BaO	1.0
UO_2	0.4
ReO	0.5
TOTAL	**100**

Table 3. Oxide composition of metakaolin (MK) determined by X-ray fluorescence (XRF) spectroscopy

Property	**Concentration %**
Al_2O_3	34.2
SiO2	53.7
K_2O	0.932
CaO	0.513
TiO2	5.97
V_2O_3	0.23
Cr_2O_3	0.057
MnO	0.061
Fe_2O_3	3.84
NiO	0.071
CuO	0.030
ZnO	0.009
Ga_2O_3	0.088
Total	**100**

2.1 Compaction Tests

In carrying out tests on compaction, the soil was air dried in the laboratory and pulverized to sizes small enough to pass through US Number 4 sieve (4.76 mm). The compaction tests were carried out in accordance with the procedure outlined in Head (1992). For the soil partially replaced with MK, five mixes were used and derived by replacing the soil in proportions of 0 % 5 %, 10 %, 15 % and 20 % MK by dry weight of the soil, respectively. The soil samples were prepared using seven molding water contents ranging from 10 to 25 % and compacted using four compaction energies, namely: Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). The characteristics of these compaction energies are shown in Table 4. The BSH and BSL compactions are the British standard (BS) equivalents of the modified and standard Proctor compaction (ASTM D 1557 and ASTM D 698), respectively. The WAS or " intermediate" compaction is the conventional energy level commonly used in this region and consists of the energy derived from a 4.5 kg rammer falling through 45.72cm onto five layers in a BS 1,000cm^3 capacity mould, each receiving 10 blows (Osinubi 1998a). The RBSL compaction is equivalent to the standard Proctor, but 15 blows are applied per layer instead of 25 (Daniel and Benson 1990). Three samples were prepared for each replacement level and the average taken. Sixty specimens of soil replaced with various proportions of MK were prepared and compacted using the four energy levels adopted in this study.

Table 4. Characterization of compaction energies

Compactive effort	Volume Of Mould (cm^3)	Weight of Rammer (kg)	Height Of Fall (cm)	Number of layers	Number of blows	Work done (Kj/m^3)
RBSL	1000	2.5	30.48	3	15	(331.088)[a]
BSL	1000	2.5	30.48	3	27	595.958
WAS	1000	4.5	45.75	5	10	(993.293)[b]
BSH	1000	4.5	45.72	5	27	2681.809

a RBSL: 331.088 kj/m^3 of compaction energy, or 55.56 % of ASTM D 698
b WAS: 993.293 kj/m^3 of compaction energy, or 166.67 % of ASTM D 698

2.2 Unconfined Compressive Strength (UCS)

The unconfined compressive strength (UCS) tests were conducted in accordance with BS 1377: part 7 (1990). Sample of the soil was crushed to sizes smaller than US Number 4 sieve (4.76 mm aperture), 3 kg of the soil was measured and five mixes were used at replacement levels of 0 %, 5 %, 10 %, 15 % and 20 % of MK by weight of soil. The soil samples were prepared using the OMCs derived from the moisture density relationship determined for the soil specimens (control) and for soil specimens replaced with various proportions of MK. After preparation of the test specimens, compaction was done using the four energy levels. After the compaction stage, three specimens of diameter 38 mm and length 76 mm were obtained and wrapped in polythene bags, labeled appropriately for ease of identification and cured for 7 days, 14 days and 28 days, respectively. Three tests were conducted for each replacement level of MK and the average of the results of the three tests was taken as the UCS.

2.3 Hydraulic Conductivity using De-ionized Water (DIW) and MSW Leachate as Permeant Fluids

The hydraulic conductivity or permeability tests were conducted using the falling head apparatus following the procedures in BS 1377 (1990) and Head (1992). The specimens were prepared using the OMCs derived from the moisture density relationship plots of the soil and soil replaced with various proportions of MK. The soil samples were prepared using the adjusted OMCs (i.e. 2 % on the wet side of optimum) and compacted using the RBSL, BSL, WAS and BSH compaction energies. EPA (1989) suggest that optimum water content can be increased by 2 % because soil compacted at water contents less than optimum tend to have a relatively high hydraulic conductivity and soils compacted at water contents greater than optimum tend to have low hydraulic conductivity and low strength.

In carrying out the hydraulic conductivity tests, the soil was air dried and pulverized to sizes small enough to pass US Number 4 sieve (4.76 mm). Five mixes were prepared at replacement levels of 0 %, 5 %, 10 %, 15 % and 20 % MK by weight of the soil and compacted using the four energy levels. The compacted soil specimens with the compaction mould for each replacement level of MK were first placed in plastic immersion tanks and de-ionized water (DIW) was gradually introduced such that the top of the compacted soils was covered with 5 cm of water. Placement of the compacted soil specimen and the mould in DIW was to prevent drying of the specimens from the lower open end of the mould. The set up was left to stand for 24 hours to achieve full saturation of the soil. After the immersion period, the DIW level in the immersion tank was reduced and the entire falling-head setup was assembled in preparation for permeation using DIW and MSW leachate as the permeant fluids, respectively. Permeation was terminated within 24 hours from the commencement of the test when the inflow approximately equal to the outflow. Equilibrium was established when there was no significant trend in the standpipe readings during testing. The geometric mean of the last three readings was computed and reported as the hydraulic conductivity for each specimen.

3. Results and Discussions

3.1 *Compaction Characteristics*

The moisture density relationships of the soil specimens compacted using the RBSL, BSL, WAS and BSH compaction energies are shown in Fig. 2. The compaction curves show that with a given compactive effort, a maximum density was achieved at certain water content (i.e. compacted density is a function of soil moisture content and compactive effort). In general, the trends of the compaction curves is one of increasing MDD values with corresponding decrease in OMC values with increase in the compaction energy. The result of this investigation are consistent with the findings of several investigators (Abichou *et al* 2000; Osinubi and Nwaiwu 2005; Umar 2014) indicating that MDD of compacted soils generally increase with increase in compactive effort. For example, Daniel, (1993) showed an increase in the dry density of soils from Texas with an increase in compaction energy. Similarly, Abichou *et al.* (2000) showed an increase in MDD with attendant decrease in OMC for soils compacted at the energy levels of modified Proctor, standard Proctor and reduced Proctor. Similar behaviors were also reported by a number of researchers (Daniel and Wu 1993; Daniel and Benson 1990; Mitchell et al. 1965; Osinubi and Nwaiwu 2005).

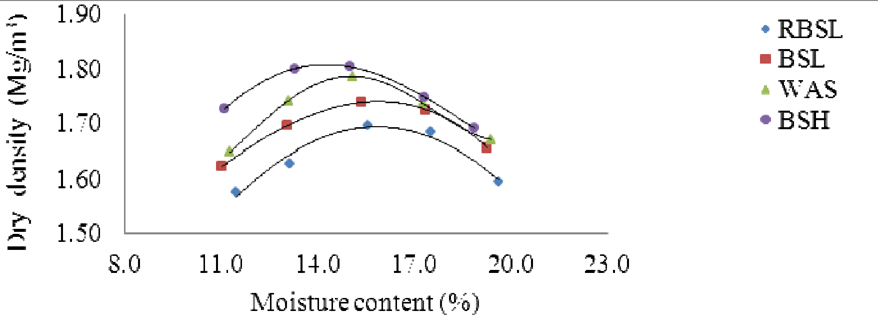

Fig. 2: Compaction curves for the lateritic soil

3.2 Effect of Compaction Condition on Dry Density and Water Content

The results obtained on the dry densities of the natural soil (control) and soil specimens replaced with MK, respectively, show that as the replacement levels are increasing the dry densities increases and the maximum achieved at 20 % MK replacement level for all the four compaction energies used in this study. These behaviors are illustrated in Figures 3-6 for compacted soil-MK specimens. The peak MDD value obtained for the soil specimens replaced with 0 %, 5 %, 10 %, 15 % and 20 % MK and compacted using the energy level of BSH was 1.96 Mg/m^3. In addition, as the replacement levels of MK are increasing the moisture content decreases, this was achieved at 20 % MK replacement level.

The lateritic soil specimens (i.e. control) gave low MDD and high OMC values when compared with the results obtained for soil specimens replaced with various proportions of MK. For the replacement levels of MK adopted in this study, specimens replaced with 20 % MK and compacted using the RBSL compaction energy gave MDD and OMC values of 1.82 Mg/m^3 and 13.6 %, respectively. For the BSL and WAS compaction, the MDDs were 1.86 Mg/m^3 and 1.91 Mg/m^3 while the corresponding OMCs are 13.0 % and 12.8 %, respectively**.** All the specimens replaced with 20 % MK yielded high MDD values with corresponding low OMC values irrespective of the compaction energy used in compacting the soil specimens.

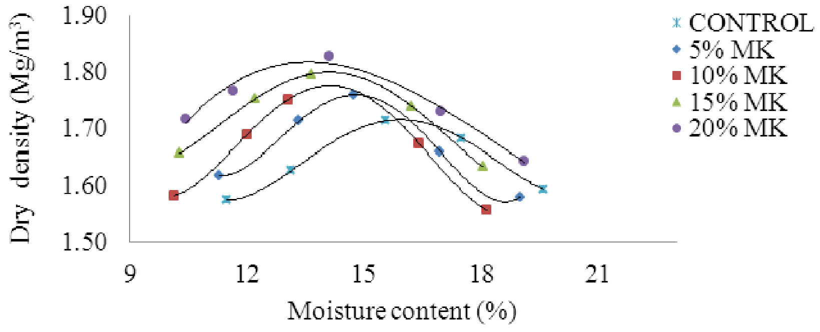

Fig. 3: RBSL compaction curves for specimens partially replaced with MK

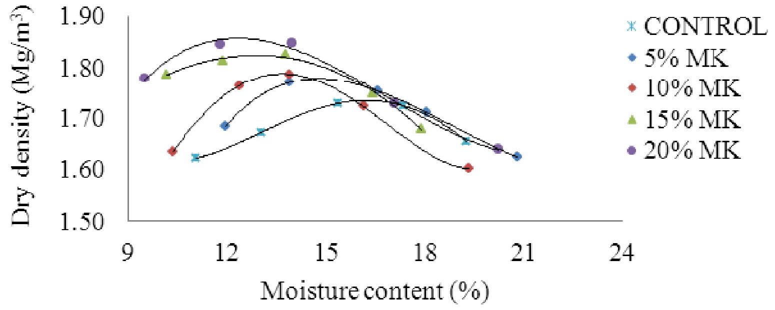

Fig. 4: BSL compaction curves for specimens partially replaced with MK

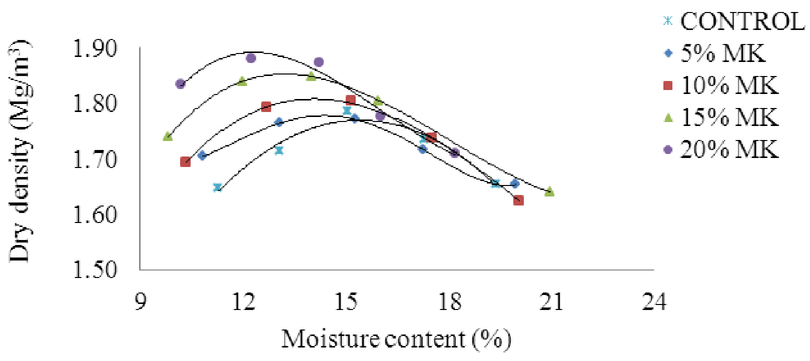

Fig. 5: WAS Compaction curves for lateritic soil partially replaced with MK

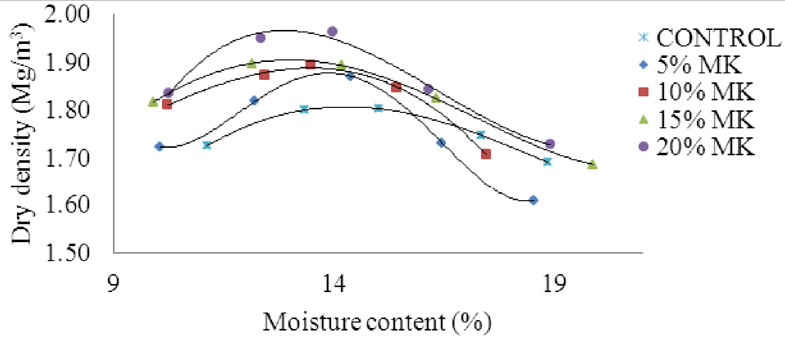

Fig. 6: BSH compaction curves for lateritic soil partially replaced with MK

3.3 Effect of MK on Maximum Dry Density and Optimum Moisture Content

The effect of MK on maximum dry density (MDD) is shown in Fig. 7. The maximum dry density increased linearly with increase in the percentage replacement of MK. Similarly, there was a general increase in MDD with increase in the energy of compaction. The variation of OMCs for the soil replaced with various proportions of MK is shown in Fig. 8. The specimens exhibited a general trend of decreasing OMC with increase in the percentage replacement of MK. The reason for the increase in MDDs with attendant decrease in the OMCs was that MK require small amount of water for pozzolanic reaction with the silt and clay fractions of the soil. This form of reaction is responsible for the formation of calcium aluminate hydrate (C-A-H) and calcium silicate hydrate (C-S-H) for strength development of the specimens.

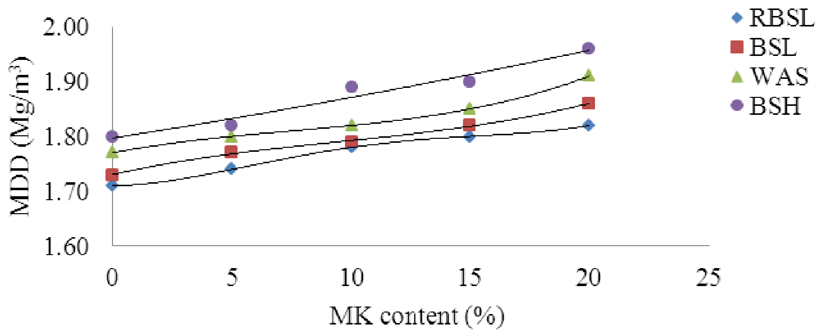

Fig. 7: Variation of maximum dry density (MDD) with MK content

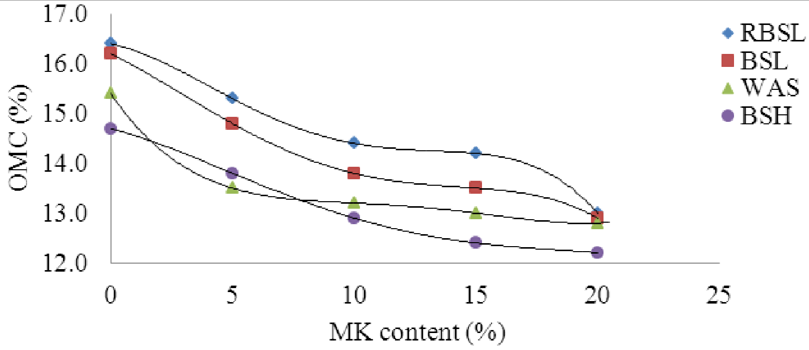

Fig. 8: Variation of optimum moisture content with MK content

3.4 Unconfined Compressive Strength (UCS)

The relationship between the UCS, molding water content and compaction energies for the for curing periods of

7, 14 and 28 days are shown in Figs. 9, 10 and 11, respectively. The specimens cured for 7 days and compacted using the BSH compactive effort resulted in UCS values that are higher than the values obtained for specimens compacted using the RBSL, BSL and WAS energy levels. Maximum UCS value of 963 kN/m^2 was obtained for lateritic soil replaced with 20 % MK and compacted using the BSH energy level. In general, the UCS increases with increase in the percentage replacement of MK and compaction energy. Similar trends were obtained for the specimens cured for 14 and 28 days, respectively. As shown in figs. 10 and 11, the UCS obtained for the specimens cured for 14 and 28 days varies from 566 kN/m^2 to 1363 kN/m^2 and 800 kN/m^2 to 1600 kN/m^2, respectively. The results of the UCS are consistent with the findings of several researchers (Daniel and Wu 1993; Osinubi and Eberemu 2009a). Moses and Afolayan (2011) found that as the molding water content for compacted foundry sand treated with cement kiln dust increase, electrolyte concentration is reduced, an increase in diffuse double layer expansion takes place and the distance between clay particles as well as the distance between alumina and silicate unit increases resulting in a reduction of internal friction and cohesion. Daniel and Wu (1993) suggest UCS of 200 kN/m^2 as the minimum required compressive strength for soil to be used in the construction of compacted soil liner and cover for stability and effective containment of MSW.

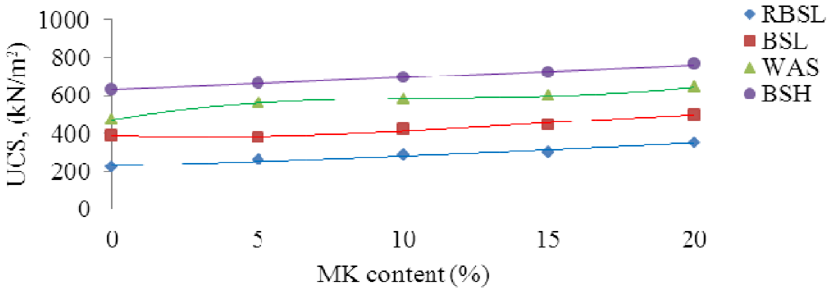

Fig. 9: Variation of UCS of the specimens cured for 7 days with MK Content

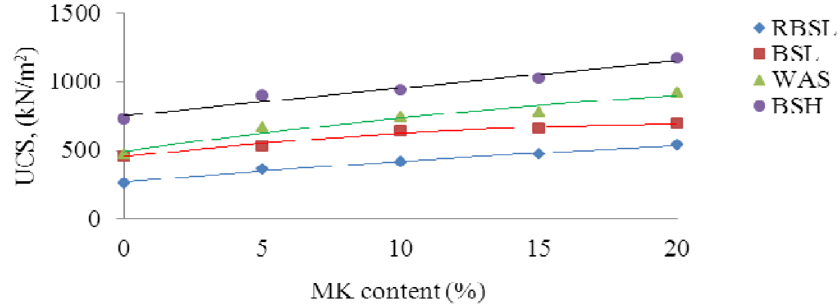

Fig. 10: Variation of UCS of the specimens cured for 14 days with MK content

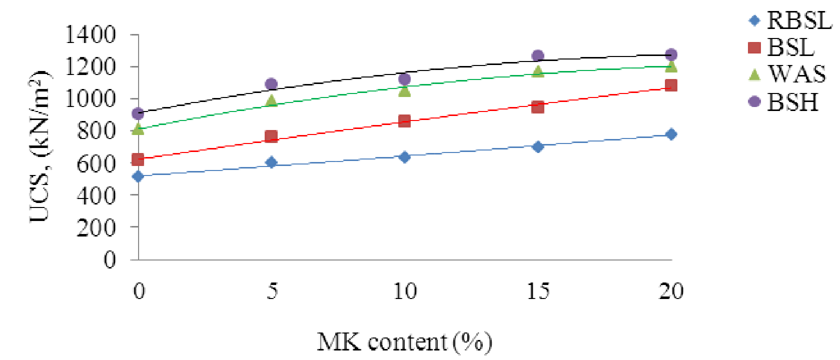

Fig. 11: Variation of UCS of the specimens cured for 28 days with MK content

3.5 Hydraulic conductivity

The relationships between hydraulic conductivity and percentage replacement of MK when de-ionized water (DIW) was used as the permeant fluid are shown in Fig. 12. There was a general decrease in hydraulic conductivity with both increases in percentage replacement of MK and compaction energy. The soil specimen compacted using the RBSL compaction energy yielded hydraulic conductivity values ranging from 1.7 x 10^{-7} m/s to 2.8 x 10^{-8} m/s, while the specimens compacted using the BSL and WAS compaction energies, yielded hydraulic conductivities ranging from 1.3 x 10^{-9} m/s to 5.8 x 10^{-9} m/s and 5.9 x 10^{-9} m/s to 1.6 x 10^{-9} m/s, respectively. The specimens compacted using the BSH compaction energy, however, gave lower hydraulic conductivities ranging from 1.7 x 10^{-9} m/s to 2.2 x 10^{-10} m/s.

The results of the hydraulic conductivity for specimens permeated with MSW leachate are shown in Fig. 13. The hydraulic conductivities obtained for specimens permeated with leachate tend to decrease linearly with increase in the percentage replacement of MK and varies from 8.1 x 10^{-8} m/s to 3.8 x 10^{-8} m/s for the specimens compacted using the RBSL compaction energy. Hydraulic conductivity values ranging from 9.3 x 10^{-9} m/s to 2.6 x 10^{-9} m/s, 6.8 x 10^{-10} m/s to 6.1 x 10^{-10} m/s and 2.1 x 10^{-10} m/s to 3.6 x 10^{-11} m/s, were obtained for the specimens compacted using the BSL, WAS and BSH compaction energies, respectively. On the effect of compaction energies on hydraulic conductivity, one would conclude that for permeation with DIW, the specimens replaced with 0-15 % MK and compacted using the RBSL, BSL and WAS compaction energies, respectively, did not meet the regulatory maximum hydraulic conductivity of < 1 x 10^{-9} m/s stipulated by EPA (1989) for liner and cover materials. The specimens replaced with 5-20 % MK and compacted using BSH compaction energy, however, yielded hydraulic conductivities ranging from 6.3 x 10^{-10} m/s to 2.2 x 10^{-10} m/s. As shown in Fig. 13, all the specimens replaced with 0-20% MK and compacted using the WAS and BSH compaction energies yielded hydraulic conductivities ranging from 6.8 x 10^{-10} m/s to 3.6 x 10^{-11} m/s based on permeation with leachate. According to Benson and Trast (1995), the effectiveness of liners and covers for waste containment is often measured in terms of the possibility of achieving hydraulic conductivity ≤ 1 x 10^{-9} m/s. In general, the hydraulic conductivity of the specimens decreased with increase in the percentage replacement of MK during leachate permeation. The steady decrease in hydraulic conductivity is attributed to the leachate-MK interactions which tend to contribute to clogging of the pores between the particles. This is consistent with the findings of Yeheyis *et-al* (2010) who observed a decrease in hydraulic conductivity due to the precipitation of new minerals as a result of chemical interactions between acid mine drainage (AMD) and fly-ash. The results of their findings also suggests that the pozzolanic and self cementing properties of fly ash result in the formation of hydration products that could possibly block void spaces and reduce the interconnection between fly ash particles.

Comparison of the hydraulic conductivities obtained when the specimens were permeated with DIW and leachate showed that the hydraulic conductivity values obtained for the specimens compacted using the WAS and BSH compaction energies were all < 1 x 10^{-9} m/s and therefore met the regulatory maximum hydraulic conductivity stipulated by EPA (1989) for construction of liner and cover systems for MSW containment. However, the hydraulic conductivities of the specimens permeated with leachate were less than the hydraulic conductivities obtained when DIW was used as the permeant fluid. Lee *et al* (2005) state that the assumption often made that compatibility between the permeant liquid and soil has no effect on hydraulic conductivity has not been established.

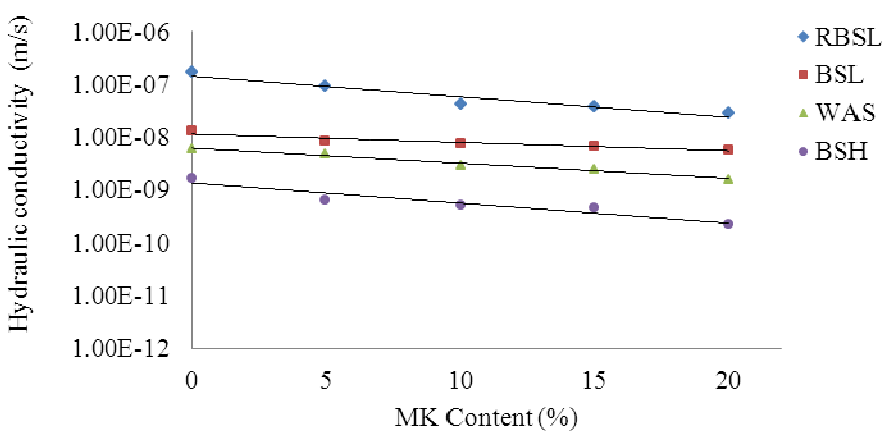

Fig. 12: Variation of hyadraulic conductivity with MK content (DIW as the permeant fluid)

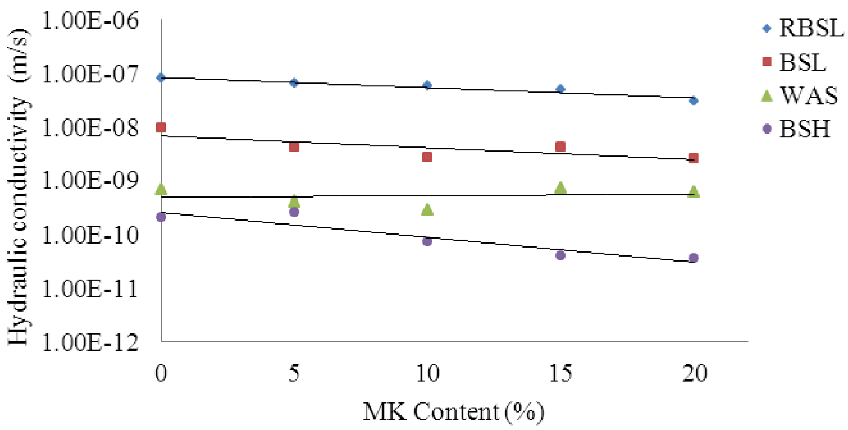

Fig. 13: Variation of hyadraulic conductivity with MK content (Leachate as the permeant fluid)

4. Conclusions

The potentials of MK in improving the properties of lateritic soil for barrier system for the containment of MSW have been presented. The soil classified as A-6 and CL using the AASHTO and the USCS falls in the category of soils that are suitable for the construction of barrier systems for effective containment of hazardous wastes. The results obtained revealed that MK is pozzolanic and beneficial in the improvement of the dry density with attendant decrease in moisture affinity of the soil specimens. The specimens replaced with 20 % MK and compacted using the energy level of the BSH yielded the highest MDD value of 1.96 Mg/m^3 with corresponding lowest OMC value of 12.1 %. The specimens compacted using the WAS compaction energy yielded MDD values that are higher than those obtained when BSL and RBSL compaction energies were used. Based on the laboratory results for determination of UCS for specimens cured for 7 days, 14 days and 28 days, respectively, the specimens yielded UCS values > 200 kN/m^2. The results of this study also show that MK is effective in improving the UCS of the specimens with increase in the age of curing. The hydraulic conductivities obtained for permeation with leachate are however lower than those obtained when DIW was used as the permeant fluid. On the view point of economy of construction, one would conclude that the hydraulic conductivity values ranging from 6.8×10^{-10} m/s to 6.1×10^{-10} m/s obtained for test specimens compacted using the WAS compaction energy based on permeation with leachate are appropriate for lateritic soil - MK to effectively prevent the diffusion of contaminants through the barrier system.

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