IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 12, Issue 1 Ver. II (Jan- Feb. 2015), PP 01-10
www.iosrjournals.org

Feasibility of Using Tincal Ore Waste as Barrier Material for Solid Waste Containment

Umar, Sa'eed Yusuf[1], Elinwa, Augustine Uchechukwu[1]
and Matawal, Danladi Slim[2]
[1] Department of Civil Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria
[2] Nigerian Building and Road Research Institute (NBRRI), Abuja, Nigeria

Abstract: *The paper investigates the potentials of tincal ore waste (TOW) as a material for improvement of the properties of lateritic soil barrier system for containment of municipal solid waste (MSW). Hydraulic conductivity and unconfined compressive strength (UCS) tests were conducted on the lateritic soil alone (control) and lateritic soil replaced with 5 %, 10 %, 15 % and 20 % TOW by dry weight of the soil and compacted using four compaction methods. All the UCS values obtained for the control specimens and the soil replaced with various proportions of TOW were above 200 kN/m^2 and thus met the UCS criterion for stability of liner materials. The hydraulic conductivities obtained when the specimens were permeated with leachate are better than those obtained when distilled water was used as the permeant fluid. Specimens containing 20 % TOW and compacted using the British Standard Heavy (BSH) compaction energy gave the overall lowest hydraulic conductivities on the orders of 2.1 x 10^{-10} m/s to 3.2 x 10^{-12} m/s based on permeation with leachate. The specimens compacted using the Reduced British Standard Light (RBSL) yielded hydraulic conductivity greater than the 1 x 10^{-9} m/s regulatory hydraulic conductivity for barrier systems. On the view point of economy, the lateritic soil could be compacted at molding water content of 15.0 % (relative to optimum) using the British Standard Light (BSL) compaction energy to yield the required hydraulic conductivity for effective containment of MSW.*

Keywords: *Tincal ore waste, landfills, lateritic soil, municipal solid waste, leachate, compactive effort, molding water content, unconfined compressive strength, hydraulic conductivity,*

I. Introduction

The ability of municipal solid waste (MSW) barrier systems (landfills) to prevent pollution of groundwater by chemicals that leach from such waste, for as long as the waste can generate leachate is of great concern. The liner is an important barrier to control intrusion of groundwater into the landfill facilities and to prevent the release of leachate contaminants to the surrounding environment. The amount of hazardous wastes and municipal solid wastes (MSW) in Nigeria are increasing along with growing economy and improved standard of living. In Nigeria disposal facilities for waste containment are however not properly designed and constructed to meet the international best practice for management of MSW. Successful design and construction of soil landfills in developed countries of the world involves many facets, e.g. selection of materials, assessment of chemical compatibility, determination of construction methodology, evaluation of settlements, consideration of environmental factors such as desiccation, and development and execution of construction quality assurance (CQA) plan (Daniel, 1987; Daniel and Benson, 1990). According to Daniel and Benson (1990) rational design of compacted soil liners should be based upon test data developed for each particular soil. For example, Lateritic soils have traditionally been used as construction materials for earth dams, road embankments, road pavements, and structural fill within the tropical and sub tropics (Gidigasu, 1976) for which strength and compressibility are of primary concern. The soils used in constructing low hydraulic conductivity barrier systems are typically placed and compacted wet compared to optimum moisture content (Mitchell et –al, 1965; Daniel, 1987; Herman and Elsbury, 1987). This practice minimizes the hydraulic conductivity of the compacted soil at the time of construction (Daniel, 1993). Engineers almost always specify that soil liners be compacted wet compared to optimum water content to comply with requirement that the hydraulic conductivity of the compacted soil not exceed a specified maximum (1 x 10^{-9} m/s for most categories of waste).

Various applications of pozzolanas as component for construction of hydraulic barrier systems for MSW containment have been investigated several investigators. The potentials of supplementary cementitious materials (SCMs) such as paper mill sludge, foundry green sand, bentonite, blast furnace slag and fly ash solely or in combination with clay additives as liner and cover materials for containment of hazardous waste have been reported by researchers (Stoffel and Ham, 1979; Kunes and smith, 1983; Gipson, 1985; Howell and Shackelford, 1997; Edil et al, 1992; Freber, 1996; Abichou et al, 1998c, Abichou et al, 2000; Osinubi and Eberemu, 2007). The economic benefits of utilization of waste resources as supplementary cementitious materials (SCMs) in soil stabilization have been highlighted in the literature (Indraratna et al, 1995; Umar and Elinwa, 2005; Olawuyi and Olusola, 2010; Yeheyis et al, 2010; Amu, 2011; Kolovos, 2013).

The paper is designed to investigate the feasibility of using tincal ore waste (TOW) as material for the construction of barrier system for the containment of municipal solid waste (MSW). Chemical analysis revealed that the material contains high proportion of silica in non-crystalline state and in form of extremely fine particles, which makes it a pozzolanic material.

II. Materials

Lateritic soil

The soil used in the study is a natural occurring lateritic soil and is reddish brown in color. The soil sample was collected from a borrow pit near the Abubakar Umar Secretariat, in 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 by method of disturbed sampling.

Tincal ore waste (TOW)

Fresh tincal ore waste (TOW) was obtained from one of the tin mining sites in Bukuru, Jos South LGA of Plateau State, Nigeria. The mineral obtained from the ground is casserite or tin stone, from which tin metal is obtained by melting. The physical properties of TOW were determined on material passing sieve 425 µm and the experimental results shows that it has a moisture content of 0.24 %, specific gravity of 3.10, bulk density of 1720 kg /m^3 and pH of 10.6.

III. Experimental Methods

Compaction tests

In carrying out the experiment on compaction, the soil material was air dried in the laboratory and pulverized to sizes small enough to pass through US Number 4 sieve (4.76 mm) in accordance with Head (1992). For the treated soil, five mixes were used and derived by replacing the soil material in proportions of 0 %, 5 %, 10 %, 15 % and 20 % of TOW by weight of the soil, respectively. The control mix contains only the soil material while the remaining four mixes were prepared at replacement levels of 5 – 20 % TOW. The soil samples were prepared using seven molding water contents ranging from 10 % to 25 % by weight of dry soil and compacted using four compaction energies, namely: the Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS), and British Standard Heavy (BSH), respectively. Three samples were prepared for each replacement level and the average optimum moisture content (OMC) and maximum dry density (MDD) were taken. A total of 45 specimens were prepared at replacement levels of 0 %, 5 %, 10 %, 15 % and 20 % TOW.

Table 1. 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	Mechanical Energy (j)	Work Done(Kj/m^3)
RBSL	1000	2.5	30.48	3	15	331.088	(331.088)[a]
BSL	1000	2.5	30.48	3	27	595.958	595.958
WAS	1000	4.5	45.75	5	10	993.293	(993.293)[b]
BSH	1000	4.5	45.72	5	27	2681.809	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

Unconfined compressive strength (UCS)

The unconfined compressive strength (UCS) was 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). Three kilograms (3 kg) of the soil was measured and five mixes were used at replacement levels of 0 %, 5 %, 10 %, 15 % and 20 % of TOW by weight of soil. The soil samples were prepared using the OMCs derived from moisture density relationship determined for the natural soil (control) and soil replaced with various proportions of TOW. After preparation of the test specimens, compaction was done using the four energy levels i.e. RBSL, BSL, WAS, and BSH, respectively. After the compaction stage, three specimens of diameter 38 mm and length 76 mm were obtained and wrapped in cellophane bags for ease of identification and cured for 7 days, 14 days and 28 days, respectively. Three tests were conducted for each blend of soil and percentage addition of TOW, respectively. The average of the results of the three tests was taken as the unconfined compressive strength of the soil for each replacement level.

Hydraulic conductivity (permeability)

The hydraulic conductivity or permeability tests determination for the soil (control) and soil replaced with various proportions of TOW, respectively were carried out using the falling head apparatus in accordance with the procedures outlined in BS 1377 (1990) and Head (1992). The specimens were prepared using the OMCs derived from the moisture density relationship plots for the soil and soil treated with various proportions of TOW. The OMCs were increased by 2 % in accordance with the recommendation of EPA (1989). Generally, soils compacted at water contents less than optimum tends to have relatively high hydraulic conductivity than soils compacted at water contents greater than optimum.

In carrying out the tests, the soil was air dried in the laboratory and pulverized to sizes small enough to pass US Number 4 sieve (4.76 mm). Five mixes were used at replacement levels of 0 %, 5 %, 10 %, 15 % and 20 % TOW by weight of soil, respectively. The soil samples were prepared using the adjusted OMCs and compacted using the four compactive efforts adopted in the study. The compacted specimens with the compaction mould for each percentage addition were first placed in plastic immersion tanks and distilled/de-ionized water was gradually introduced such that the top of the compacted soils was covered with 5 cm of water. Placement of the compacted soil specimen in distilled water and the mould 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 distilled water level in the immersion tank was reduced and the entire falling – head setup was assembled in preparation for permeation using distilled water and 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.

IV. Results And Discussions

Atterberg Limits

From Table 1, the soil was classified as A-6 and CL using the American Association of State Highway Transportation Officials (AASHTO, 1986) soil classification system and Unified Soil Classification System (ASTM, 1992), respectively. 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 particle size distribution curve for the natural soil (Fig. 1) indicate that 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 (1989), 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 0.005mm. Therefore, the soil is clayey sand and ideal for construction of barrier systems for containment of MSW. Daniel (1993) showed that such soils have adequate plasticity to yield low hydraulic conductivity, and high percentage of sand to minimize volumetric shrinkage upon drying.

Characteristics of tincal ore waste (TOW)

The results of the chemical properties of the TOW determined using X-ray fluorescence (XRF) are presented in Table 2. The major chemical compositions of TOW calculated as major oxides are Silicon oxide (S_iO_2), Aluminium oxide (Al_2O_3), Iron oxide (Fe_2O_3) and Titanium oxide (T_iO_2) contributing 15.9 %, 2.8 %, 40.71 % and 29.73 %, respectively of the total.

Table 1. Physical properties of the natural 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: X- ray fluorescence (XRF) results of TOW

Compound	Concentration %
Aluminium, Al	2.8
Silicon, Si	15.9
Pottasium, K	0.25
Calcium, Ca	0.889
Titanium, Ti	29.73
Vanadium, V	0.23
Chromium, Cr	0.057
Manganese, Mn	2.41
Iron, Fe	40.71
Nickel, Ni	0.008
Copper, Cu	0.030
Zinc, Zn	0.046
Tantalum, Ta	1.70
Niobium, Nb	3.49
Lithium, Li	0.45
Rhenium, Re	0.07
Vanadiun	0.61
Chromium, Cr	0.64
TOTAL	**100**

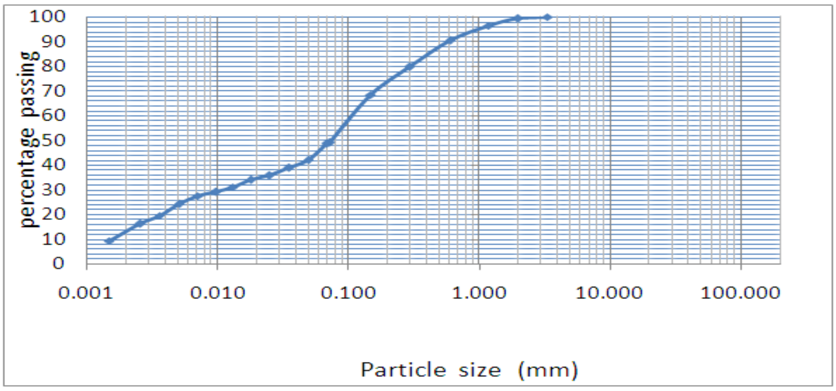

Fig. 1: Particle size distribution curve of lateritic soil

Compaction characteristics

The moisture density relationship of the untreated lateritic soil (Figure 2) show an increase in MDD and corresponding decrease in OMC with increase in compaction energy. The soil compacted using the energy level of the BSH (equivalent to 2681.809 kJ/m^3) yielded the highest MDD of 1.80 Mg/m^3 with corresponding OMC of 14.7 %. On the other hand, soil compacted at the energy level of the RBSL (equivalent to 331.088 kJ/m^3) gave the lowest MDD value of 1.70 Mg/m^3 and highest OMC value of 16.4 %. The specimens compacted using the WAS energy level (equivalent to 993.263 kJ/m^3) gave MDD values that are higher than those obtained for the specimens compacted at the energy level of BSL (equivalent to 593.958 kJ/m^3).

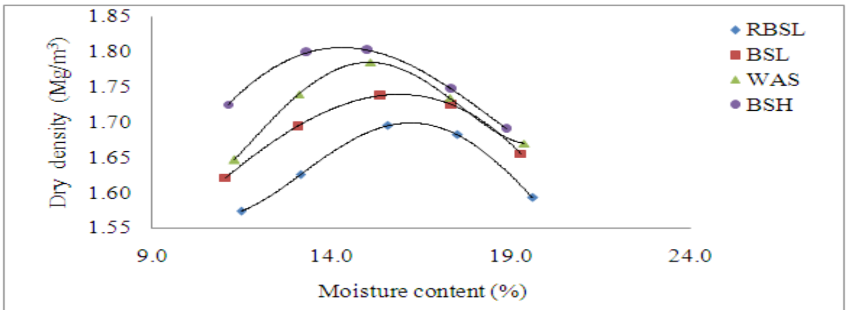

Fig.2: compaction curves for the lateritic soil

The moisture density relationship of the lateritic soil replaced with 5 %, 10 %, 15 % and 20 % TOW and compacted using the four energy levels are shown in Figures 3 to 6. The trend of the compaction curves are similar to those obtained for the soil without any addition. In this case, the MDD increased with both increase in energy of compaction and increase in percentage addition of TOW. On the other hand, the OMC decreased with increase in percentage addition of TOW and decreased with increase in compaction energy. Abichou (2000) proposed a similar explanation for soil- foundry green sand hydraulic barrier systems.

For the specimens replaced with 20 % TOW and compacted using the RBSL, BSL, WAS and BSH compaction energies, the MDDs were found to be, 1.88 Mg/m^3, 1.93 Mg/m^3, 1.95 Mg/m^3, 2.01 Mg/m^3 and the corresponding OMCs were 14.0 %, 13.6% and 13.4 % and 12.8 %, respectively. The specimens replaced with 5 % TOW yielded the least MDD with attendant high OMC values for all the compaction energies used. The reason for the increase in MDD and decrease in OMC with TOW contents is that the additives require less water for pozzolanic reaction with the clay and silt fraction of the soil. Due to the presence of S_iO_2, Fe_2O_3 and T_iO_2 in the additive, the mechanical properties of the soil were greatly enhanced. The blend of soil and TOW produced heavier agglomerate particles with attendant rise in the density of the soil. The excess free lime product of hydration reaction of these elements led to an increase in the overall surface area of the treated lateritic soil. The excess free lime is responsible for the increase in workability of the specimens which eases compaction and the formation of coarser particles resulting in an increase in dry unit weight (Matawal et – al, 2006).

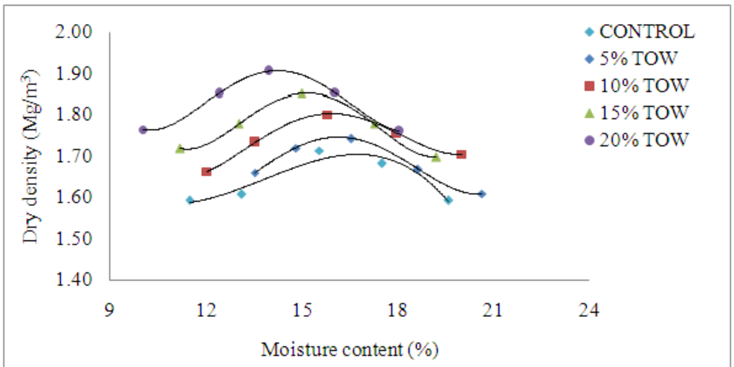

Fig. 3: RBSL compaction curves for lateritic soil treated with TOW

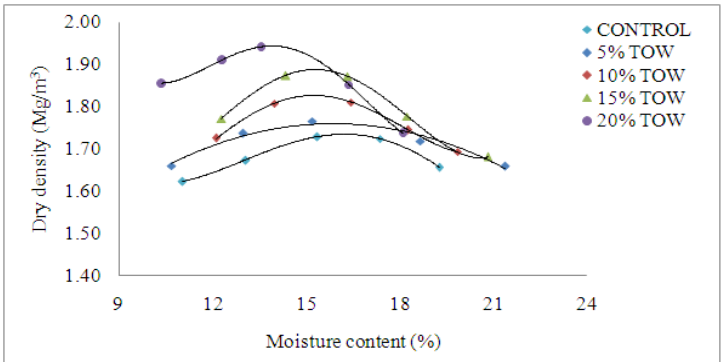

Fig. 4: BSL compaction curves for lateritic soil treated with TOW

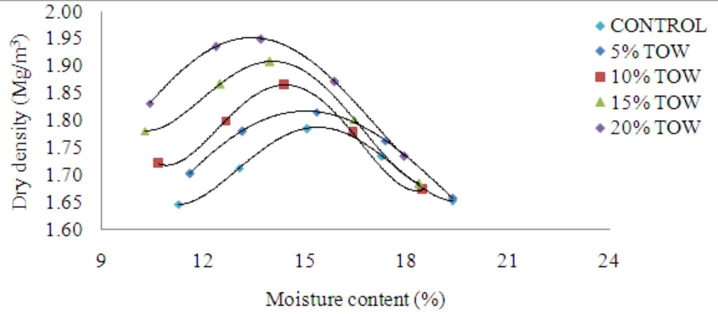

Fig. 5: WAS compaction curves for lateritic soil treated with TOW

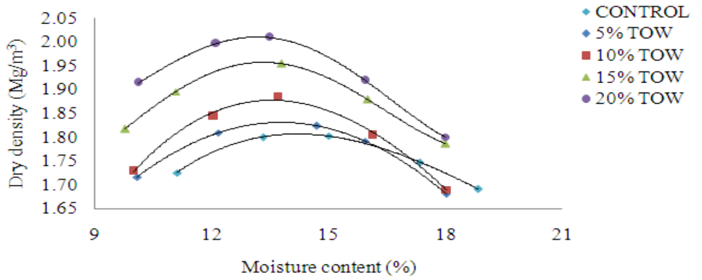

Fig. 6: BSH compaction curves for lateritic soil treated with TOW

Unconfined compressive strength (UCS)

The relationship between the UCS and molding water content for the lateritic soil replaced with 5 %, 10 %, 15 %, and 20 % TOW and compacted at the energy levels of RBSL, BSL, WAS and BSH and cured for 7, 14 and 28 days, respectively are shown in Figs. 7 to 9. The specimens compacted using the BSH compactive effort yielded UCS values that are higher than the values obtained for the specimens compacted using the RBSL, BSL and WAS energy levels. For the natural soil (control) and the soil replaced with 5 to 20 % TOW, the trend of the plots is one of increasing UCS with age of curing and increase in compaction energy, the UCS ranged from 254 kN/m^2 to 1324 kN/m^2. The results exhibited a decline in UCS with increase in molding water content the trend is in agreement with the findings of several investigators (Daniel and Wu, 1993; Osinubi and Nwaiwu, 2005; Osinubi and Eberemu, 2009a). Moses and Afolayan (2011) found that as the molding water content increases for compacted foundry sand treated with cement kiln dust, 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. In terms of strength requirements for hydraulic barrier materials the molding water contents used in preparing the specimens using the four compaction energies adopted in this study met the UCS criterion stipulated for liner material. On the view point of economy of construction, BSL compaction energy is hereby suggested for compaction of the lateritic soil investigated in this study and any fined grained soil having similar grading, plasticity and mineralogical characteristics can be compacted at optimum water content, for example, to obtain compressive strengths greater than 200 kN/m^2. It can therefore be concluded that TOW is suitable for use as a material in construction of barrier systems for the containment of MSW.

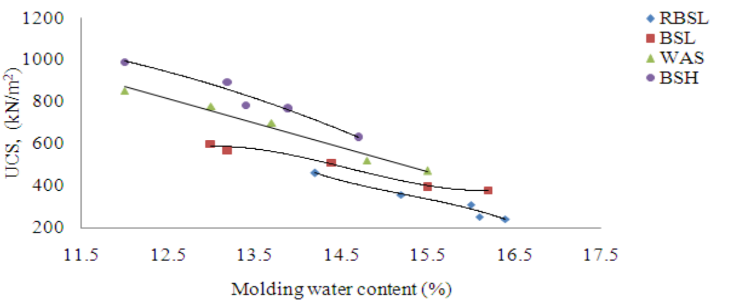

Fig. 7: Variation of 7 days UCS of TOW treated lateritic soil with water content

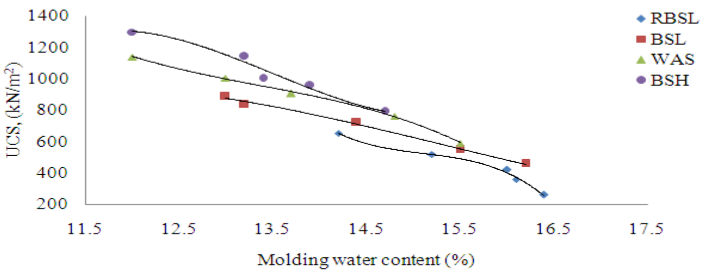

Fig. 8: Variation of 14 days UCS of TOW treated lateritic soil with water content

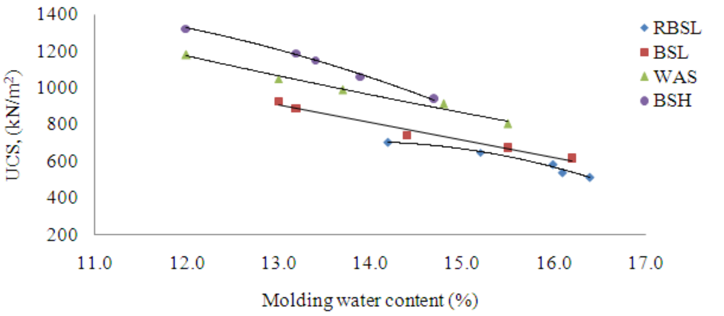

Fig. 9: Variation of 28 days UCS of TOW treated lateritic soil with water content

Hydraulic conductivity

The relationship between hydraulic conductivity and molding water contents (relative to optimum) when distilled water was used as the permeant fluid is shown in Fig. 10. The trend is one of increasing hydraulic conductivity with increase in molding water content and decrease in hydraulic conductivity with increase in compaction energy. The hydraulic conductivity obtained for lateritic soil (control) ranged from 1.7 x 10^{-9} m/s to 1.7 x 10^{-7} m/s. these values are greater than 1 x 10^{-9} m/s and hence did not meet the minimum regulatory hydraulic conductivity for hydraulic barrier systems. For soil specimens replaced with 5 – 20 % TOW and compacted using the BSH compaction energy, the hydraulic conductivities are on the orders of 3.8 x 10^{-10} m/s to 1.9 x 10^{-10} m/s. These values are less than 1 x 10^{-9} m/s and satisfy the hydraulic conductivity criterion for barrier systems for effective containment of hazardous waste. The moisture content to achieve this was found to range from 14.0 % to 15.9 % on the wet side of OMC. For this addition, the best hydraulic conductivity of 1.9 x10^{-10} m/s was achieved at 20 % TOW replacement level and BSH compaction energy.

The variation of hydraulic conductivity and molding water contents (relative to optimum) when leachate was used as the permeant fluid is shown in Fig. 11. The natural soil (control) permeated with leachate gave hydraulic conductivity on the orders of 2.1 x 10^{-10} m/s to 8.1 x 10^{-8} m/s for the four compaction energies used. Specifically, the specimens compacted using the WAS and BSH compaction energies gave hydraulic conductivity values of 6.8 x 10^{-10} m/s and 2.1 x 10^{-10} m/s, respectively, which are lower than the 8.1 x 10^{-8} m/s and 9.3 x 10^{-9} m/s obtained for the specimens compacted using the RBSL and BSL compaction energies.

For the lateritic soil replaced with 5 – 20 % TOW, the specimens compacted using the RBSL compaction energy gave hydraulic conductivities on the order of 8.1 x 10^{-8} m/s to 6.6 x 10^{-9} m/s. The lateritic soil replaced with 15 % and 20 % TOW and prepared at OMC of 15 % (relative to optimum) and compacted using the BSL compaction energy gave hydraulic conductivities of 7.1 x 10^{-10} m/s and 3.1 x10^{-10} m/s. The specimens prepared using molding water contents ranging from 14 % to 17.5% and compacted using the WAS and BSH specimens yielded hydraulic conductivities on the order of 9.4 x 10^{-11} m/s to 6.8 x 10^{-10} m/s and 3.2 x 10^{-12} m/s to 2.6 x 10^{-11} m/s. The values are higher than 1 x 10 $^{-9}$ m/s which is considered the target regulatory hydraulic conductivity for compacted soil liners. The lateritic soil alone prepared with molding water content of 17.5 % on the wet side of optimum, permeated with leachate and compacted using the WAS and BSH compaction energies can be used for the design of liner materials using this type of soil and other soils having similar properties. For lateritic soil replaced with 0 to 20 % TOW, the specimens prepared at replacement level of 20 % TOW and molding water content of 14 % on the wet side of OMC gave best hydraulic conductivity of 3.1 x 10^{-12} m/s.

On the view point of economy of construction, one may conclude that the natural soil permeated with leachate can be prepared using molding water content of 17.5 % on the wet side of optimum and compacted using the WAS energy level to achieve hydraulic conductivity less than 1 x 10^{-9} m/s. The hydraulic conductivity of 3.1 x 10^{-10} m/s obtained based on permeation with leachate, using molding water content of 15 % at replacement level of 20 % TOW and compacted using the BSL compaction energy is adjudged adequate for the design and construction of the barrier system using the lateritic soil investigated in this study.

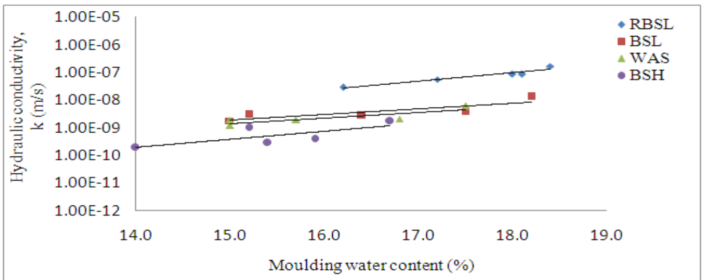

Fig. 10: Variation of hydraulic conductivity of TOW treated lateritic soil with water content (Distilled water as the permeant fluid)

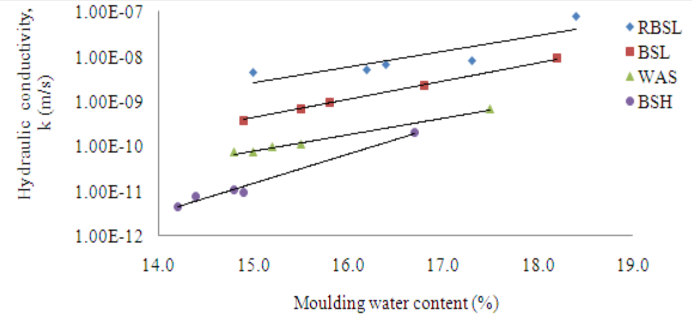

Fig. 11: Variation of hydraulic conductivity of TOW treated soil with water content (Leachate as the permeant fluid)

Effect of TOW on hydraulic conductivity

The relationship between the hydraulic conductivity and TOW contents when distilled water and leachate were used as the permeant fluids respectively are shown in Figs. 12 and 13. Generally, the trend of the plots is one of decreasing hydraulic conductivity with increase in percentage addition of TOW. The decrease in hydraulic conductivity with increase in TOW content and compaction energy is attributable to the reduction in pore spaces of the soil due to TOW filling the voids thereby reducing the flow of fluid in the voids of the treated soil. In addition, the effect of the high content of iron oxide (Fe_2O_3) and titanium oxide (T_iO_2) in the TOW may in part be responsible for the formation of cementitious compounds which lead to increase in strength. The cementing action of TOW through the tobermorite gel was responsible for the decline in the moisture affinity of the lateritic soil – TOW blend.

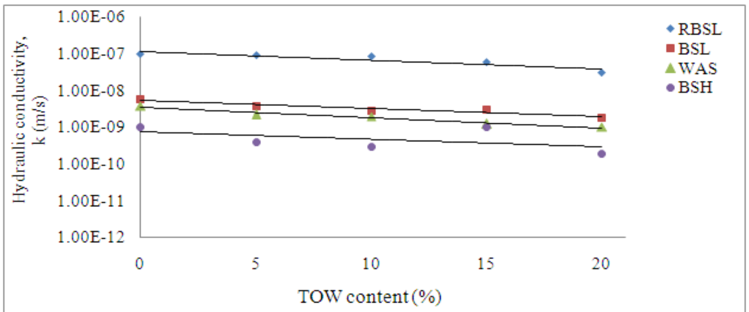

Fig. 12: Variation of hydraulic conductivity with TOW content (Distilled water as the permeant fluid)

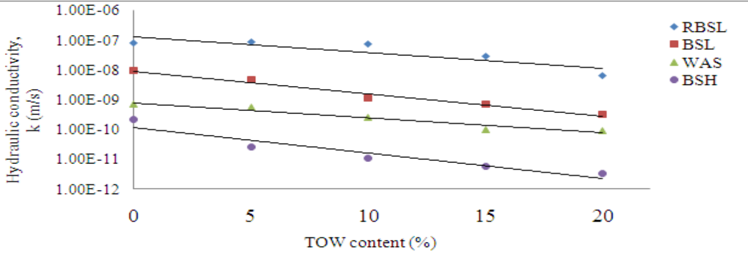

Fig. 13: Variation of hydraulic conductivity with TOW content (Leachate as the permeant fluid)

V. Conclusions

The effects of compaction energies become more important as the TOW contents increased. Both the unconfined compressive strength and the hydraulic conductivity of the soil replaced with TOW increased with increase in the energy of compaction and decreased with increase in molding water content. For MSW barrier systems, compressive strength of 200 kN/m^2 is recommended to be achieved for stability. From the obtained results all the UCS values obtained for both the natural soil (control) and the soil replaced with 5 – 20 % TOW met the 200 kN/m^2 compressive strength stipulated by EPA (1989) for stability of liner materials in landfills. The lateritic soil replaced with 20 % TOW and compacted using the energy level derived from the BSH and WAS compaction energies gave hydraulic conductivities on the order of 10^{-11} m/s to 10^{-12} m/s which are much lower than the regulatory hydraulic conductivity of $\leq$ 10^{-9} m/s stipulated for barrier material for effective containment of hazardous waste. Interestingly, the specimens treated with 20 % TOW and compacted using the BSL compaction energy met the regulatory hydraulic conductivity of 1 x 10^{-9} m/s for barrier systems. The molding water content (relative to optimum) to achieve the regulatory hydraulic conductivity for liner systems when leachate was used as the permeant fluid was found to range from 14.0 % to 17.5 % for the natural soil (control) and 14.0 % to 17.5 % on the wet side of OMC for the soil replaced with 5 – 20 % TOW. In general the hydraulic conductivities obtained when leachate was used as the permeant fluid were better than hydraulic conductivities obtained when distilled water was used. In terms of performance the lateritic soil permeated with leachate, treated with 20 % TOW and compacted using the BSL compaction energy would perform better as a barrier material than the natural soil (control).

References

[1]. AASHTO (1986) Standard specifications for transportation materials and methods sampling and testing, 4th edition, American Association of State Highway and Transportation Officials, Washington, D.C.

[2]. Abichou,T., Benson, C.H. and Edil,T. (1998c) Using waste foundry sand for hydraulic barriers, recycled materials in geotechnical applications, GSP 79, ASCE, Reston, Va., 86 – 99

[3]. Abichou,T., Benson, C.H. and Edil, G.T. (2000) Foundry green sand as hydraulic barriers laboratory studies Journal of Geotechnical and Geoenvironmental Engineering, ASCE, **126**, 1174 – 1183.

[4]. Abdullah, W. S., Alshibli, K.A. and Al-Zoubi, M.S. (1999) Influence of pore water chemistry on the swelling behaviour of compacted clays Applied Clay Science, **15**, 447 – 462.

[5]. Amu, O.O., Ogunniyi, S.A. and Oladeji, O.O. (2011) Geotechnical properties of lateritic soil stabilized with sugarcane straw ash. American Journal of Scientific and Industrial Research, 2, 323 - 331

[6]. Annual Book of ASTM Standards (1992) **04.08**, American Society for Testing and Materials, ASTM, Philadelphia.

[7]. BS 1377 (1990) Methods of Testing Soils for Civil Engineering Purposes, British Standard Institution, London.

[8]. Daniel, D.E. and Benson, C.H. (1990) Water - content density criteria for compacted soil liners Journal of Geotechnical Engineering, ASCE, **116**, 1811 – 1830.

[9]. Daniel, D.E. (1987) Earthen liners for land disposal facilities Proceeding of Geotechehnical Properties for Waste Disposal, R. D. Woods ed. ASCE, Reston, Va, 21 – 39.

[10]. Daniel, D.E. (1993) Geotechnical Practice for Waste Disposal Chapman and Hall, London, 683p.

[11]. Edil, T.B., Sandstrom, L.K. and Berthouex, P.M. (1992). Interaction of inorganic leachate with compacted pozzolanic fly ash Journal of Geotechnical Engineering, ASCE, **118,** 1410 – 1430.

[12]. Freber, B. (1996) Beneficial reuse of selected foundry waste material Proc. 19th Int. Madison Waste Conf. Dept. of Engr. Professional Dev. Univ. of Wisconsin, Madison, Wisconsin, 246 – 257.

[13]. Gidigasu, M.D. (1976) Lateritic soil engineering paedologenesis and engineering principles Developments in geotechnical engineering, **9**, Elsevier, Amsterdam

[14]. Gipson, A. (1985) Permeability testing on clay soil and silty sand – bentonite mixture using acid liquor Hydraulic Barriers in Soil and Rock, ASTM STP 874, ASTM, Philadelphia, 140 – 154.

[15]. Head, K.H. (1992) Manual of soil laboratory testing: soil classification and compaction tests, (2nd ed.) **1**, Pentech Press, London.

[16]. Herman, J.G. and Elsbury, B.R. (1987) Influential factors in soil liner construction for waste disposal facilities Geotech. Practice for Waste Disposal '87, R. D. Woods ed., ASCE, 522 – 536.

[17]. Howell, J. and Shackelford, C.D. (1997) Hydraulic conductivity of sand admixed withprocessed clay mixtures. Proceeding of 14th International Conference on Soil Mechanics and Foundation Engineering, Balkema, Rotterdam, The Netherlands, 307 - 310

[18]. Indraratna, B. Balasubramaniam, A.S. and Khan, M.J. (1995) Effect of Fly Ash with Lime and Cement on the Behaviour of Soft Clay. The Quarterly Journal of Geology, Vol. 28 ,131 – 142.

[19]. Kolovos, K.G., Asteris, P.G., Cotsovos, D.M., Badogiannis, E. and Tsvilis, S. (2013) Mechanical properties of soilcrete mixtures modified with metakaolin. Construction and Building Materials, Elsevier, **47**, 1026 – 1036.

[20]. Kunes, T and Smith, M. (1983) Waste disposal considerations for green sand use in the foundry industry. Proceeding AFS – CMI Conference on Green Sand Productivity for the 80s, Cast Metals Institute American Foundry – Men's Society, Des Plaines Illinois, 143 – 165.

[21]. Matawal, D.S., Umar, S.Y. and Bala, U.Y. (2006) Effect of oil palm ash on cement stabilized soil. Journal of Civil Engineering, Nigerian Institution of Civil Engineers (NICE), **5**, 5 – 12.

[22]. Mitchell, J.K., Hooper, D.R. and Campanella, R.G. (1965) Permeability of compacted clay. Journal of Soil Mechanics and Foundation Division, ASCE, **91**, 41 – 65.

[23]. Moses, G. and Afolayan, J.O. (2011) Compacted foundry sand treated with cement kiln dust as hydraulic barrier material. Electronic Journal of Geotecnical Engineering (EJGE), **16**, 337 - 355

[24]. Olawuyi, B.J. and Olusola, K.O. (2010) Compressive strength of volcanic ash/ordinary portland cement laterized concrete. Civil Engineering Dimension, **12**, 23 – 28.

[25]. Osinubi, K.J. and Eberemu, A.O. (2009) Compatibility and Attenuative Properties of Blast Furnace Slag Treated Laterite The Journal of Solid Waste Technology and Management, **35**, 7 – 16.

[26]. Sharma, H.D. and Lewis, S.P. (1994). Waste Containment Systems, Waste Stabilization, and Landfills. Design and Evaluation, John Wiley and Sons Inc., Canada, 588.

[27]. Stoffel, G. and Ham, R. (1979) Testing of High Ash Content Paper – Mill Sludge for use in Sanitary Landfill Construction. Prepared for City Education Claire, W. S Avers and Association Inc.

[28]. Umar, S.Y. and Elinwa, A.U. (2005) Effects of iron ore tailings and lime on engineering properties of problem laterite. Journal of Raw Materials Research (JORMAR) Raw Materials Research and Development Council, Abuja, **2,** 56 – 66.

[29]. US EPA (1989) Requirements for Hazardous Waste Landfills, Design, Construction and Closure. Publication No. EPA – 125/4 - 89. 022. EPA, Cincinnati.

[30]. Yeheyis, M.B., Shang, J.Q. and Yanful, E.K. (2010) Feasibility of using coal fly ash for mine waste containment. Journal of Environmental Engineering, ASCE, **136,** 682 – 690.