JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT

ISSN: 2339-076X (p); 2502-2458 (e), Volume 7, Number 3 (April 2020): 2185-2191 DOI:10.15243/jdmlm.2020.073.2185

Research Article

Potentials of bentonite enhanced termite mound soil for bottom lining in waste containment system

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Received 8 January 2020, Accepted 22 February 2020

Abstract: The sole purpose of a compacted landfill liner is to contain and mitigate the impact of leachate on the environment. This research assessed the engineering properties of bentonite enhanced termite mound mixture to ascertain their suitability as an alternate landfill liner. The mixture of mound soil and bentonite was proportioned by percentage weight as (100:0), (95:5), (90:10) and (85:15) respectively. The compaction analysis reveals an optimum moisture content ranging from 13.80% to 18.52% and a maximum dry density that varied from 1.72 g/cm³ to 1.88 g/cm³. The hydraulic conductivity result of 15% bentonite-mound soil mixture (0.23 x 10^{-9} m/s) established hydraulic conductivity less than 1 x 10^{-9} m/s, which satisfied the criteria for landfill liner. Hence, a mixture of 15% bentonite enhanced mound soil is found suitable as an alternate bottom liner.

Keywords: bentonite, compaction, hydraulic conductivity, landfill liner, termite mound

To cite this article: Opafola, OT., Adekunle, A.A., Badejo, A.A. and Adeosun, O.J. 2020. Potentials of bentonite enhanced termite mound soil for bottom lining in waste containment system. J. Degrade. Min. Land Manage. 7(3): 2185-2191, DOI: 10.15243/jdmlm. 2020.073.2185.

Introduction

The rise in human population growth across the globe without sustainable control measures had resulted in a vast volume of waste generated per day. The holistic management of these generated wastes is a perpetual challenge in both developed and developing countries. Waste containment systems are designed and constructed to mitigate the impact of waste on human health and their environments. Materials such as compacted clayey soils, compacted bentonite enhanced soil mixture, geosynthetic clay liner or the combination of all arranged in a systematic layer are used as liner materials. The overall aim of a compacted landfill liner is to reduce the soil pore spaces and its hydraulic conductivity. The design of a waste disposal system is dependent on the hydraulic conductivity characteristics of the clay liner to be applied. Typically, hydraulic conductivity value must be less than or equal to 1×10^{-9} m/s for soil liners and covers used to contain hazardous waste, industrial waste, and municipal solid waste (Kavya and Anjana, 2016). Rakshit and Pal (2015) examined the effect of local soil on compaction and hydraulic conductivity characteristics of bentonite. The amended local soil with bentonite increases the value of dry density and decreases the optimum moisture content and hydraulic conductivity. The application of bentonite-local soil mixture was recommended for different geotechnical uses. Kavya and Anjana (2016) investigated the influence of bentonite on the permeability of compacted soil liners. The bentonite mix proportion varied from 3-15% by weight. The soil mixture with 12% sodium bentonite was adjudged to be satisfactory for liner applications. Ojuri and

Oluwatuyi (2017) investigated the engineering qualities of Igbokoda sand mixed with bentonite at varying percentages (2-10%) to ascertain its eligibility as an alternate bottom liner. The 8% bentonite mixture was recommended for the design of a landfill liner. This research assessed the engineering properties (hydraulic conductivity and compaction characteristics) of bentonite enhanced termite mound soil mixture to ascertain its suitability as alternate landfill liner in a waste containment system.

Materials and Methods

Materials

Termite mound soil: This material was obtained from Ifo located in Ogun state. The area lies within the geographical coordinates of latitude 6° 48' 39.82" N and longitude 3° 5' 58.76" E. (Figure 1). Bentonite: It was sourced from a major supplier in Lagos, Nigeria (Figure 2). Table 2 exhibits the physical qualities of termite mound and bentonite. The soil samples utilised are entitled as follows: BC: Bentonite Clay; MS: Termite Mound Soil.



Figure 1. Termite mound before sampling, broken mound and pulverized mound sample.



Figure 2. Bentonite clay.

Properties	Bentonite	Termite mound
Colour	Yellowish-brown	Reddish-brown
Specific gravity	2.37	2.53
pH	7.88	-
Natural moisture content (%)	-	7.43
Electrical conductivity (S/cm)	550	-
Cation Exchange Capacity		
(meq/100)	75.21	-
Sand,		
4.75 - 0.075 mm (%)	20.1	87.5
Silt,		
0.075 - 0.002 mm (%)	20.4	2.3
Clay,		
≤0.002 mm (%)	59.5	10.2
Liquid limit (%)	189	49
Plastic limit (%)	61	27
Plasticity index (%)	128	22
USCS classification	-	Poorly graded soil with silty clay (SP-SC)

Table 1. Characterization of bentonite and termite mound soil.

Methods

Bentonite was mixed with mound soil to enhance the engineering properties of the soil. Bentonite of different percentages (5%, 10% and 15%) was mixed with mound soil by dry weight (Table 2). The index properties of the soils were determined in the soil laboratory in accordance with the procedures outlined in BS 1377 (1990). The Atterberg limits analysis were performed on the prepared sets of soil samples based on BS 1377 standard. The compaction characteristics of the soil samples were determined using the standard compaction in accordance with the procedures outlined in BS 1377: part IV (1990). The strength characteristics of the compacted termite mound

soil-bentonite mixtures were assessed and the test specimens used for the UCS experiment were prepared according to the procedures outlined in BS 1377: part 7 (1990). The hydraulic conductivity qualities of the soil mixtures were investigated through falling head permeability test in conformity with the methodology outlined in BS 1377: part V (1990).

Table 2. Sample mix proportions and designation.

SYMBOL	BC (%)	MS (%)
T1	0	100
T2	5	95
Т3	10	90
T4	15	85

Results and Discussion

Influence of Atterberg limits

The termite mound-bentonite mixtures exhibit an increase in the Atterberg limits with the stepped

Table 3. Atterberg limits of the soil samples.

introduction of bentonite into the mound soil (Table 3). Figure 3 presents the increase variation of the Atterberg limits with respect to bentonite content. Soils with a high liquid limit are characterised with low permeability. The prospective barrier soils to be applied in landfills should possess a minimal liquid limit value of 20% (Benson et al., 1994; Kabir and Taha, 2004; Amadi and Eberemu 2013; Tuncan et al., 2016). The liquid limit results were more than 20%. The result is in tandem to that of Kabir and Taha (2004), Amadi and Eberemu (2013), and Oyediran and Iroegbuchu (2013). Subsequently, Daniel (1991) accounted that soils with a plasticity index greater than 35% tend to exhibit overwhelming shrinkage and settlement. The entire soil samples analysed exhibit plasticity index of less than 35%. Furthermore, prospective barrier soils to be applied in landfills should possess a minimal plasticity index value of 7% (Rowe et al., 1995; Benson et al., 1994; Daniel, 1993). The plasticity index values obtained were greater than 7%. Hence, the soil mixtures tend to exhibit low hydraulic conductivity.

Sample	Mixture	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
T1	0% BC + 100%MS	49	27	22
T2	5% BC + 95%MS	58	29	29
T3	10% BC + 90%MS	60	30	30
T4	15% BC + 85%MS	66	32	34

BC = Bentonite Clay; MS = Mound Soil.



Figure 3. Variation of Atterberg limits with bentonite content.

Compaction properties

The results of compaction qualities are presented in Table 4. The maximum dry density (MDD) ranged from 1.72 to 1.88 g/cm³ with a mean value of 1.80 g/cm³ while the optimum moisture content (OMC) varied from 13.80 to 18.52% with an average value of 16.20%. The MDD decreases from 1.88 to 1.72

g/cm³ and OMC increases from 13.80 to 18.52% with the stepped introduction of bentonite mixed with mound soil. Kabir and Taha (2004), Amadi and Eberemu (2013), Amadi et al. (2015), and Tuncan et al. (2016) recommended soils with MDD \geq 1.50 g/cm³ to be applied as landfill bottom liner.

Table 4. Dry density and optimum moisture content of the soil samples.

Sample	Mixtures	MDD (g/cm ³)	OMC (%)
T1	0% BC + 100%MS	1.88	13.80
T2	5% BC + 95%MS	1.86	14.29
Т3	10% BC + 90%MS	1.74	18.20
T4	15% BC + 85%MS	1.72	18.52

MDD = Maximum Dry Density; OMC = Optimum Moisture Content.

Influence of bentonite on dry density

The variation of dry density with different percentage of bentonite is illustrated in Figure 4. The dry density decreases with stepped introduction of bentonite (Table 4). The reduction in maximum dry unit weight with stepped introduction of bentonite may be as a result of high swelling qualities of bentonite that could form a gel around the soil particle (Amadi and Eberemu, 2013).



Figure 4. Variation of dry density with different percentage of bentonite.

Influence of bentonite on optimum moisture content

The stepped introduction of bentonite mixed with mound soil produces a significant increase in the optimum moisture content of the soil samples. The phenomenon might be connected with the relative increase of fines content originating from the addition of bentonite which will subsequently affect the permeability of the soils. Figure 5 shows the variation of OMC with the increase in the percentage of bentonite.



Figure 5. Variation of OMC with different percentage of bentonite.

Strength properties

The Unconfined Compressive Strength (UCS) values varied from 221.73 to 298.42 KN/m² (Table 5). Similar trends were reported by Amadi and Eberemu (2013), Kavya and Anjana (2016). The UCS values obtained for all the soil samples surpassed the general specification of UCS ≥ 200 kN/m² required for the optimum performance of a material to be used in waste containment systems (USEPA, 1989). Figure 6 highlights the variation of UCS at different OMC compaction with an increase in bentonite content. The incremental content of bentonite in the soil samples resulted in the gradual reduction of the UCS values. The reduction in shear strength could be ascribed to the increment in clay size particles present in bentonite which lowered the frictional resistance between the solid particles at their contact points (Amadi and Eberemu, 2013).

Table 5. Unconfined compaction strength of the soil samples.

Samples	Mixtures	UCS (KN/m²)
T1	0% BC + 100%MS	298.42
T2	5% BC + 05% MS	283.27
Т3	10% BC +	257.64
T4	90%MS 15% BC +	221.73
	85%MS	

BC = Bentonite Clay; MS = Mound Soil.



Figure 6. Variation of UCS with different bentonite content.

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Hydraulic conductivity properties

The influence of bentonite on the hydraulic conductivity properties of the soil mixture is illustrated in Figure 7. The figure shows that hydraulic conductivity decreases with stepped introduction of bentonite content. The results varied from 789.4 x 10^{-9} to 0.23×10^{-9} m/s (Table 6). The soil mixture with 15% bentonite content recorded the lowest hydraulic conductivity value of 0.23×10^{-9} m/s which conformed to the USEPA standard of 1×10^{-9} m/s for any material to be used as a liner in waste containment systems.

Table 6.	Hydraulic	conductivity	of	the	soil
	samples.				

Samples	Mixtures	Hydraulic conductivity (m/s)
T1	0% BC + 100%MS	783.4 x 10 ⁻⁹
T2	5% BC + 95%MS	19.14 x 10 ⁻⁹
Т3	10% BC + 90%MS	4.17 x 10 ⁻⁹
T4	15% BC + 85%MS	0.23 x 10 ⁻⁹

BC = Bentonite Clay; MS = Mound Soil.



Figure 7. Variation of hydraulic conductivity with different bentonite content.

Conclusion

The experimental investigation results affirmed that the blend of 15% bentonite enhanced termite mound soil mixture satisfied the criteria for landfill liner application. Hence, the blend ratio is recommended for the design of liner in a waste containment system for sustainable prevention of groundwater pollution. Its application as barrier soil for industrial waste management would mitigate the degradation of environmental resources.

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