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Influence of bentonite on clayey soil as a landfill baseliner materials

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Abstract. With the geometric population growth in developing nations comes increase in waste generation, these wastes ranging from industrial to agricultural to municipal solid waste calls for measure for its effective management and disposal so as to preserve the ecosystem. An effective measure of containing this large waste generated, is through the use of landfills which are designed and built to protect infiltration of leachates from decomposed waste to the groundwater. It is with this in mind, that this study seeks to assess the effect of bentonite (0 to 15%) on clayey soil as a base liner for landfills. In achieving this aim, two clayey samples gotten from a borrow site at a depth of 1.5 and 2.0m for samples A and B respectively were modified with bentonite. Particle size analysis, moisture- density relationship and permeability tests were performed on the test and the bentonite-modified samples in accordance with relevant standards. Result shows an increasing plasticity index, and liquid limit of both samples with increasing bentonite content. Permeability and dry densities of the samples decreases on bentonite modification. The application of bentonite modified the soil as it improves their plasticity and hydraulic properties. Bentonite modification made the clayey soil suitable for use as a liner material in landfills for municipal solid waste containment.

Keywords: Bentonite modification; clayey soils; landfill; municipal solid waste.

1. Introduction

Effective liner system in landfills are essential in protecting groundwater from leachate contamination as communities depends on groundwater for consumption due to increasing contamination of available surface water sources. According to Pries and Clitus [1], engineered landfill are important sealing systems employed as containment strategy for waste disposal. It inhibits infiltration of precipitation, incidental discharge and leachate into the subsoil and groundwater. According to Daniel [2], engineered landfills is one of the best method of overcoming waste disposal crisis associated with groundwater contamination with leachate. Liner system in an engineered landfill acts as a barrier for leachate and prevents the transportation of contaminants to



the surrounding pollution prone environment. Hence, liner system in a landfill becomes one of the critical design considerations.

Waste is an unwanted substance generated from human and animal activities, its generation increases with growth in population and industrialization [3, 4]. With these large amount of waste generated, environmental concern arises in urban centres of developing nations due to tropical climatic conditions and inefficient waste disposal and management practice [5]. This concern is further reinforced with the adoption and reliance of populace of developing nations on open-dump method of waste disposal. Under this method, deposited waste are subjected to open burning as a form of waste management and control, thereby altering the atmospheric configuration and groundwater quality. Groundwater quality in dry zone is of high importance because inhabitant in this area depends on it for daily use, hence the need for effective liner system.

Clay materials [6], expansive soil [7], pond ash [8], laterite and cement kiln dust [9], fly ash, gypsum and lime [10], compacted silty loess [11], bentonite and embedded zeolite [12], bentonite [13, 14], bentonite with coated gravel [15], sand (laterite) and bentonite mixture [4, 16, 17, 18, 19], soil and lime [20] and clay and lime [21] among others were identified as a suitable material for landfill liners due to their high adsorption capacities and low hydraulic conductivity. Daniel [2] in his studies on hydraulic properties of different liners stated that landfill liner is to be of low permeable barrier which usually involves the use of clay and/or synthetic material layer. However, owing to the operational, and construction cost of synthetic materials, there is a need to access the effect of modifying the hydraulic properties of compacted clay, so as to effectively contain municipal solid waste. In the research of Ebina et al. [22], natural bentonite, which is predominantly montmorillonite in mineral composition [23] can be adopted as a mixture or individually as a liner materials for containing industrial and domestic waste. EPA [24] requirement stated that it is of utmost importance to carefully select liner materials, hence, this research investigated the effect of bentonite at varying percentages on an A-7 expansive soil in continuance and contribution to research community on liner materials.

2. Materials and Methods

2.1 Materials

Material used for this study are bentonite and natural clay soil. Clay soil used in this study is a natural clay soil collected from a borrow pit of (RCC) Reynolds construction company, along Ogbomoso-Ilorin road, Nigeria. To be precise, Aroje, Surulere local govt. Oyo state (latitude $8^{\circ} 13' N$ and longitude $3^{\circ} 40' E$) at depths of between 1.5m to 2.0m. The bentonite employed in this research work is procured off the local market where it exists in powdered form.

2.2 Methods

The basic test such as natural moisture content determination, particle size distribution and permeability were carried out both the test and stabilized samples in a quality controlled laboratory. Stabilization of two samples with bentonite clay at different percentage and atterberg's limits of the soil were performed. Engineering test generally used in the investigation of the suitability of materials proposed as a liner and mineral sealant in landfills are particle size analysis, atterberg's limit test, moisture-density relationship and permeability. These tests were performed on soil-bentonite mixture with bentonite varied with 5% increment. All test were performed in accordance to the requirement of BS 1377 [25].

2.3 Equipment adopted

Based on the provisions of BS 1377 [25], some of the equipment used are Riffle box, spatula, standard B.S. molds, Electric oven set at 105-110°C, desiccator, Cassangrandre tools, sets of spatula, permeameter, set of B.S. sieve, sieve shaker etc. Selection of this tools and equipment are selected based on the set out objectives of study.

3. Result and Discussion

3.1 Properties of test samples

Engineering properties of the test samples are presented in table 1, from the table samples A and B can be classified according to AASHTO method of classification as an A-7 soil and USCS as CL soil implying a sandy lean clay.

Table 1: Engineering properties of test soil

Properties	Sample A	Sample B
Percent passing sieve <0.075mm	57.25	55.44
Liquid limit (%)	49	48
Plasticity index (%)	14	13
Maximum dry density (g/cm ³)	1.45	1.41
Permeability(x 10 ⁻⁷ cm/s)	0.42	0.8

The analysis curve test samples A and B were presented in figure 1, it can be deduced from the curve that the co-efficient of uniformity (Cu) and curvature (Cc) presents the samples as fine-grained. Figure.1 shows the relationship between percentage passing each sieve and particle sizes which gives the proportion of silty-clay, sand and gravel present in the clayey soil sample. From figure 1, Sample A has 57% silty-clay, 33% of fine and medium sand and 10% of gravel-sized coarse sand which can be further sub-classified as 16% fine sand, and 17% medium sand. The gravel proportion was found to contain 10% of fine gravel only. Furthermore, Sample B contain 55% silty-clay, 31% of sand and 14% of gravelly sized coarse sand which was further sub-classified as 16% fine sand, 15% medium sand and 14% coarse sand. According to EPA [24], USEPA [26] requirement and Rowe et al [27], soil liner must have an hydraulic conductivity of $\leq 1 \times 10^{-7}$ cm/s, contain at least 15–20% of sample size <0.075 mm, plasticity index (PI) > 10% and coarser fragments not more than about 10% gravel-size particles. Therefore, sample A and B satisfies the requirement of a landfill liner material on the basis of index properties.

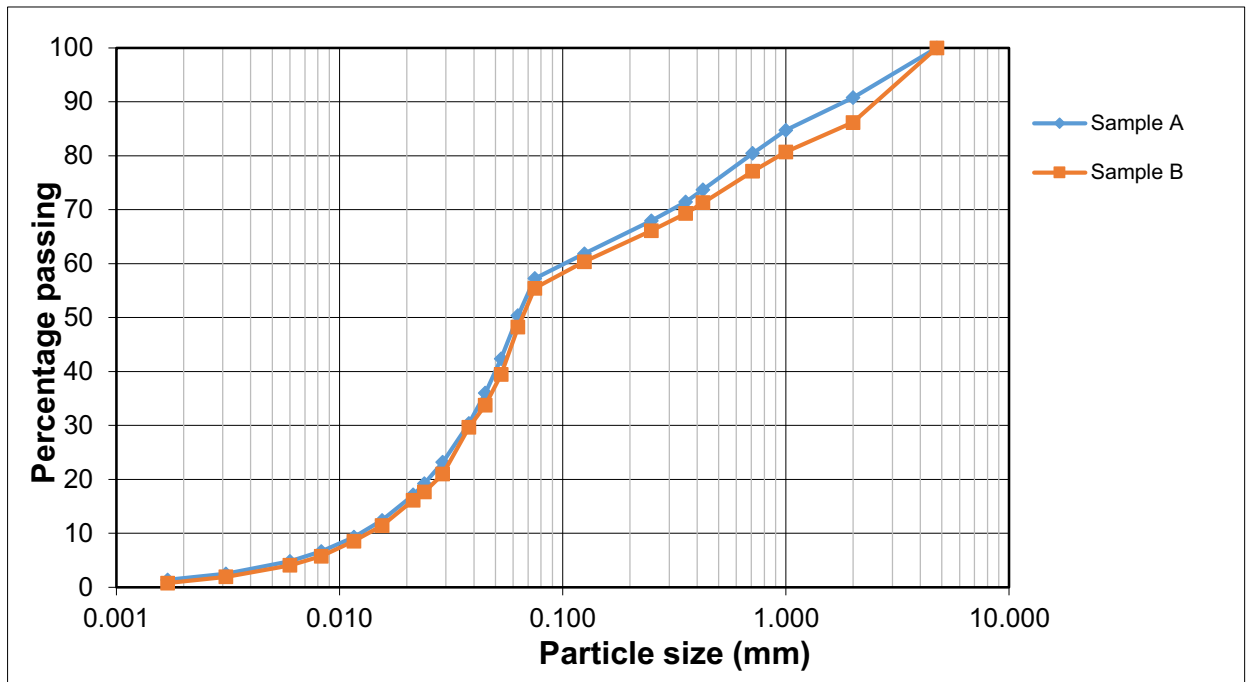


Figure 1: Sieve Analysis Graph of Sample A and B

3.2 Influence of bentonite on the engineering properties of test samples

3.2.1 Atterberg limit test.

The test of liquid limit, plasticity limit and plasticity index of the clay–bentonite mixture with a bentonite mixture of 5% increment was presented in figure 2. From this figure, it can be seen that liquid limit and plasticity index increases with increasing bentonite contents for both samples. Furthermore, the plasticity index of samples A and B has a bentonite optimal content at 5 and 15% respectively in accordance to EPA requirement, Rowe et al [27] and Benson et al [28] which stated that liner materials with high plasticity index (PI) > 30–40% are sticky and relatively difficult to work with. Hence, the addition of bentonite to test samples positively alters their plasticity properties as a base liner materials in accordance to EPA [24] requirement. Also, from Figure 2, due to the mineralogy of the mixture, there is an increasing liquid limit with corresponding increase in bentonite content.

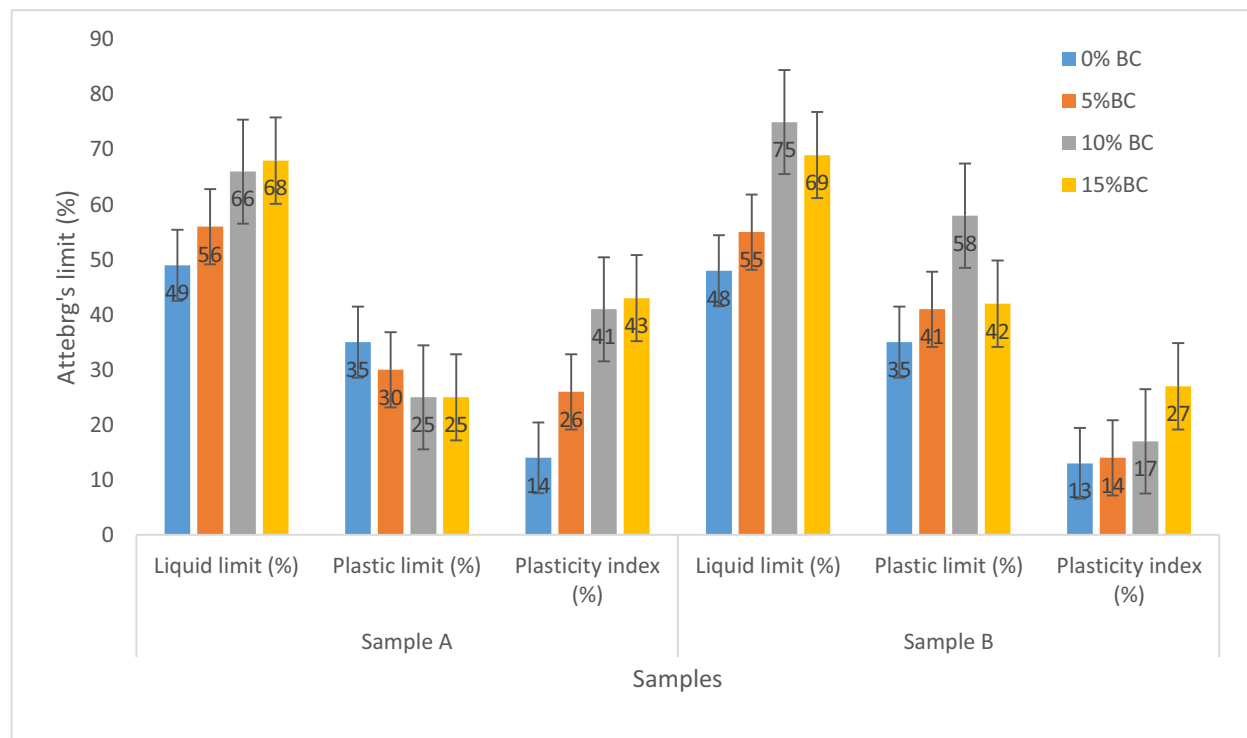


Figure 2: Influence of bentonite on plasticity properties test samples

3.2.2 Compaction Test. Compaction of soil is the re-arrangement of particles into a closer state of cohesion. Results of this new state of cohesiveness make the soil to have higher shear strength, lower compressibility and to reduce sensitivity to water content changes of the soil. The method of re-arranging soil particles in the laboratory are dynamic compaction and static compaction. Both the dynamic and static compaction may be subjected to compactive levels of British Standard (BS), West African Standard (WAS), and modified American Association of State Highways and Transportation Officials (AASHTO). But in this project work, the static and dynamic compaction was subjected to BS.

The maximum dry density and optimum moisture contents (OMCs) for bentonite modified specimens are presented in Figure 3. Marginal decrease in optimum moistures with corresponding

decrease in dry unit weights were recorded in sample B, but for sample A, OMC increases with increasing bentonite content which is an indication of an extra water required to complete the hydration process affinity for more moisture during reaction. Decreasing MDD can be attributed to immediate reactions between bentonite and the soil [9, 29].

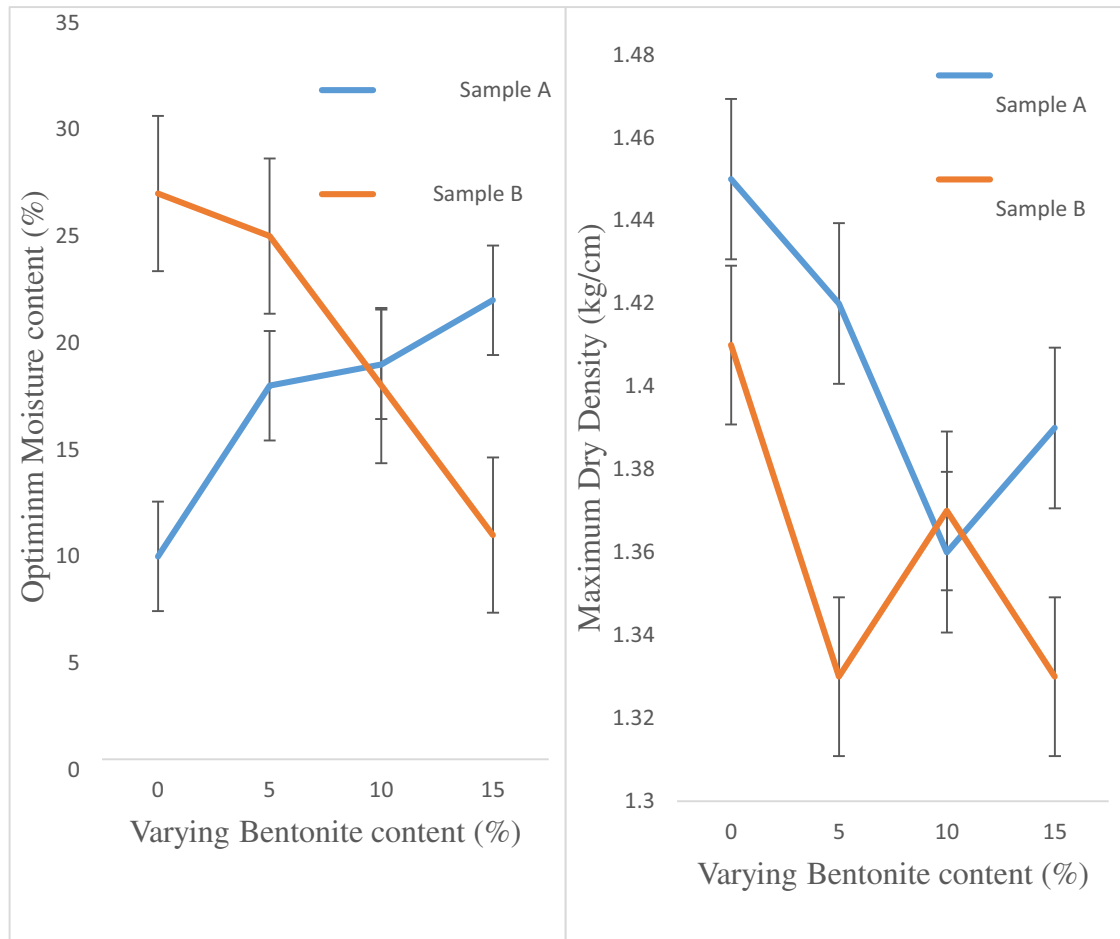


Figure 3: Influence of bentonite on compaction properties of the samples

3.2.3 Permeability test.

As shown in Figure 4, permeability of sample A ranges from $0.76 \times 10^{-7} \text{cm/s}$ to $0.42 \times 10^{-7} \text{cm/s}$ while sample B ranges from $0.89 \times 10^{-7} \text{cm/s}$ to $0.80 \times 10^{-7} \text{cm/s}$. This shows that permeability of test samples decreases with increasing bentonite addition in conformity with the test performed by Amadi and Eberemu [9], Arrua and Aissa [11] and Varma et al [8]. Furthermore, Rowe et al. [27], Benson et al. [28] and Daniel and Wu [32] stated that the hydraulic conductivity of liner materials for effective performance is to be $\leq 1 \times 10^{-7} \text{cm/s}$, a criterion that that was met for both samples at an optimal content of 15% depicting that bentonite addition to test samples positively affect the hydraulic properties of the samples.

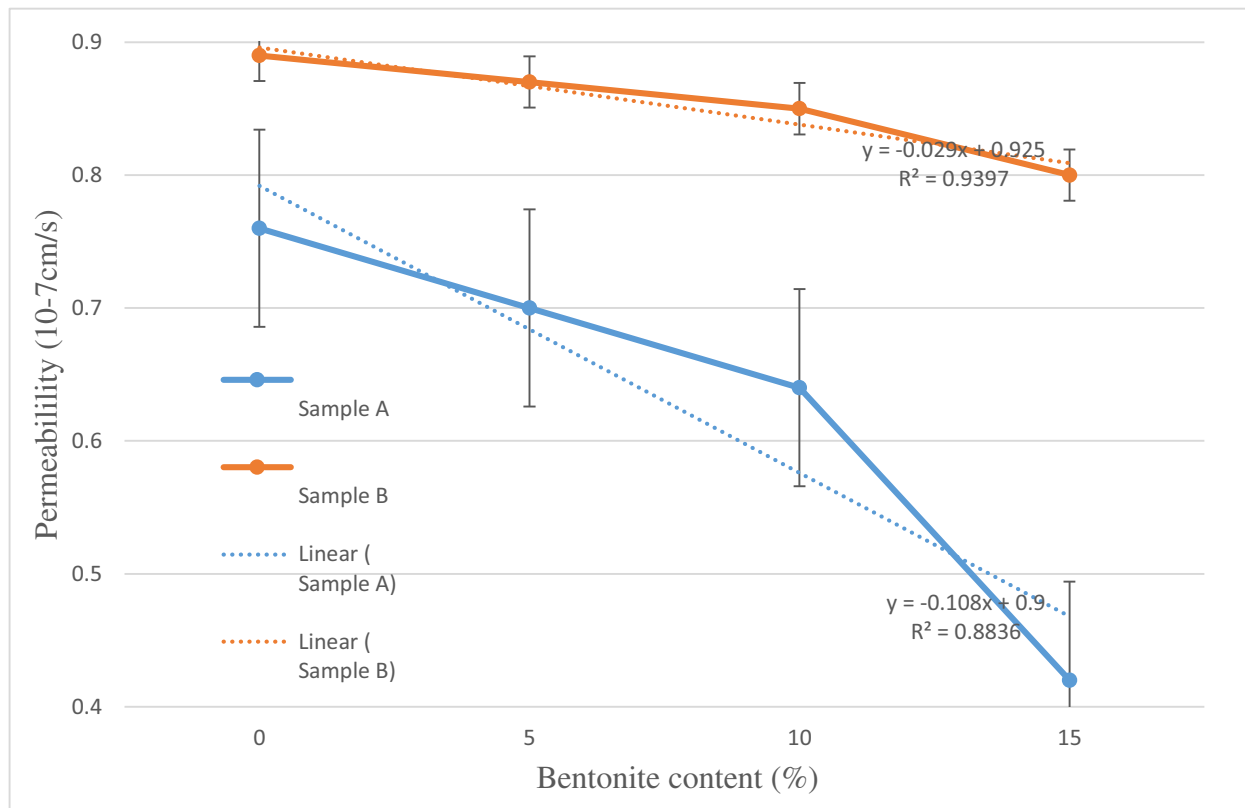


Figure 4: Permeability constant with bentonite variation on test sample

Conclusion.

Following an evaluation of the effect on bentonite on two selected clayey soil samples, the following are concluded on

- i. Gradation of both samples are in conformation with EPA requirement of a liner materials
- ii. There is an observed increase in plasticity properties of the samples with increasing bentonite content for both samples. However, in accordance with relevant literatures and standards, samples A and B has an optimal bentonite content of 5 and 15% respectively.
- iii. The hydraulic properties of the bentonite modified samples decreased with increasing bentonite content, which further reinforces their permeability property.
- iv. Clayey soil modified with bentonite can be effectively used as a liner material in landfills

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