EFFECT OF COMPACTIVE EFFORT ON THE GEOTECHNICAL PROPERTIES OF METAKAOLIN TREATED BLACK COTTON SOIL

T. S. IJIMDIYA, G. IMAM, T. IGBORO AND A. TANKO
Department of Civil Engineering, Ahmadu Bello University Zaria, Nigeria
[tsijimdiya@gmail.com]

ABSTRACT
This study examines the influence of compactive efforts on the geotechnical properties of compacted black cotton soil treated with metakaolin (MTK) to assess its suitability for use as a barrier material in waste containment application. Black cotton soil treated with up to 10% MTK (obtained from calcinations of kaolin) by dry weight of soil was used. The natural soil classifies as A-7-6(22) and Clay with high Plasticity CH according to American Association of State Highway and Transportation Officials AASHTO and Unified Soil Classification System USCS respectively. The laboratory result obtained showed that there was a significant improvement in some of the geotechnical properties of the soil. The liquid limit and plastic limit decreased from 50 and 27.38% for the natural soil to 47.1 and 16.7 % when treated with 10 % metakaolin while the plasticity index increased from 22.59 % for the natural soil to 30.93% when treated with 10 % metakaolin content The hydraulic conductivity value decreased from 1.91 x 10^{-8}, 1.81 x 10^{-8} and 1.72 x 10^{-8} to 0.38 x 10^{-8}, 0.66 x 10^{-8} and 0.66 x 10^{-8} cm/sec for the three compactive efforts of British Standard Light (BSL), West Africa Standard (WAS) and British Standard Heavy (BSH) respectively. It was recommended that MTK treated black cotton soil could be used as a liner or cover material in waste containment facilities.

Keywords: *metakaolin treatment, black cotton soil, hydraulic conductivity, compactive efforts.*

INTRODUCTION

Rapid industrialization and unsafe waste management practices in developing countries like Nigeria have resulted in complex and challenging problems in the surface and subsurface environment (Ahamefule, 2005). If not properly managed, these wastes will be a source of land, air, surface water and groundwater pollution as their common way of disposal is either by landfill or open dump. In other to minimize the effects of these wastes, one of the most attractive options of managing such wastes is to look into the possibility of waste minimization and recovery (Oluremi, *et al.,* 2012).

Research has shown that the impact of a waste disposal facility on groundwater quality will depend principally on the nature of barrier which is intended to minimize and control contaminant migration (Rowe *et al*., 1995). The primary objective of engineered components in containment facilities is to decelerate contaminant migration into the underlying subsurface during both the active disposal period and the post closure period. Barrier system is therefore one of the most important elements of a modern engineered landfill (Daniel and Benson 1990).

Compacted soil liners are normally used as an integral component of the lining system, to impede the transport of contaminants, to cover landfills, municipal and hazardous waste impoundments, and also to cap new or old waste disposal units (Daniel and Benson 1990; Benson 1999; Albrect and Benson 2001). For a compacted natural soil to be used as a hydraulic barrier it must possess a hydraulic conductivity of less than or equal to 110^{-9}m/s or 1×10^{-7} cm/sec, volumetric shrinkage upon drying (maximum of 4%) and shear strength (minimum of 200 kN/m^2. Further required characteristics of liners and the total lining systems are described in the European regulations and national document (Rogowski *et al*., 1985).Other materials used as liners or cover in waste containment systems, include natural clayey soils, processed clay/sand-processed clay mixtures, Geosynthetic materials and industrial waste products (Bowders and Daniel, 1987; Frebrer 1996; Albrecht and Benson, 2001).

Metakaolin (MTK) is refined kaolin that is fired (calcined) under carefully controlled condition to create an amorphous alumino-silicate that is reactive in concrete. Like other pozzolanas (fly ash, silica fume etc), MTK react with calcium hydroxide by-product produced during cement hydration. The ability of MTK to absorb water is not far-fetched from its chemically dehydrated nature, which results from the thermal treatments it receives in the system. The action of absorbing water (rehydrating) releases a significant amount of heat from non-weathered crust, a phenomenon that can be exploited in beneficial reuse in order to improve the inadequacy of some avoidable extensive clay material for use in waste containment facilities (Oriola and Moses 2011).

MATERIALS AND METHODS

Materials:

Black Cotton Soil: The soil used in this study was dark grey in colour and wasknown as black cotton soil, it was obtained from Cham town in Balanga Local Government Area of Gombe State in the northern eastern part of Nigeria using the method of disturbed sampling. The location lies along (latitude 09° 44'N and longitude 11° 44'E). Specimens were treated varying MTK contents of 0, 2.5, 5, 7.5 and 10% by dry weight of soil.

Metakaolin (MTK): The Metakaolin (MTK) used in this study was obtained at Kaduna state bricks industry Maraba Rido, Kaduna state. The MTK was obtained by calcinations of kaolin clay at a regulated temperature of 650 – 800 °C for 120 minutes leading to the breakdown of crystal lattice structure forming a transition phase i.e. dryness state after which it was grounded into powered form and sieved through BS No. 200 sieve.

Methods

Index Properties: Laboratory tests were conducted to determine the index properties of the natural and soil – MTKmixtures in accordance with BS 1377 (1990) and BS 1924 (1990) for the natural and treated samples respectively. A summary of the soil index properties was presented in Table 1.

Compaction: Compaction tests were carried out to determine the optimum moisture content(OMC) and the maximum dry density(MDD) using three energy levels of British Standard light (BSL), West African Standard (WAS) and British standard heavy (BSH). Air dried soil samples passing through BS sieve with 4.76mm aperture mixed with 0%, 2.5%, 5%, 7.5% and 10% metakaolin by weight of dry soil were used. The British standard light wasthe effort derived from 2.5kg rammer falling through 30cm onto three layers, each receiving 27 uniformly distributed blows; the West African standard compactive effort (WAS), carried out using energies derived from a rammer of 4.5 kg mass falling through a height of 45 cm in a 1000 cm^3 mould. The soil was compacted in five layers, each layer receiving 10 blows. The British standard heavy compactive effort (BSH), carried out using energies derived from a rammer of 4.5 kg mass falling through a height of 45 cm in a 1000 cm^3 mould. The soil was compacted in five layers, each layer receiving 27 blows.

Hydraulic Conductivity: This was measured using the rigid wall permeameter under falling head condition as recommended by Head (1992). A relatively short sample was connected to a standpipe, which provided the head of water flowing through the sample. Compacted soil –Metakaolin samples at optimum moisture content with varying Metakaolin contents up to 10 % compacted using BSL, WAS and BSH compactive efforts, respectively was used to run the falling head permeability test. Specimens were soaked in a water tank after compaction for a minimum period of 24 hours to allow for full saturation and the samples were restrained from swelling vertically during saturation. The fully saturated test specimen were then connected to a permeant liquid (tap water).

During permeation, test specimens were free to swell vertically (i.e., no vertical stress was applied). Hydraulic gradient ranged from 5 to 15.Tests were only discontinued when hydraulic conductivity readings were steady.

RESULTS AND DISCUSSION

Index Properties: Results of tests carried out on the natural soil are summarized in Table1. The soil was classified under the A – 7 – 6 (22) according to American Association of State Highway and Transport Officials AASHTO classification or CH according to the Unified Soil Classification System, (USCS).

Table 1: Properties of the natural soil

Property	Quantity
Percentage Passing BS No. 200 Sieve	86.5
Natural Moisture Content, %	39.1
Liquid Limit, %	50
Plastic Limit, %	27.4
Plasticity Index, %	22.5
Linear Shrinkage, %	17.56
Free Swell, %	40
Specific Gravity	2.49
AASHTO Classification	A-7-6 (22)
USCS	CH
NBRRI Classification	Low swell potential
Maximum Dry Density, Mg/m^3	
British Standard light	1.65
West African Standard	1.73
British Standard heavy	1.75
Optimum Moisture Content, %	
British Standard light	21
West African Standard	18.3
British Standard heavy	17.3
Hydraulic conductivity (K) cm/sec	
British Standard light	1.90×10^{-8}
West African Standard	1.81×10^{-8}
British Standard heavy	1.71×10^{-8}
Dominant clay mineral	Montmorillonite

Atterberg Limit

The Liquid and Plastic limits decreased with increasing metakaolin treated black cotton soil content from 50and 27.38%for the natural soil to 47.1 and 16.7 % when treated with 10 % metakaolin. The overall decrease in liquid limit could be attributed to the cation exchange reaction that liberated adsorbed water particles in the soil leading to the flocculation and aggregation of the soil particles and the accompanying reduction in surface area and increase in strength (Ijimdiya *et al.,* 2012).Plasticity index values increased from 22.59 % for the natural soil to 30.93% when treated with 10 % metakaolin content. The increase in the plasticity index is a manifestation of the cation exchange reaction between the additive where the higher valence cations in the cement and GSA replaced the weakly bonded ions.

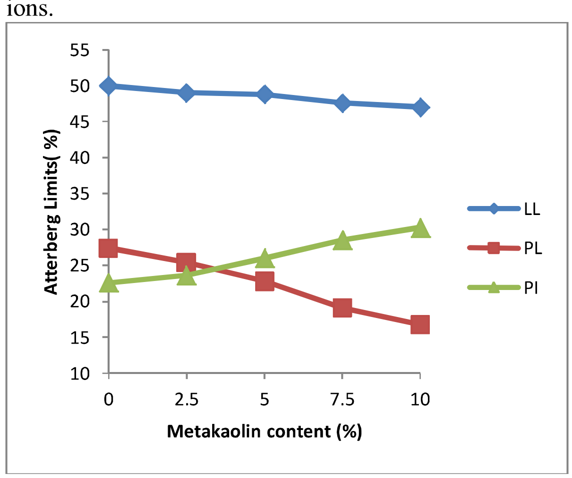

Figure1: Variation of Atterberg limits with matakaolin content.

Maximum Dry Density: The results of maximum dry density (MDD) for samples compacted using BSL, WAS and BSH compactive efforts was shown in Figure 2. MDD values decreased from 1.65, 1.73 and 1.75 Mg/m^3 for the natural soil to 1.53, 1.67 and 1.68 Mg/m^3. The MDD of black cotton soil decreased with higher doses of metakaolin. The reduction in MDD may not be unconnected with the replacement of soil by metakaolin in the mixture which has relatively lower specific gravity of 2.1 compared to that of the natural soil of 2.49. The decrease may also be attributed to the resistance offered by the flocculated soil (Okafor and Okonkwo, 2009; Neeraja, 2010; Osinubi and Stephen, 2007).

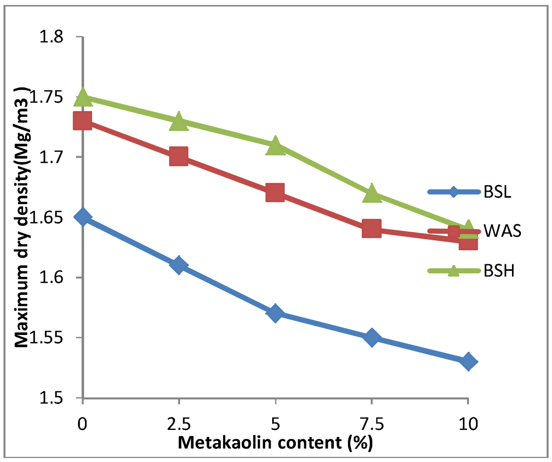

Figure 2: Variation of Maximum Dry density with Matakaolin content.

Optimum Moisture Content: The OMCs of natural and metakaolin treated black cotton soil was shown inFigure 3. For specimens compacted usingBSL and WAS compaction energies an increase in OMC was recorded. The OMC values obtained for the natural soil compacted using BSL and WAS increased from 18.8 and 17.4 %to 29.8 and 25.5 %, respectively. While the OMC values of metakolin treated samples decreased from 17 to 16 % with higher doses of the additive when compacted using BSH compactive effort. The increase in OMC may be attributed to the addition of metakaolin which decreased the silt and clay-sized fraction and forming coarser materials with larger surface area. This may also not be unconnected with additional water held within the flocculated soil (Osinubi, 1995).

Hydraulic Conductivity: Hydraulic conductivity is the key parameter affecting performance of liners and cover (Daniel 1993b, 1990).The variation of hydraulic conductivity with metakaolin content was shown in Figure 4. Generally, the hydraulic conductivity values decreased with higher doses of metakaolin content. The hydraulic conductivity for the natural soil decreased from 1.91×10^{-8},1.81×10^{-8} 1.71×10^{-8} to 3.8×10^{-10}, 5.6×10^{-10} and 6.6×10^{-10} cm/sec when treated using 10 % metakaolin compacted using BSL, WAS and BSH compactive efforts, respectively. These values all met the recommended hydraulic conductivity value of $< 1.0 \times 10^{-7}$ cm/sec as given by regulatory agencies (Benson and Daniel, 1990). The decreases in hydraulic conductivity valued may not be unconnected to the decrease in the micro scale pore spaces of the sample and water content which facilitates deflocculation of the particle structure, reducing the void. This was shown in Figure 5 and 6 as the void ratio progressively decreased with higher metakaolin contents. This was in conformity with the findings of other researchers (Lambe, 1958 Mitchell *et al.*1965; Benson and Daniel, 1990; Osinubi and Nwaiwu, 2009 Umar *et al*, 2015.).

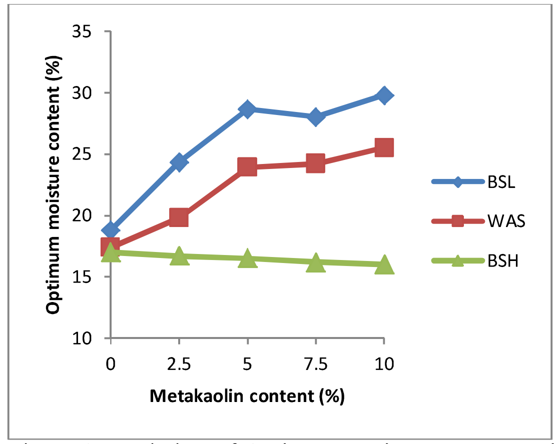

Figure 3: Variation of Optimum Moisture content with Metakaolin content.

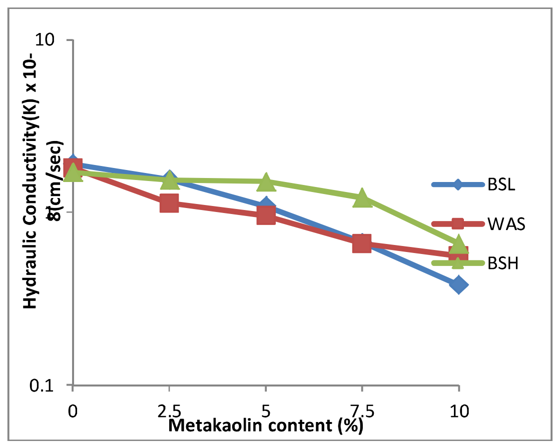

Figure 4: Variation of Hydraulic Conductivity with Metakaolin content.

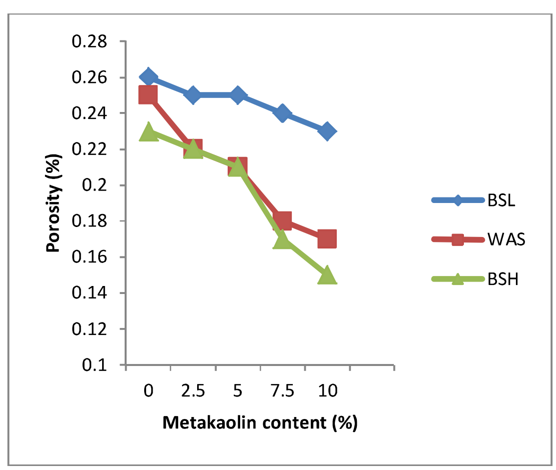

Figure 5: Variation of porosity with Metakaolin content.

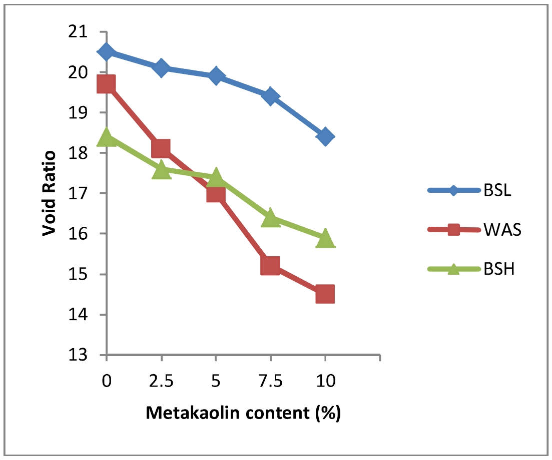

Figure 6: Variation of void ratio with Metakaolin content.

CONCLUSION

- The natural black cotton soil was obtained from Cham town in Balanga Local government Area of Gombe State in the north eastern part of Nigeria. It falls under A-7-6 (22) according to AASHTO classification and CH according to USCS.
- The liquid and plastic limits decreased from 50 and 27. 4% to 47.1 and 16.7 %, while the plasticity index increased from 22.59 to 30.93% with higher doses up to optimal 10%MTK. This show improvement in the properties of the soil
- The hydraulic conductivity, void, ratio and porosity of metakolin treated black cotton soil decreased with higher amounts of the additive up to 10 % metakaolin contents by dry weight of soil.
- The hydraulic conductivities of metakolin treated black cotton soil met the specified maximum hydraulic conductivity of 1 $\times 10^{-7}$ cm/sec required for materials suitable for use in waste containment facilities.

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