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The Impact of Time on the Properties of Cement-Stabilised Soil Intended for Use as Bottom Liner in Municipal Solid Waste Landfills

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ABSTRACT: *Classification, compaction, CBR and hydraulic tests were undertaken on soil samples obtained from two borrow pits in Ado Ekiti, Nigeria. Classification using the BS 5930 indicated soil A as clay with a high plasticity and soil B as silt with a low plasticity. Similarly, AASTHO classification indicated soil A as soil type A-7-5 and soil B as A-4. The soils were stabilised with 2.5%, 5%, 7.5% and 10% cement respectively. The maximum dry density and CBR of the stabilised soils increased with the increasing cement content andlength of timefrom mixture totesting of the composites. The saturated hydraulic conductivity of the stabilised soils decreased with increased cement content and time period totesting. More importantly, the effect of period of time to testing on the saturated hydraulic conductivity was significant as the values of the stabilised soils with 10% cement content decreased from 4.48×10^{-5} m/sto 1.09×10^{-9}m/s at 28 days. It was concluded that the essential properties of the cement-stabilised soil intended for use as bottom liner in MSW landfills improved with age.*

Keywords: *stabilisation, time, soil, compaction, hydraulic conductivity*

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I. INTRODUCTION

Owing to a growing population and increased wealth, the management of solid waste has become very important for sustainable development in the world. It is reported that the global wealth increased in capital terms by 17% between 1995 and 2005 [1]. No wonder the volume of waste generated in world cities is expected to increase from 1.3 billion tonnes in 2012 to 2.2 billion tonnes in 2025. In fact, it is projected that the generation of solid waste will be more than double in low income countries in the next twenty years [2]. Waste management is particularly imperative as human needs such as clean water, clean air and safe food are severely affected by inadequate management of solid waste, often resulting to great damage on public health [3].

Whereas efforts have been made to improve the management of solid waste in the developed countries [4, 5], uncontrolled disposal of solid waste remains persistent in the poor countries of the world. One of the reasons likely to influence the negative attitude of governments in the developing countries of the world to effective waste management is the lack of funds as integrated waste management is capital-intensive. It is not surprising as poor countries in the world, which constitutes 10 percent of the global population accounts for less than 1 percent of the global wealth [1]. The belief that soil and water bodies provide natural attenuation of pollutants and thus absolute protection of the environment from the ills of anthropogenic activities had been disproved by several cases of groundwater pollution due to the disposal of solid waste in non-engineered landfills-open dumps [6-13]. These have caused health problems among the people living in the vicinity such dumps [14-17]. The use of engineered landfills, which commonly comprise a composite bottom liner, protects the immediate environment of the disposal sites from air, soil, surface water and groundwater pollution respectively [18, 19]. The majority of the modern municipal solid waste (MSW) landfills consist of composite layer of compacted clay overlain by flexible membrane layer, usually high density polyethylene [20, 21] or Geosynthetic clay liners (GCLs), which is arelatively thin layer of clay-bentonite fixed between two sheets of geotextile [22]. The compacted clay liners usually have hydraulic conductivity less than $1\text{x}10^{-9}$m/s [23]. In developing countries such as Nigeria where financial resources for waste management are scarce, it is mandatory to devise low-cost methods to minimize the increasingly unabated pollution owing to disposal of MSW at open dumpsites since it is very expensive to remediate any polluted surface water and groundwater. By doing this, human health, ecology and indeed the environment will be safeguarded. As it may be difficult for the majority of locally available soils to meet the permeability requirement of less than $1x10^{-9}$m/s [18, 24], a low-cost solution is to stabilise the soils to improve its properties, especially the hydraulic conductivity, whose minimum value requirement is stated in the regulation of MSW landfills.

Some researchers in Nigeria have reported improved properties of soils owing to stabilisation, however, the focus has been mainly on the compressive strength of the stabilised soils [25-27], except few instances where hydraulic properties have been improved as a result of the admixture comprising blast furnace slag, and also cement kiln dust [28, 29]. In these studies, the parameters were tested as soon as the samples were brought to the laboratory. Since the characteristics of composites comprising cement, water and materials such as aggregates changes with time owing to hydration, it is therefore necessary to study the effect of time on cement-stabilised soils to be used as bottom liners in MSW landfills. As it is generally accepted that concrete, which is a composite material that consists of water, cement, fine and coarse aggregates attains approximately 90% of its strength after 28 days of curing [30], the impact of time (age) on the properties of cement-stabilised soil has been studied up to 28 days in this paper.

II. MATERIALS AND METHODS

Soil samples were carefully obtained from selected borrow pits in Ado Ekiti, at depths just below the top soil, using the standard method. Sample A was obtained from the borrow pit along IlaweEkiti Road while sample B was obtained from the borrow pit along IjanEkiti Road. The samples were taken to the laboratory in suitable plastic bags to minimise adverse weather effects. The samples were mixed with ordinary Portland cement at varying proportions of 2.5%, 5%, 7.5% and 10%. A maximum cement content of 10% was used owing to previous studies that indicated this quantity as the optimal percentage for soil cement mixtures [31, 32]. Laboratory tests to determine the moisture content, sieve analysis, Atterberg limits, compaction test, California bearing ratio and hydraulic conductivity were undertaken on the samples in accordance with BS 1377 (1990). All the samples to be tested were mixed with the varied cement content in first day. The initial samples were tested in the first day while the other samples were kept in suitable plastic bags till being tested on the 7^{th} and 28^{th} day respectively.

III. RESULTS AND ANALYSIS

The natural properties of the soils are presented in Table 1. Using the BS 5930, soil A can be classified as clay that has a high plasticity while soil B can be classified as silt that has a low plasticity. In the AASTHO classification, soil A can be classified as soil type A-7-5 while soil B can be classified as A-4. The high values of the maximum dry density of the soils are indicative of high structural and mechanical strength of the soil particles. The reddish-brown colour of the soils is synonymous with tropical lateritic soils, which are prevalent in Ado Ekiti. The values of the saturated hydraulic conductivity of the soils are less than the stipulated values of $1x10^{-10}$ ms^{-1} for basal liners in MSW landfills

The relationship between the maximum dry density and various degree of cement stabilisation of the soils for variouslengths of time from mixture to testing of the compositesis shown in Figures 1 and 2 respectively. The maximum dry density of the soils increased with an increase in the cement content. Similarly, the maximum dry density of the stabilised soils increased with increase in length of time to testing.This can be explained in terms of hydration of the ordinary Portland cement in composite mixture. As soon as the soils were mixed with the cement, the calcium silicates, which are the main compounds responsible for strength in cement, reacted with the inherent (natural)water in the soils to form hydrates. The volume of the hydrate formed would depend on the volume of inherent water in the soils. Since hydrates normally harden with time, they were likely responsible for the observed increase in maximum dry density with elapsed time of the mixture of the soils with cement. As the amount of hydrates formed depends on the volume of cement, it is apparent that the observed increase in the maximum dry density of the stabilised soils with increasing cement content was also due to the increased hydrates. This phenomenon can also be used to describe the increased values of CBR for the stabilized soils, as shown in Figures 3 and 4 respectively. The hardened binding hydrates acted as hard gels that created resistance to the CBR loading, therefore increasing it values with increasing cement content and age of the stabilised soils. The saturated hydraulic conductivities for the stabilised soils are depicted in Figures 5 and 6 respectively. Generally, the saturated hydraulic conductivities decreased with increase in the cement content and length time to testing of the stabilised soils, however, the impact of time on the saturated hydraulic conductivity of the stabilised soils was more than the cement content, especially for clay.

Table 1: Properties of the soils

Properties	Values	
	Soil A	Soil B
Natural moisture content (%)	17	12
Liquid limit	53.2	35.3
Plastic limit (%)	36.8	30.1
Plastic Index (%)	17	5.2
Gravel content (%)	12.5	18.2
Sand content (%)	25.7	45.6
Silt/Clay content (%)	61.8	36.2
Maximum dry density (kg/m^3)	1860	1860
Optimum moisture content (%)	18.22	18.66
Hydraulic conductivity (m/s)	5.9×10^{-5}	7.63×10^{-5}
Classification according to BS 5930	CLAY of high plasticity	SILT of low plasticity
AASTHO classification	A-7-5	A-4
Colour	Reddish Brown	Reddish Brown

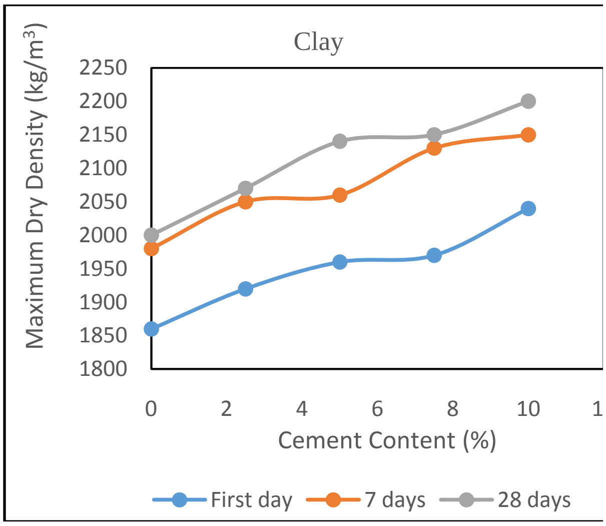

Figure 1: Maximum Dry Density versus Cement Content at First Day, 7 Days and 28 Days Clay

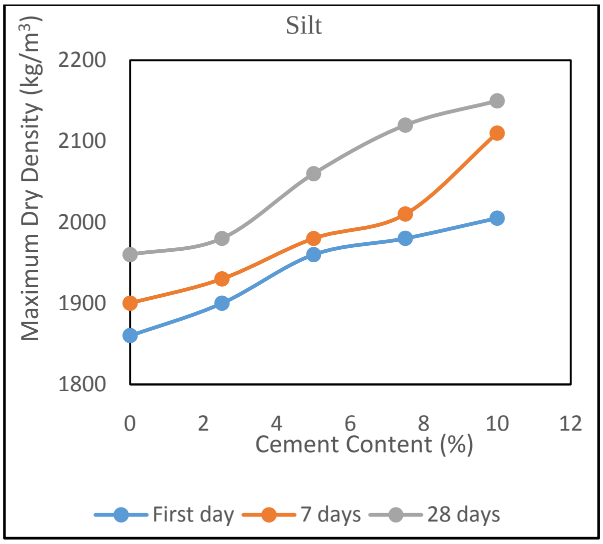

Figure 2: Maximum Dry Density versus Cement Content at First Day, 7 Days and 28 Days for Silt

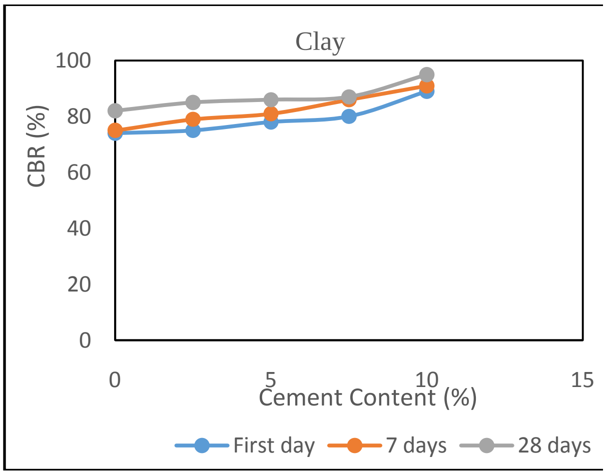

Figure 3: CBR versus Cement Content at First Day, 7 Days and 28 Days for Clay

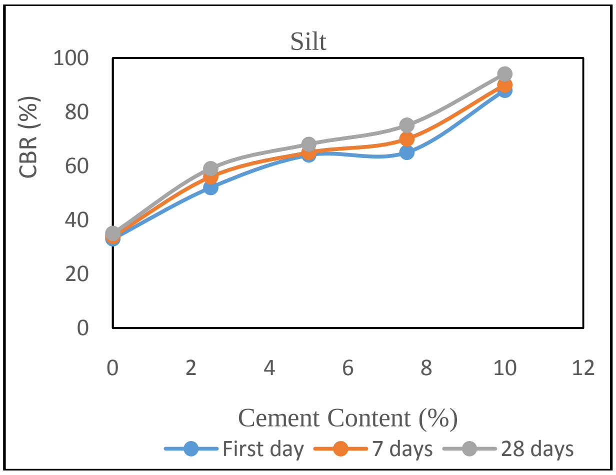

Figure 4: CBR versus Cement Content at First Day, 7 Days and 28 Days for Silt

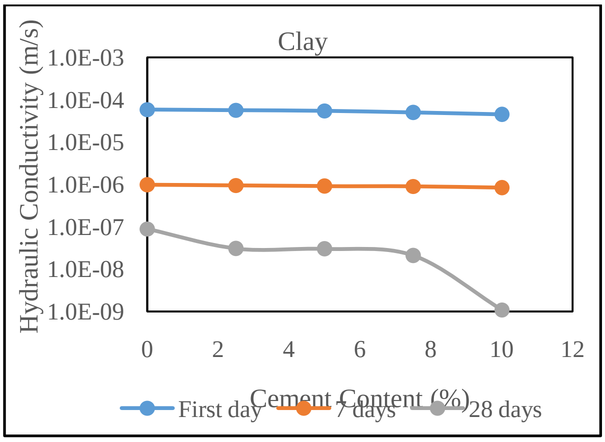

Figure 5: Saturated Hydraulic Conductivity versus Cement Content at First Day, 7 Days and 28 Days for Clay

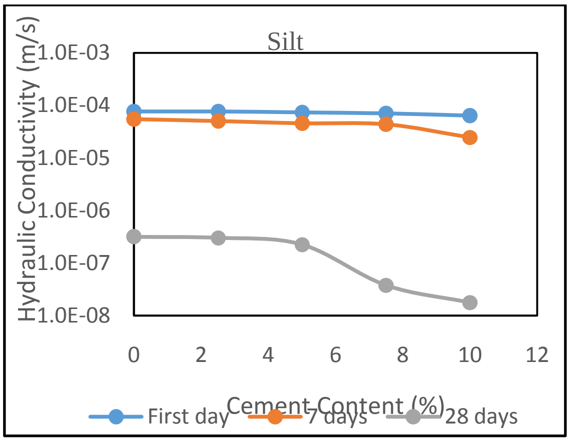

Figure 6: Saturated Hydraulic Conductivity versus Cement Content at First Day, 7 Days and 28 Days for Clay

The saturated hydraulic conductivities of 10% cement-stabilised clay and silt at 28 days were 1.09 x10^{-9}m/s and 1.78 x10^{-8} m/s respectively while on the first day were 4.48 x10^{-5}m/s and 6.35 x10^{-5} m/s respectively. Therefore, reporting the test values obtained during the first day will seriously underestimate the capability of the stabilised soils as barrier to moisture flow. As the value of saturated hydraulic conductivity is the major characteristic requirement for bottom liners used in MSW landfills, it is thus imperative that permeability tests undertaken to determine the suitability of cement- stabilised materials should consider the temporal properties of such mixtures. Bearing in mind that the length of time from mixture to testing of the composites is the age of the stabilised soil at the time of testing in this study, it can be concluded that the principal properties of cement-stabilised soil to be used as bottom liner in MSW landfills will improve with age.

IV. CONCLUSION

According to BS5930, soil A and Soil B used in this study can be classified as clay with a high plasticity and silt with a low plasticity respectively. According to AASTHO classification, soil A can be classified as soil type A-7-5 and soil B can be classified as A-4. Results showed that the maximum dry density and CBR of the stabilised soils increased with increase in cement content and length of time to testing of the composites. The saturated hydraulic conductivity of the stabilised soils also decreased with increase cement content and length of time to testing of the composites. The decrease in saturated hydraulic conductivity of the stabilised soils was however most significant in the 10% cement-stabilised clay, which was tested at 28 days. In general, length of time from mixture to testing of the composites significantly affected the properties of the cement-stabilised soils, and thus, studies involving suitability of cement-stabilized soil as bottom liner should be carried out over a period of at least 28 days, as it is done when determining concrete strength.

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