Consistency Characteristics and Behaviors of Eggshell Powder Stabilized Black Cotton Soil on Basement Complex of Part of South-Western Nigeria

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Abstract: *Expansive soils are one of those kinds of soils whose volume change takes place while it comes in contact with water. Therefore, prior to construction of a road on such sub-grade, it is important either to remove the existing soil and replace it with a non-expansive soil or to improve the engineering properties of the existing soil by stabilization using additives which are sourced locally. The black cotton (expansive) soil was obtained from a borrow pit on the basement complex at Igbo-Ora in Oyo State, South-Western Nigeria. The borrow site lies within the coordinates Longitude 7 ^{0}24'45" and latitude 3 ^{0}18'34". The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The eggshell wastes were taken from Obasanjo Farms, Ota, Ogun State, Nigeria. The eggshells were milled into powder and then substituted for black cotton soil from 0% to 30% at 10% intervals while 0% eggshell powder substitution served as control experiment. In line with BS 1377 (1990) and other relevant codes, consistency tests were conducted on the composite materials of black cotton (on basement complex) mixed with varying degrees of eggshell powder for the determination of liquid limit, plastic limit, shrinkage limit, etc. It is evidently clear from the results that the percentage shrinkage limit became constant at 30% eggshell powder substitution in black cotton soil on basement complex which is an indication of constancy of volume.*

Keywords: *Black Cotton Soil, Consistency, Basement Complex, Eggshell Powder*

Introduction

Waste could be converted to wealth by using it as a stabilizer in black cotton soil due to the peculiar problems of swelling and shrinkage of the soil, since few years ago, the use of local materials in the construction industry has been campaigning by the stakeholders to limit costs of construction. There have been several calls for the sourcing and development of alternative to lime for stabilization, agro-based such as eggshell and, non-conventional local construction materials in view to harness the maximum potential of agricultural waste in agricultural sector. However, road built on black cotton soil experience early failure particularly in pavement with heavy traffic. In many situations, soils cannot be used directly as road service layers, foundation layers and as a construction material; hence the properties of those soils should be changed. Expansive soils are one of those kinds of soils whose volume change takes place while it comes in contact with water and it expands during the rainy season due to intake of water and shrinks during dry season. The wetting and drying process of a sub-grade layer composed of black cotton soil result into failure of pavements in form of settlement and cracking. Therefore, prior to construction of a road on such sub-grade, it is important either to remove the existing soil and replace it with a non-expansive soil or to improve the engineering properties of the existing soil by stabilization using additives such as eggshell powder and palm kernel shell which is source locally. Stabilization of the expansive soil can be of great value in improving the strength or bearing capacity of soil through controlled compaction test with suitable admixtures or stabilizers. Soil is a naturally occurring material which needs to be stabilized to increase the strength and durability as well as design life of civil engineering projects. Properties of soil vary according to location, physical properties and so on. Different methods are available to stabilize the soil and the method should be first analyzed in the soil laboratory using the soil material before applying it on the field conditions. The basic property of the soil should be good strength and load bearing capacity so that external loads can be transferred to the layers below effectively without encountering any structural failure; therefore it is paramount to enhance the desired properties of those soils (Billman, 1976; BS1377, 1990; Chen, 1975; Elinwha and Mohmood, 1986; Egbuniwe, 1982; Faridi and Arabhosseini, 2018; Gundaliya and Oza, 2013; Kameswara, 1998; Kogbe, 1976; Kogbe and Obialo, 1976; Kosun, 1990; Lung et al. 2011; Okonkwo et al. 2012; Omatsola and Adegoke, 1981; Rahaman and Ocan, 1978; Sensale, 2009; Udoeyo et al. 2006).

Background Study

Stabilization of soil needs be cheap to handle, long-term physical and chemical alteration of soil will improve their physical properties which can increase shear and unconfined compressive strength and in return permanently lower the soil permeability. The major principles of soil stabilization are to evaluate the soil properties, to decide lacking property of soil, choosing the effective method for stabilization and designing the stabilized soil mix sample. Gradation of the soil is also a very important property which is considered where the soil may be well – graded. This is desirable as it has less number of voids or uniformly graded which could sound stable but has more voids. However it is important to mix different types of soils together to improve the soil strength properties because it is very expensive to replace the problematic soil completely during construction. Advantages of soil stabilization are effective utilization of locally available soils and other suitable stabilizing agents. It is more economical both in terms of cost and energy to increase the bearing capacity of the soil and to provide more stability to the soil as embankment construction material leading to increase in workability and durability. Soil stabilization is used in many sectors of the construction industry such as roads, parking lots, airport runways, building sites, landfills, etc. The use of soil stabilization for slope protection, dam cores, impervious liners are feasible based on both economical and service life considerations. Water infiltration weakens the underlying soil and variable vehicular wheel loads moving on the surface layer will damage the pavement structure, therefore, the use of chemical stabilization in roadway design speaks directly to these issues of long - term life - cycle stability of the soil. Okeke et al. (2020) investigated Atterberg limits on samples of expansive soils derived from Imo Shale on Anambra Basin, in order to infer their behavior. The liquid limits range from 33-56% while the plasticity index value range from 30-31%. The results have shown that the samples fall into clay of high plasticity with corresponding and high swelling potentials. Soils with high/medium swelling potentials tend to have moderate/high compression index. The growing concern over environmental degradation due to borrowing of large quantity of soil and aggregates for construction of pavement has made the search for new techniques of stabilization. The sub-grade soil should have high maximum dry density (MDD) and low optimum moisture content (OMC) so that it can take up the load of the overlying layers and the traffic. The high MDD and corresponding OMC can be achieved by stabilizing the soil using suitable stabilizer (Billman, 1976; BS1377, 1990; Chen, 1975; Elinwha and Mohmood, 1986; Egbuniwe, 1982; Faridi and Arabhosseini, 2018; Gundaliya and Oza, 2013; Kameswara, 1998; Kogbe, 1976; Kogbe and Obialo, 1976; Kosun, 1990; Lung et al. 2011; Okonkwo et al. 2012; Omatsola and Adegoke, 1981; Rahaman and Ocan, 1978; Sensale, 2009; Udoeyo et al. 2006).

The effect of using Nano Polymer called SoilTech MK III as a stabilizer to improve the properties of black cotton soil collected from Ranibennur region, Karnataka, India were determined (Kartikey et al. 2012). The property of black cotton soil can be effectively improved by using varying percentage of lime contents from 3% to 5%. By the experimental analysis in the laboratory it was observed that addition of 3% of lime to the BC soil, there is a considerable decrease in the liquid limit by 2.70% while with 5% addition of lime reflects a decrease of 15.27%. In addition, there is an increase in MDD by 6.29% and 5.59% at 3% and 5% lime content respectively. The liquid limit of black cotton soil continuously decreases with increase in percentage of lime content. Plasticity index of black cotton soil will also decrease with increase in lime fine content. Optimum moisture content increases with decrease in dry density for an increase in lime content in the soil, whereas the optimum moisture content decreases with increase in MDD. With the increase in the plasticity index induces decrease in the angle of internal friction and the compaction characteristics were observed to be fair for black cotton soils (Billman, 1976; BS1377, 1990; Chen, 1975; Elinwha and Mohmood, 1986; Egbuniwe, 1982; Faridi and Arabhosseini, 2018; Gundaliya and Oza, 2013; Kameswara, 1998; Kogbe, 1976; Kogbe and Obialo, 1976; Kosun, 1990; Lung et al. 2011; Okonkwo et al. 2012; Omatsola and Adegoke, 1981; Rahaman and Ocan, 1978; Sensale, 2009; Udoeyo et al. 2006).

Methodology

The black cotton (expansive) soil was obtained from a borrow pit on the basement complex at Igbo-Ora in Oyo State, South-Western Nigeria. The borrow site lies within the coordinates Longitude 7^{0}24'45" and latitude 3^{0}18'34". The black cotton soils used in the study were collected from depths between 0.3-1.0m below ground level. The eggshell wastes (Figure 1b) were taken from Obasanjo Farms, Ota, Ogun State, Nigeria. The eggshells were milled into powder (Figure 1c) and then substituted for black cotton soil from 0% to 30% at 10% intervals while 0% eggshell powder substitution served as control experiment. In line with BS 1377 (1990) and other relevant codes, consistency tests were conducted on the composite materials of black cotton (on basement complex) mixed with varying degrees of eggshell powder for the determination of liquid limit, plastic limit, shrinkage limit, etc (Joseph E. B., 1981: Ola, (1983); Craig, 1987; BS 1377, 1990; Olarewaju and Tella, 2022).

Figure 1: (a) Black Cotton (Expansive) Soil (b) Eggshell (c) Eggshell Powder

Results and Discussion

The results of consistency tests (liquid limit, plastic limit, shrinkage limit, etc.) for various substitutions of eggshell powder in black cotton soil on basement complex from 0% to 30% substitutions with 0% serving as control experiment are presented in tabular forms in Tables 1 to 5 respectively. Less emphasis is laid on 5% eggshell powder substitution. From the results shown in Table 1, the percentage moisture content varies from 39.8 to 36.4% in descending order while the corresponding number of blows varies from 13 to 49. The percentage moisture content for plastic limit determination varies from 27.5 to 25.3% in descending order and shrinkage limit is 1.8cm. In addition to this, from the results shown in Table 3, the percentage moisture content varies from 45.8 to 34.2% in descending order while the corresponding number of blows varies from 16 to 46. The percentage moisture content for plastic limit determination varies from 24.6 to 23.2% in descending order and shrinkage limit is 1.6cm. Furthermore, from the results shown in Table 4, the percentage moisture content varies from 35.8 to 37.6% in descending order while the corresponding number of blows varies from 16 to 46. The percentage moisture content for plastic limit determination varies from 32.5 to 30.3% in descending order and shrinkage limit is 2.0cm. Finally, from the results shown in Table 4, the percentage moisture content varies from 33.8 to 28.8% in descending order while the corresponding number of blows varies from 14 to 49. The percentage moisture content for plastic limit determination varies from 22.8 to 20.4% in descending order and shrinkage limit is 1.9cm. It is evidently clear from the results that the percentage shrinkage limit became constant at 30% eggshell powder substitution in black cotton soil on basement complex which is an indication of constancy of volume. This is an indication that the optimum percentage substitution of eggshell powder in black cotton soil on basement complex is 30%. This is similar to the conclusion of Olarewaju and Tella (2022) and Olarewaju and Bamisaye (2022). In geo-mechanics, cohesion limit is that moisture content at which soil crumbs, just stick together while sticky limit is that moisture content at which soil just stick to a metal surface such as a spatula blade. In addition to this, a shrinkage limit is the moisture content below which the soil is non-plastic. Furthermore, liquid limit is that moisture content below which the soil behaves as a plastic material, at this moisture content, the soil in on the verge of becoming a viscous fluid. The liquid limit is sometime used to estimate settlement in consolidation problems (Joseph, E. B. 1981).

Table 1: Results of Consistency Test on 0% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Basement Complex

Liquid Limit Determination				
Moisture can no	ORA 1	ORA 2	ORA 3	ORA 4
Percentage moisture content %	45.8	43.8	40.4	37.6
No of blows	16	23	30	46

Plastic Limit Determination

Plastic Limit Determination		
Moisture can no	ORA 5	ORA 6
Percentage moisture content %	32.5	30.3

Percentage Shrinkage Limit Determination	
Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.6

Table 2: Results of Consistency Test on 5% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Basement Complex

Plastic Limit Determination

Moisture can no	ORA 35	ORA 36
Percentage moisture content %	28.9	27.3

Percentage Shrinkage Limit Determination

Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.4

Table 3: Results of Consistency Test on 10% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Basement Complex

Liquid Limit Determination

Moisture can no	ORA 37	ORA 38	ORA 39	ORA 40
Percentage moisture content %	39.8	39	37.4	36.4
No of blows	13	22	39	49

Plastic Limit Determination

Moisture can no	ORA 41	ORA 42
Percentage moisture content %	27.5	25.3

Percentage Shrinkage Limit Determination

Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.4

Table 4: Results of Consistency Test on 20% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Basement Complex

Liquid Limit Determination

Moisture can no	ORA 43	ORA 44	ORA 45	ORA 46
Percentage moisture content %	35.8	35.2	34.6	34.2
No of blows	12	23	36	45

Plastic Limit Determination

Moisture can no	ORA 47	ORA 48

Percentage moisture content %	24.6	23.2

Percentage Shrinkage Limit Determination	
Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.2

Table 5: Results of Consistency Test on 30% Replacement of Eggshell Powder in Black Cotton Soil (Control) on Basement Complex

Liquid Limit Determination				
Moisture can no	ORA 49	ORA 50	ORA 51	ORA 52
Percentage moisture content %	33.8	32.4	30.4	28.8
No of blows	14	24	38	49

Plastic Limit Determination		
Moisture can no	ORA 53	ORA 54
Percentage moisture content %	22.8	20.4

Percentage Shrinkage Limit Determination	
Length of Wet soil (cm)	14.2
Length of Dry soil (cm)	12.3

Conclusion

Consistency characteristics and behaviors of stabilized black cotton soil on basement complex have been investigated. From the results, it is evidently clear from the results that the percentage shrinkage limit became constant at 30% eggshell powder substitution in black cotton soil on basement complex which is an indication of constancy of volume. This is an indication that the optimum percentage substitution of eggshell powder in black cotton soil on basement complex is 30%. Efforts are still on-going to determine the relevant consolidation parameters and settlement indices of stabilized black cotton soil on basemen complex as well as sedimentary formation. The materials used for stabilization of these black cotton soils are palm kernel shell and eggshell powder.

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