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EVALUATION OF COMPACTED BLACK COTTON SOIL – SAWDUST ASH MIXTURES AS ROAD CONSTRUCTION MATERIAL

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ABSTRACT
This study was aimed at the evaluation of the stabilization potential of sawdust ash (SDA) on black cotton soil. Soil samples were treated with up to 10 % SDA content by dry weight of soil compacted with reduced British Standard light (RBSL) energy. Index properties of the natural soil showed that the soil belongs to A-7-5 (36) in American Association of State Highway Transportation Officials (AASHTO) classification system and CH in Unified Soil Classification System (USCS) classification system. The natural soil has liquid limit, plasticity index and free swell values of 60.0, 32.4 and 50.0 %, respectively. These properties suggest a soil that cannot be used for engineering purpose in its natural state and requires improvement. The liquid limit, plastic limit and linear shrinkage decreased to minimum values of 54 %, 24.4 %, and 14.2 %, respectively, while plasticity index increased to 14.2 % at 10 % SDA content. Also optimum moisture content (OMC) increased to a maximum value of 30 % while maximum dry density decreased to a minimum value of 0.86Mg/m^3 at 10 % SDA content. Peak unsoaked California bearing ratio (CBR) value of 4 % was recorded at 2% SDA content. On the other hand peak 7 days unconfined compressive strength (UCS) value of 90kN/m^2 was recorded at 8 % SDA content. This value fell of specification requirement of the CBR value to be used as sub-base or base material. The durability of samples determined by immersion in water recorded peak resistance to loss in strength of 48.24 % (i.e., loss in strength of 51.76 %) at 8 % SDA content. The results recorded indicate that black cotton soil compacted with RBSL energy cannot be used as a road pavement material, but for low load bearing structures such as road shoulders and pedestrian walkways. However, SDA can be beneficially used as an admixture in road construction when a higher compactive effort is used.

Keywords: *Black cotton soil, Saw dust ash, Stabilization, Durability, California bearing ratio.*

INTRODUCTION

The increase in world population, industrialization and economic development led to a global demand for reduction in the rising cost of waste disposal. Increase in waste generated led to a global research towards economic utilization of wastes for engineering purposes. The safe disposal of industrial and agricultural waste products demand urgent and cost effective solutions because of their debilitating effects on the environment and the health hazards that they constitute. Nearly all industrial activities lead to depletion of natural resources, a process that may result in the accumulation of by-products and/or waste materials. In most cases there are problems associated with the disposal of these waste heaps. Continuous generation of waste arising from industrial by-product and agricultural residue, create acute environmental problems both in terms of their treatment and disposal (Oriola and Moses, 2010).

Black cotton soils are problem soils with expansive behaviour having potential for shrinking or swelling under changing moisture condition (Ola, 1983). Such unusual behavior with changing moisture conditions causes damage to structures, buildings and pavements .They are produced from the breakdown of basic igneous rocks where seasonal variation of weather is extreme. The soils are formed under conditions of poor drainage from basic rocks or limestone under alternating wet or dry climatic conditions. These soils are problematic when used as building foundation and pavement sub-grades. They constitute the major problem soils in north eastern Nigeria where they occupy an estimated area of 104,000 km^2 in the north eastern part of the country (Ola, 1983; Osinubi *et al.*, 2011).

Osinubi and Katte, (1997) referred to soil stabilization as the alteration or control of any soil property. Because of the swelling and shrinkage properties of black cotton soils with changing moisture condition, there is need for improving its engineering properties. Different techniques for improving the engineering properties of the soil have been developed by various researchers such as improvement of black cotton soil with agricultural and industrial waste with pozzalanic properties. Factors normally considered in the use of such options include availability, cost, accessibility, location and workability. Materials that have been used to improve such black cotton soils include cement and lime, pozzolanic admixture like bagasse ash, sawdust ash, locust bean waste ash etc (Moses, 2008).

Lime and Portland cement are industrial manufactured additives which have been in use for improving soil properties (Nerville, 2000). The use of industrial manufactured additives such as cement and lime has always been restricted due to the high cost of purchasing them. There is need for cheaper but efficient materials to be used for soil stabilization, Recent studies have also focused on the use of industrial and agricultural waste as possible admixtures for improving black cotton soils (Ferguson, 1993; Osinubi and Stephen, 2005; Roy *et.al.,* 2007; Osinubi and Ijimdiya, 2008; 2009; Osinubi and Mustapha, 2009; Srirama and Rama, 2008; Amadi, 2010; Osinubi and Oyelakin, 2012; Eberemu and Sada, 2013; Osinubi *et al.*, 2015; Eberemu *et al.*, 2016). Sawdust is an industrial waste in the timber industry and poses a nuisance to the health and environment when not properly managed (Elinwa and Abdulkadir, 2012). The waste is disposed indiscriminately most of time by incineration with the formation of sawdust ash which poses environment hazard due to the toxic nature of the smoke it emits (KEPA, 2012).

The study was aimed at the evaluation of the stabilization potential of sawdust ash (SDA) on black cotton soil. The objective was to determine the changes in the strength properties of the soil with varying stepped concentration of sawdust ash when the reduced British Standard light compaction energy is used.

MATERIALS AND METHODS

Materials

Soil: Black cotton soil (BCS) used for the study was sourced from Deba Local government Area of Gombe state, Nigeria. Soil sample was collected by method of disturbed sampling. The soil was air-dried, pulverized and passed through British Standard (BS) No. 4 sieve (4.75 mm aperture) as required for laboratory test (Head, 1982).

Sawdust ash: The sawdust ash used for this study was procured locally from a timber shed situated in Bakori town of Katsina state, Nigeria. The sawdust collected was air-dried and burnt under atmospheric condition. The ash was then passed through the BS No. 200 sieve (75µm aperture to meet the requirement of ASTM C618-78 (2013)

Methods

Index Properties: Laboratory tests were performed to determine the index properties of the natural soil and soil–SDA mixtures in accordance with British Standards BS 1377 (1990) and BS 1924 (1990), respectively.

Compaction: Compaction tests were carried out in accordance with BS 1377 (1990) to determine the compaction characteristics of black cotton soil – SDA mixtures. Specimens were prepared in stepped concentrations of 0, 2, 4, 6, 8 and 10 % SDA by dry weight of soil. Specimens were compacted with reduced Proctor energy that involves a 2.5 kg rammer falling 300 mm onto three layers in a British Standard mould, each receiving fifteen (15) blows.

Unconfined compressive strength: The unconfined compression tests were performed on the soil samples according to BS 1377: (1990) Part 7 test 2 using the reduced Proctor compactive effort, at their respective OMCs.

California bearing ratio: The California bearing ratio (CBR) tests were conducted in accordance with BS 1377 (1990) and BS 1924 (1990) for the natural and treated soils, respectively.

Durability: The durability assessment (under adverse field conditions) of the soil sample was determined by resistance to loss in strength when immersed in water. It was expressed as the ratio of UCS of the specimen wax-cured for 7 days and de-waxed top and bottom before being soaked for another 7 days to the UCS of the specimen cured for 14 days:

$$\text{Resistances to Loss in Strength} = \frac{\text{USC}(7\text{Days cured} + 7\text{ Days})}{\text{UCS}(14\text{ Days cured})}$$

RESULTS AND DISCUSSION

Index properties: The natural soil was classified as A-7-5(36) soil based on AASHTO Classification system (AASHTO, 1986), CH soil based on Unified Soil Classification System (USCS) (ASTM, 1992). Some geotechnical properties of the natural black cotton soil are given in Table 1.

Table 1: Properties of the natural black cotton soil

Properties	Quantity
Percentage Passing No. 200 Sieve (75 µm aperture)	91.4
Natural moisture content, %	16.1
Specific gravity	2.46
Free swell %	50.0
Liquid limit, %	60.0
Plastic limit, %	27.6
Plasticity index, %	32.3
Linear shrinkage, %	16.5
Maximum dry density, Mg/m^3	1.36
Optimun moisture content, %	26.0
UCS (7 days), kN/m^2	52.87
CBR (unsoaked), %	3
CBR (soaked), %	2

Effect of Sawdust Ash on Black Cotton Soil

Specific gravity: The specific gravity decreased with increase in sawdust ash treatment as indicated in Fig. 1. The reason for this trend of decrease is due to low specific gravity of SDA (2.20) replacing the soil with higher specific gravity. However, with increment in sawdust ash content, the proportioning of the sample result in decreased quantity of soil and increased sawdust ash, thereby leading to a continuous drop in specific gravity with higher SDA content.

Cation exchange capacity: The cation exchange capacity (CEC) which measures the amount of positively charged cations a soil can hold had decreased with increase in sawdust ash content as shown in Fig 1. The CEC values decreased from 38.3 Cmol/kg for the natural soil to 20.4 Cmol/kg at 10 % SDA treatment. The decrease in CEC value was as a result of decrease in the clay size fraction of the soil (Warrick, 2002;

Salahedin, 2013; Osinubi *et al.*, 2015). The decrease in CEC value could also be attributed to the reduction in pH of black cotton soil by SDA that had a higher calcium hydroxide content that supplied free Ca^{2+} required for the cation exchange between the clay mineral particles. This agrees with the findings of Akinmade, (2008) who worked on stabilization of black cotton soil using locust bean waste ash.

Atterberg limits

Liquid limit: The variation of liquid limit of BCS with SDA content is shown in Fig. 2. The results indicated a decrease in liquid limit from 60 % for the natural soil to a value of 54 % for the soil treated with 10 % SDA, the overall decrease in liquid limit could be attributed by the flocculation and aggregation of clay particles and the accompanying reduction in surface area and increase in strength(Al karagooly, 2012). This decrease may also be due to flocculation and agglomeration arising from cation exchange reactions where by Ca^{+} in the additives reacted with ions of lower valence in the clay structure. This is in agreement with the findings of Al-Zoubi (2008), Portelinha et.al. (2012) and Ramesh et al. (2013).

Plastic limit: The variation of plastic limit of BCS with SDA is shown in Fig. 2. There was increase in plastic limit from 27.6% for the natural soil to a value of 31.1% at 4% SDA. This atteration of soil character probably occurred due to bi-valent calcium ion supplied by the SDA replacing less firmly attached monovalent ions in the double layer surrounding clay particles (Koteswara,2004)

Plasticity index: The result for plasticity index of black cotton soil treated with sawdust ash is as presented in Fig 2. Plasticity index decreased to a minimum at 4 % sawdust ash content and thereafter increased with increase in sawdust ash content. This trend was as a result of substitution of finer particles of the soil with ash, and shows less workability resulting in a higher probability of existance of macropore and poor interlift of the soil (Osinubi *et al.,* 2011).

Linear shrinkage: The variation of linear shrinkage of BCS with SDA content is shown in Fig. 3. Linear shrinkage value range from 16.54 % to 14.2 % and the trend shows that shrinkage is highly dependent on the amount of fines in the soil. Linear shrinkage occur as the water surronding the individual soil particles of the specimen is removed, the particles move closer together more movenment are experience in finear particles than coaser particles (Osinubi *et al*., 2011)

Compaction characteristics

Maximum dry density*:* The variation of maximum dry density (MDD) of BCS with SDA content is shown in Fig. 4 The MDD values decreased on addition of SDA to a value of 0.86 Mg/m^3 at 10 % SDA content. The decrease in MDD with addition of SDA was probably due to the lower specific gravity of the SDA occupying spaces with lattice there by decreasing the MDD.Similar behaviour was observed by Phanikumar *et al.,* (2004), Osinubi and Stephen, (2007), Jadhao and Nagarnaik (2008) as well as Kumar and Puri (2013).

Optimum moisture content: The variation of optimum moisture content (OMC) of black cotton soil with sawdust ash (SDA) content is shown in Fig. 4. The OMC of the natural soil was 26% and it increased to a value of 30.0 % at 10 % SDA content. The increase in OMC agrees with the results reported by Osinubi and Katte (1997). They attributed the increase to the amount of water required for pozzolanic reactions to take place.

Strength characteristics

Unconfined compressive strength: The variation of unconfined compressive strength (UCS) of black cotton soil with sawdust ash SDA content at 7, 14 and 28 days curing periods is shown in Fig. 5. It was observed that the UCS of the SDA treated black cotton soil initially increased up to 8 % SDA content and thereafter decreased for all the curing periods considered, Peak UCS values of 104.23, 174.83 and 175.50 kN/m^2, respectively, were obtained at 8 % SDA content. The increased UCS values could be attributed to ion exchange at the surface of clay particles as the Ca^{2+} in the stabilizer reacted with the lower valence metallic ions in the clay microstructure which resulted in agglomeration and flocculation of the clay particles (Koteswara, *et al.,* 2012).

California bearing ratio**:**The results presented in Fig. 6 show the variation of soaked and unsoaked California bearing ratio (CBR) of black cotton soil with sawdust ash content. The CBR values of the natural soil is 3% for both unsoaked and soaked conditions. The unsoaked CBR value increased to a peak value of 4 % at 2 % SDA content and progressively decreased to 3 % at 8 % SDA content, then increased to 4 % at 10 % SDA content. For the soaked condition CBR value decreased to a minimum value of 2 % at 2 % SDA and progressively increased to 3 % at 10 % SDA content. There was a a marginal improvement with higher SDA content. The reason for the slight improvenment in the strength for the unsoaked condition was due to inadequate amount of calcium available for the formation of calcium silicate hydrate (CSH), which is the major compound responsible for the strength gain.(Koteswara Rao, *et al.,* 2012) The Nigerian General Specifications (1997) recommends that a CBR value of 180% should be attained in the laboratory for cement stabilized material to the constructed by the mix in place method. Although the SDA treated black cotton soil did not meet the criterion specified for use as base course material, SDA can be used in admixture stabilization with a more potent stabilizer(i.e cement or lime) in order to reduce cost of construction.

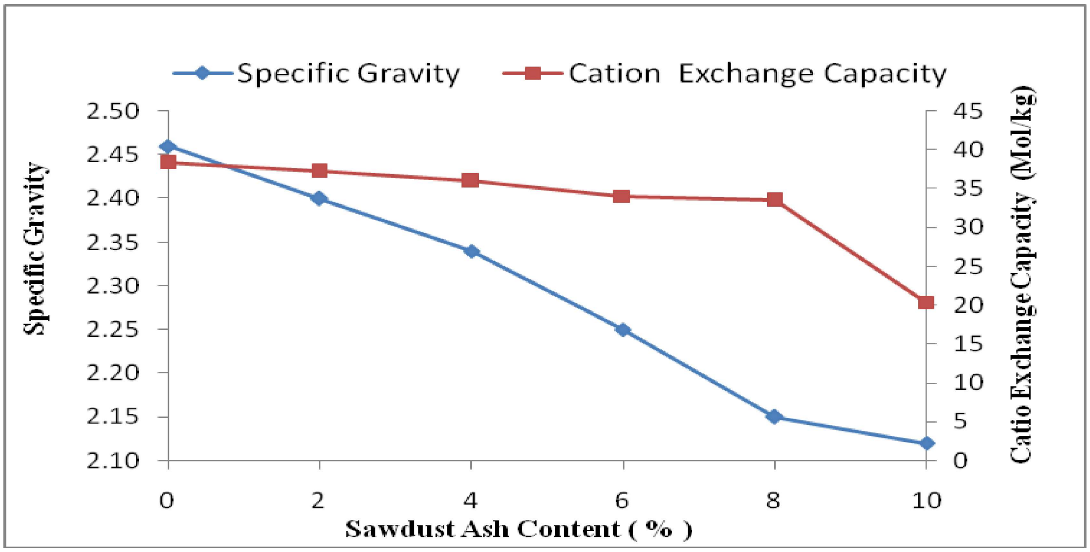

Fig. 1: Variation of specific gravity and cation exchange capacity of black cotton soil with sawdust ash content.

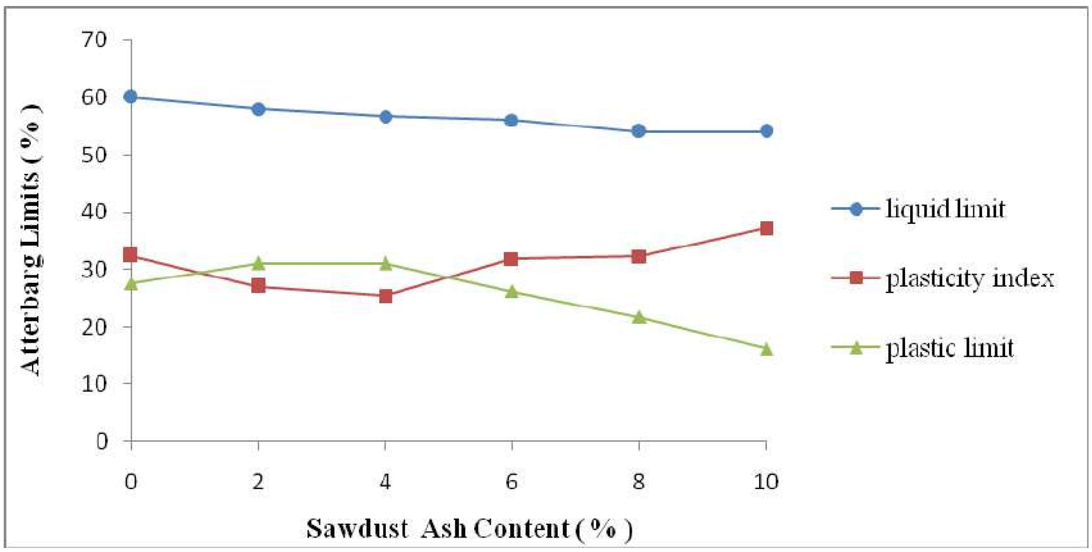

Fig. 2: Variation of Atterbarg limits of black cotton soil with sawdust ash content

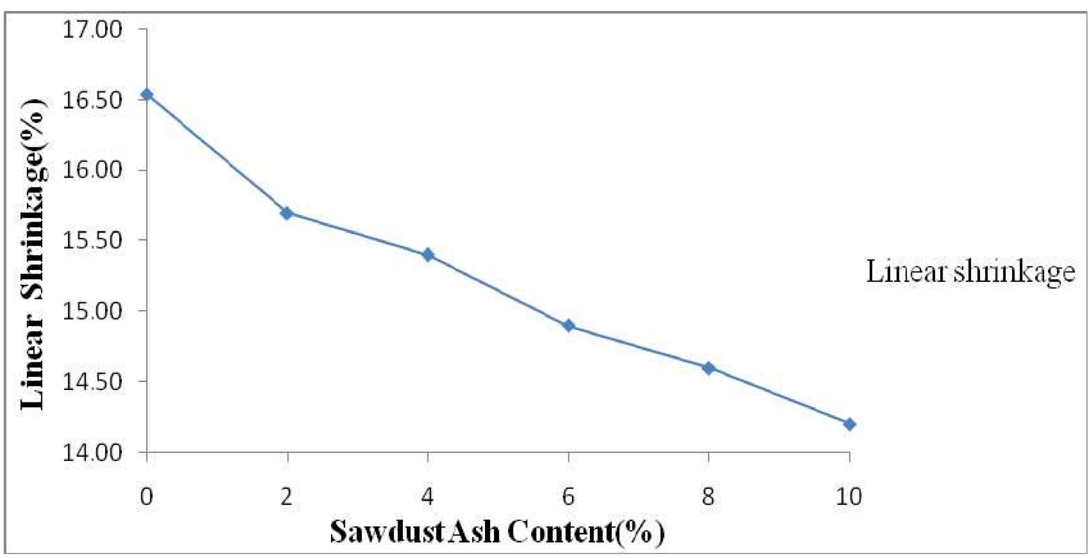

Fig. 3: Variation of linear shrinkage of black cotton soil with sawdust ash content

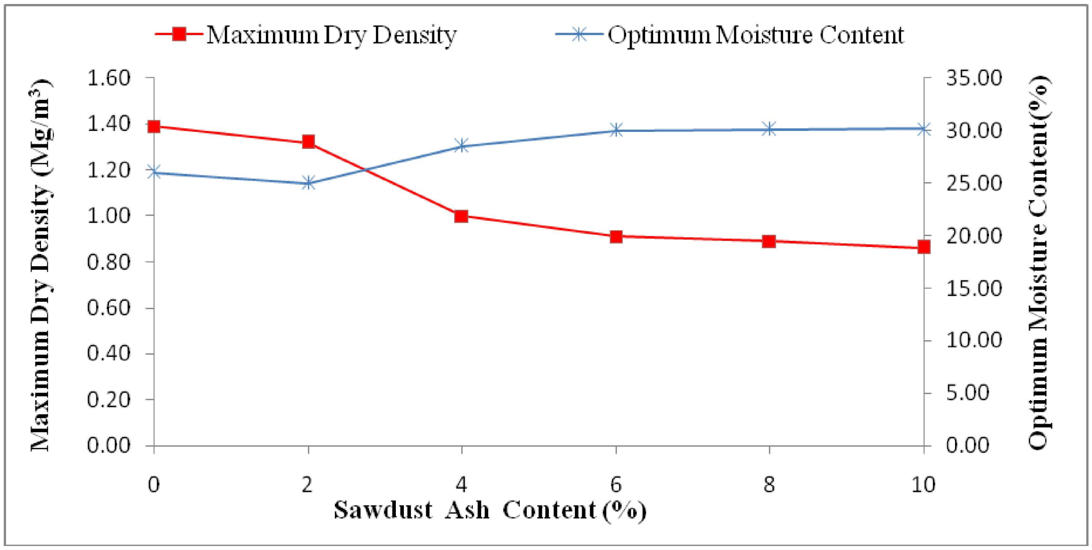

Fig. 4: Variation of maximum dry density and optimum moisture content of black cotton soil with sawdust ash content.

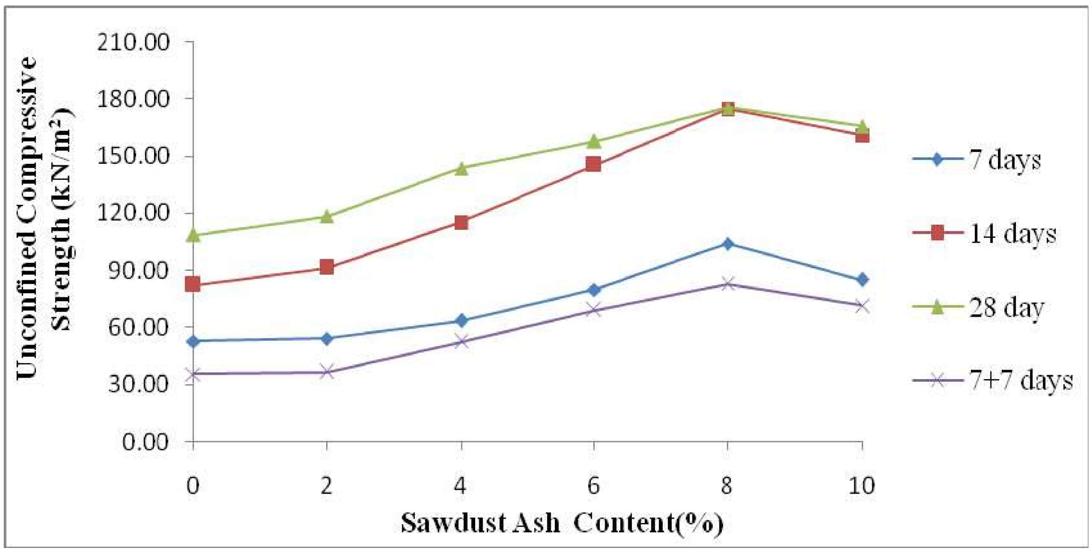

Fig. 5 Variation of unconfined compressive strength of black cotton soil with sawdust ash content.

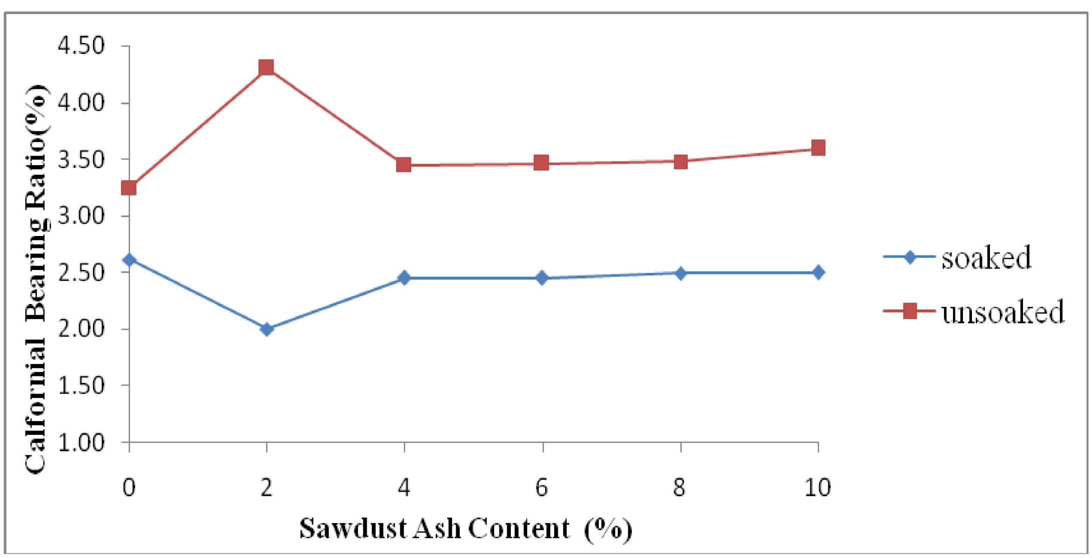

Fig. 6. Variation of California bearing ratio of black cotton soil with sawdust ash content

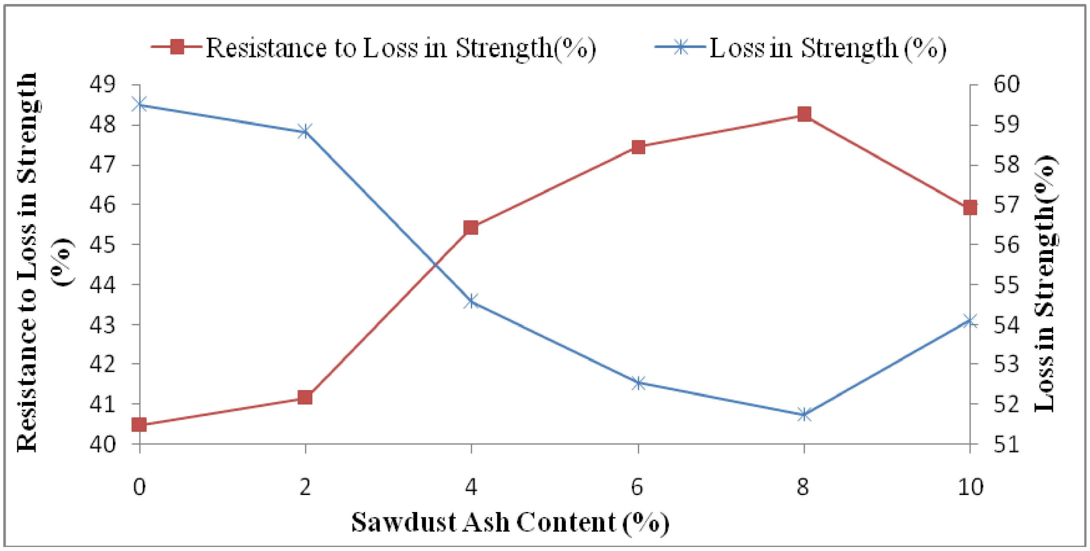

Fig. 7: Variation of loss in strength and resistance to loss in strength of black cotton soil with sawdust ash content.

Durability: The resistance to loss in strength for the black cotton soil shows the variation of the durability of black cotton soil with sawdust ash content as shown in Fig. 7. The resistance to loss in strength increased as SDA content increased to a peak value of 48.24 % (i.e, 51.76 % loss in strength) at 8 % SDA content and thereafter decreased for the range of SDA content considered. The recorded loss in strength was more than the maximum 20 % allowable loss in strength (Osinubi *et al.,* 2009). Regardless of the harsher 7 days immersion period used in this study, the SDA stabilized blackcotton soil did not meet the durability requirement for use in pavenment construction.

CONCLUSION

Results of preliminary investigations conducted on the natural properties of the soil showed that the soil is classified as A-7-5(36) subgrade of the AASHTO classification system, CH soil according to USCS. The natural soil was highly silty and clayey with 96.6 percent passing BS sieve No. 200, with a liquid limit of 60%, plastic limit of 27.6% and plasticity index 37.37%. The liquid limit decrease to a minimum value of 50 % at 10 % S D A, the plastic limit, plasticity index and linear shrinkage at a minimum value at 10 % S D A with the values 24.4 %, 14.2% and 14.2 % respectively. Addition of sawdust ash significantly improvesd the index properties, compaction and strength characteristic of black cotton soil under study. Addition of sawdust ash brought about an improvement in the compaction parameters of the study soils, by increasing the optimum moisture content of the soils with decrease in the corresponding value of the maximun dry density. There was a general increase in the UCS value with SDA content and curing period. The CBR value of the treated soil (unsoaked) recorded a peak value of 4 % at 6 % SDA content. This value is significantly lower than the CBR value of 180% recommended by the Nigerian General Specification (1997). It implies that SDA cannot be used as a stand-alone stabilizer for black cotton soil in road construction work. but could used in areas where less strength is required such as shoulders and pedestrian walkways. The benefit of the technique includes the reduction of the cost of stabilization when it is used as an admixture and the adverse enviromental impact of sawdust waste.

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