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Original Article

Effect of selected admixtures on the geotechnical properties of Black Cotton Soil

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ABSTRACT

The effect locust bean waste ash (LBWA) and cement kiln dust (CKD) on black cotton soil (BCS) was studied. BCS was modified with 0, 2, 4, 6, 8 and 10 % LBWA and 0, 1, 2, 3 and 4 %CKD in relation to the soil dry weight. Test carried out include cation exchange capacity (CEC), Atterberg limits, compaction and shear strength test. Results show that a combination of LBWA and CKD have negative effect on the geotechnical properties of soil with exception in few cases. The CEC increased with increase in both the LBWA and CKD contents with deviations in few cases. Values of 21.9, 24, 34.1, 33.5, 32.1 and 33.8 Cmol/Kg were recorded at 0, 2, 4, 6, 8 and 10% LBWA content. Similar trend was observed for 1, 2, 3 and 4% CKD. Liquid limit generally increased with increase in LBWA content while plastic limit generally decreased. In the case of plasticity index, values increased with increase in LBWA content. Peak values were recorded at 6%LBWA content. Maximum dry density (MDD) decreased with increase in LBWA content. MDD values of 1.68, 1.67, 1.66, 1.65, 1.63 and 1.61 were recorded at 0, 2, 4, 6, 8 and 10% LBWA content. Similar trend was observed for 1, 2, 3 and 4% CKD. Optimum moisture content (OMC) increased with increase in LBWA content. Cohesion of soil decreased with increase in LBWA content. Values of 140, 110, 95, 60, 120 and 180 kN/m^2 was recorded at 0, 2, 4, 6, 8 and 10% LBWA content, while angle of internal friction improved from its natural value up to 10% LBWA content. Statistical studies by means of two–way analysis of variance (ANOVA) reveal that LBWA and CKD have significant effect on the soil properties. Although the modified soil did not effectively improve the consistency and shear strength parameters of BCS, an optimal blend of 2% CKD/10% LBWA blend slightly improved the soil properties. The optimally modified soil could be utilised for lightly trafficked roads construction as sub-base materials.

1. Introduction

Black cotton soils (BCS) are inorganic clays of average to high potentials for compressibility, they have high potential for shrinkage as well as swelling depending on how dry or wet they are [1-3]. BCS is rigid once dry, but slurry when wet, losing its expected strength totally when in very wet form. When dried, BCS cracks and when wet, the cracks close-up, causing perpendicular movement in the soil mass. This movement point to differential settlements, depressions, cracking, and unevenness in pavements, embankments and foundations. BCS pose major challenge to the geotechnical engineer, due to their shrinkage when dry and expansion when wet [4]. BCS are predominantly available around semiarid and tropical areas with prominent dry season and slight rainfall. BCS are equally narrowed to semi-arid provinces of temperate climate where yearly evaporation surpasses precipitations

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anywhere in the world [5-6].

Ola [1] as well as Moses *et al.*, [7] reported that BCS can be modified using additives. Additives like cement, lime, coal bottom ash, cement admixtures, cement with phosphatic wastes, periwinkle shell ash and quarry dust have remained useful for modifying and improving geotechnical properties of BCS with substantial results [2, 8-10]. Additional researches into economical ways of modifying and stabilizing BCS have produce big assistance from the costly modification of the soil by means of cement and lime. Improvement of black cotton soil, whether by mechanical or chemical process, for engineering purpose can be expensive and difficult. Therefore, the necessity for substitute to a low-cost improvement material.

Many researches have tried to utilize locally obtainable waste materials for modifying and stabilize lateritic and BCS. Illustrations of such latest researches include the use of bagasse ash and rice husk ash mixed with cement or lime to modify or stabilize black cotton soils [11-14]. The pozzolanic nature of locust bean waste ash (LBWA) implies that, itself is not cementitous but can react with calcium hydroxide in the BCS and CKD in the company of water to produce compounds having cementitous properties. The cementations nature of LBWA and CKD favours their suitability for soil improvement as reported in literatures [15-16].

The importance of using industrial and agricultural waste with cementations properties like CKD and LBWA is for the purpose of reducing the overall cost of construction, also serving as a method of waste disposal. It serves to reduce construction cost by replacing industrial manufactured additives like lime and cement which are very expensive. Also, lime and cement production process is not environmentally friendly. Other materials for soil improvement have also been reported in literatures [17-19]. For instance, Gobinath et al., [17] used silica waste from various industries as stabling materials to improve black cotton soil, results shows an improvement in the soil properties. California bearing ratio (CBR) values increased significantly with increase in the concentration of the additives. Research work of Annand et al., [18] showed a reduction in liquid limit and free swell while unconfined compressive strength increased, for black cotton soil treated with lime and quarry dust.

The aim of this study is to modify samples of BCS with LBWA and CKD. The specific objectives were to evaluate variations in the modified soil with changes LBWA and CKD content in relation to the dry weight of soil.

2. Materials and Methods

2.1 Materials

2.1.1 Soil: Disturbed sample of BCS use was sourced from Gombe State, Nigeria. Soil was collected at an average depth of 0.5m. After collection, the soil was dried prior conveying to the laboratory. BS No. 4 and 40 sieves were used to prepare sample for laboratory tests.

2.1.2 Locust Bean Waste Ash: LBWA was gotten by burning of locust bean husk gathered from Duduguru in Obi Local Government Area of Nasarawa State, Nigeria. After burning, the ash was sieve through BS 0.075mm sieve prior laboratory tests

2.1.3 Cement Kiln Dust: CKD was sourced from Benue cement factory, Gboko. Sample was obtained and preserved in cement bags and then conveyed to the laboratory. Sample was sieve via BS 0.075mm sieve prior laboratory tests.

2.2 Methods

2.2.1 Index Properties: Tests on untreated soil and soil – LBWA/CKD blends were done based on BS 1377 [20] and BS 1924[21] in that order. Soil samples were varied with 0, 2, 4, 6, 8 and 10% LBWA and 0, 1, 2, 3 and 4% CKD content by dry weight of soil.

2.2.2 Free Swell: Free swell test for the untreated soil was done by first sieving the soil through 425μm sieve. The soil was then poured into a 100ml cylindrical tube to a 10ml mark. Water was then added and stirred thoroughly, thereafter filled to the 100ml mark. The sample was allowed to swell for a period of 24hours. The difference in level of the graduated cylinder at 10ml mark before water was added (A) and the level of soil in the cylinder after 24 hours (B) divided by the 10ml mark before water was added (A) is the free swell of the soil. Multiplying the results by hundred (100) gives the free swell in percentage. The free swell was computed with the aid of eq (2):

$$\text{Free swell} = \frac{B - A}{A} \times 100 \tag{1}$$

2.2.3 Atterberg Limits: Tests comprises of liquid limit, plastic limit and plasticity indices of the untreated and modified soil. Tests were carried out based on BS 1377 [20] and BS 1924 [21] for untreated and modified soils in that order. Soil samples were varied with LBWA and CKD as shown in section 2.2.1

2.2.3.1 Liquid limit. Sample was sieve via 425 μm sieve. 200g was weighed, placed on a flat glass surface prior addition of water to form paste with the help of a knife. A small part of the paste was put into the Casagrande apparatus, then smoothed parallel to the bottom of the chip. With the help of the grooving tool, a line is drawn via the centre of the hinge to divide the sample equally in the apparatus into two equals. The crank was rotated so as to raise and drop the cup at the speed of 2 revs/s, counting the blows that make the bottom two parts of the groove come together. Moisture content determination was done by taking some small sample of the paste in to the moisture cans. This test was reiterated for wide range of moisture content. Finally, a plot of moisture content verses number of blows on a semi-logarithmic plot was used to estimate the liquid limit. It is drawn from the plot at moisture content matching to 25 blows. Similar process was followed for soil samples varied with LBWA and CKD in the order presented in section 2.2.1.

2.2.3.2 Plastic limit: 20g of the dried natural soil sieved via 425μm sieve was mixed with water and positioned on a smooth glass plate then rolled between the two fingers to form a thread of about 3mm in diameter. Threads were then put in weighing pan for the determination of its moisture content. Similar process was followed for soil samples varied with LBWA and CKD in the order presented in section 2.2.1.

2.2.3.3 Plasticity index: Plasticity indices were obtained from the already determined liquid and plastic limits values using eq (2).

$$\mathrm{PI} = \mathrm{LL} - \mathrm{PL} \quad (2)$$

2.2.4 Cation exchange capacity: CEC test was done as proposed by ISRIC [22] for the natural soil. The CEC was computed with the aid of eq (3):

$$\mathrm{CEC} = \frac{(\mathrm{Titre} - \mathrm{B}) \times \mathrm{NA}}{\mathrm{Weight\ of\ soil}} \times 100 \quad (3)$$

Where: B = Blank; NA = Normality of acid

Similar approach was followed for soil samples mixed with LBWA and CKD as shown in section 2.2.1

2.2.5 Compaction: Test was carried out in agreement with BS 1377 (1990) for BCS/LBWA/CKD mixtures. Samples were blended with LBWA and CKD as shown in section 2.2.1. Samples were compacted with British Standard Light (BSL) energy.

2.2.6 Shear Strength: Test was done using a quick undrained triaxial test technique in agreement with BS 1377[20]. The samples were not subjected to saturation prior to the test. BCS/LBWA/CKD mixtures were compacted at their individual optimum moisture content (OMC) of BSL compaction and removed from the compaction mould. Samples were extruded into cylinder of diameter 38.1 mm and corresponding height 76.2 mm. The extruded sample was then positioned in the triaxial cell. Three samples were used at 103, 206, and 310 kN/m^2 cell pressures in that order. Highest stresses were gotten via the stress–strain graphs.

2.2.7 Statistical Analysis: Statistical analysis on the laboratory measured results was done using the Microsoft excel statistical tool park. Two way analysis of variance (ANOVA) was carried out because two factor variables were considered (*i.e* LBWA and CKD). 95% (*i.e* 0.95) confidence interval and 5% (*i.e* 0.05) level of significance was used for the analysis. For every analysis, if the measured parameter (p-value) is less than 0.05 level of significance, it means the additives has significant effect on the measured parameter or else have no significant effect.

3. Results and Discussion

3.1 Natural soil properties

Initial analysis shows that the BCS is a fine-grain soil, with greyish-black colour. Tests done on the natural soil shows 68.5% passed sieve 0.075 mm and it was classified as CH[23] or A-7-6(13) [24]. 52.8%, liquid limit, 19.16% plastic limits and 33.64% plasticity index was recorded for the natural soil. Detailed properties are contained in Table 1. The grain size curve is revealed in Fig. 1

Table 1: Properties of natural soil

Properties	Quantity
Moisture content, %	18.6
Passing BS No 200 sieve	68.5
Free swell, %	85
Cation exchange capacity, Cmol/kg	21.9
AASHTO Classification	A-7-6 (13)
USCS	CH
Liquid limit, %	52.8
Plastic limit, %	19.16
Plasticity index, %	33.64
MDD, Mg/m^3	1.68
OMC, %	17.2
Cohesion, kN/m^2	140
Angle of internal friction(degree)	3
Colour	Greyish black

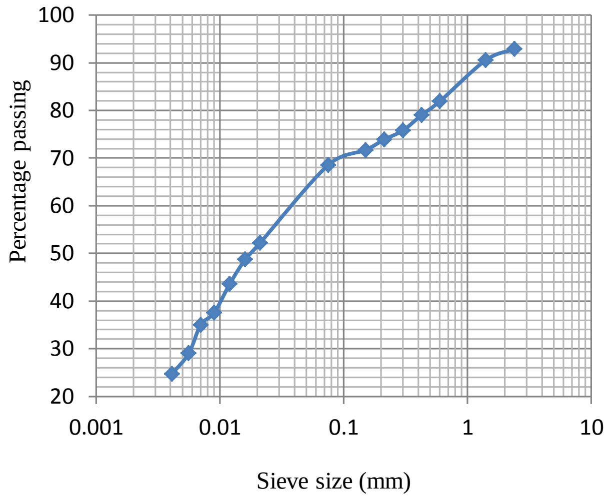

Fig 1. The grain size curve of natural soil

3.2 Cation Exchange Capacity

The differences in CEC of soil – CKD combinations with LBWA content is revealed in Fig. 2. Results show a general trend of increase in CEC with increase in both CKD and LBWA content. Values of 21.9, 24, 34.1, 33.5, 32.1 and 33.8 Cmol/Kg were recorded at 0, 2, 4, 6, 8 and 10% LBWA content. Similar trend was noted for 1, 2, 3 and 4% CKD. The CEC of the natural soil increased by 54.3%, which show a significant flocculation and agglomeration that accompanied increasing percentages of admixtures. These percentage combinations agree with the ½ - 4 % admixture ratios that is significantly enough to change or modify a soil [7].

Two–way analysis of variance (ANOVA) test for CEC result reveal that the impact of CKD and LBWA on BCS were statistically relevant (F_{CAL} = 3.35 > F_{CRIT} = 2.87) for CKD and (F_{CAL} = 15.07 > F_{CRIT} = 2.71) for LBWA. The influence of LBWA on the CEC of BCS is more noticeable when put into comparison to that of CKD.

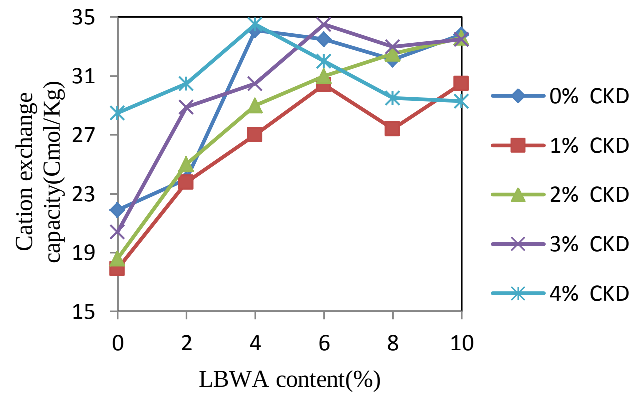

Fig. 2: Plot of CEC of soil – CKD blends with LBWA content

3.3 Atterberg Limits

3.3.1 Liquid Limit

The change in liquid limit with CKD/LBWA blend is reveal in Fig 3. Liquid limit generally increased with increase in LBWA content, when compared to that of the natural soil. Liquid limit rise from 52.8% to the highest value of 55.6% at CKD/LBWA blend of 3% CKD/6% LBWA content. Values of 52.8, 53, 54.4, 54.6, 53.4 and 52.6% were recorded at 0, 2, 4, 6, 8 and 10% LBWA content. Similar trend was observed for 1, 2, 3 and 4% CKD. The rise in liquid limit could be due to higher amount of ash demanding progressive incremental quantity of water for pozzolanic reaction in the mix. Also, the possible trend of increased could be linked to flocculation and agglomeration arising from cation exchange reactions(CER) where by Ca^{2+} in the admixtures undergo chemical reaction with the lower valence ions found in clay structure. Similar statement were made by Osinubi et al., [25] and Etim et al., [2]. The increasing trend for liquid limit with increase in both LBWA and CKD is an indication of swelling of the soil with treatment. This has negative impact on the suitability of the treated soil for use as flexible pavement material.

Two–way analysis of variance (ANOVA) test on the liquid limit result shows that the impact of CKD and LBWA on BCS were statistically relevant (F_{CAL} = 15.57 > F_{CRIT} = 2.87) for CKD and (F_{CAL} = 14.47 > F_{CRIT} = 2.71) for LBWA. The impact of CKD on the liquid limit of BCS is more noticeable when put into comparison to that of LBWA.

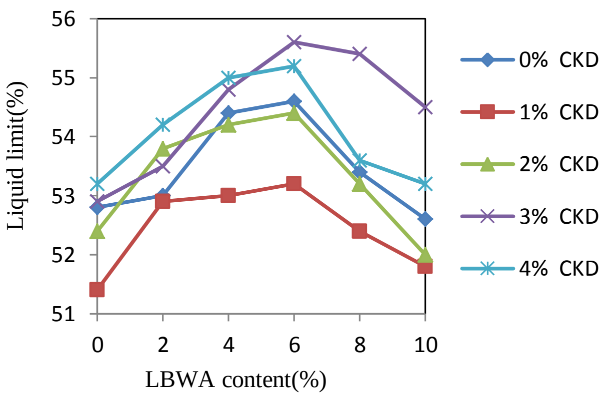

Fig. 3. Plot of liquid limit of soil – CKD mixtures with LBWA content

3.3.2 Plastic Limit

The plot of plastic limit with CKD/LBWA content is revealed in Fig 4. It was noticed that plastic limit generally decreased with increase in LBWA content. The least plastic limit of 15.6 % at 3 %CKD/6 %LBWA treatment of BCS indicated a 3.6 % reduction from the unmodified or natural value of 19.2%. The plastic also decreased with increase in the CKD content.The possible explanation to this trend could be link to cation exchange reaction that pave way for adsorbed water elements in the soil giving way to flocculation and aggregation [7, 25].

Two–way analysis of variance (ANOVA) test on plastic limit shows that the impact of CKD and LBWA on BCS were statistically relevant (F_{CAL} = 12.96 > F_{CRIT} = 2.87) for CKD and (F_{CAL} = 48.58 > F_{CRIT} = 2.71 for LBWA). The Impact of LBWA on the plastic limit of BCS is more noticeable when put into comparison to that of CKD.

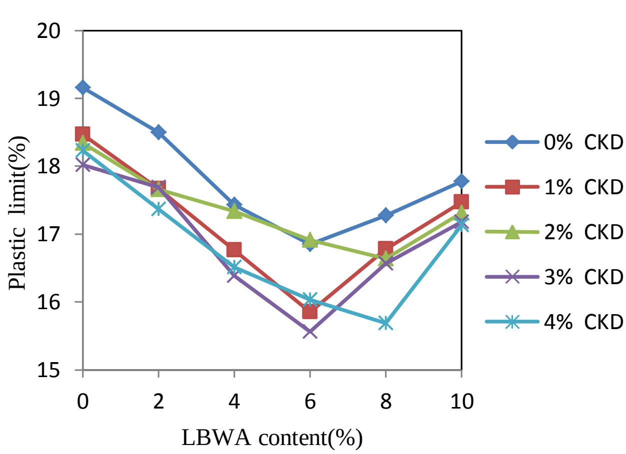

Fig 4. Plot of plastic limit of soil – CKD mixtures with LBWA content

3.3.3 Plasticity Index

Graph of variation in plasticity index with CKD/LBWA blend is shown in Fig. 5. In general, plasticity index values increased with increase in LBWA content. Peak values were recorded at 6%LBWA content. Plasticity index of the natural soil increased from 33.6% to a maximum value of 40% at 3%CKD/6%LBWA blend. The general trend shows that plasticity of the soil increased.The reason for the increased may be associated with the swelling behaviour of the additves by their adsorption of water which significantly led to the increase in plasticity index of the treated soil. This also shows that addtion of LBWA and CKD increased the soil plasticity, making the soil behave like a clayed material. This has negative effect on the suitability of the treated soil for use as flexible pavement material. Stabilise soil for use as flexible pavement materials are usaully granuallar in nature to avoid swelling and contraction of the compacted soil with moiture variation, which will lead to failure of the road or embankment structure.

Two–way analysis of variance (ANOVA) test on plasticity index result shows that the impact of CKD and LBWA on BCS are statistically significant (F_{CAL} = 98.17 > F_{CRIT} = 2.87) for CKD and (F_{CAL} = 78.53 > F_{CRIT} = 2.71) for LBWA. The effect of LBWA on the plasticity index of BCS is more noticeable when put into comparison to that of CKD.

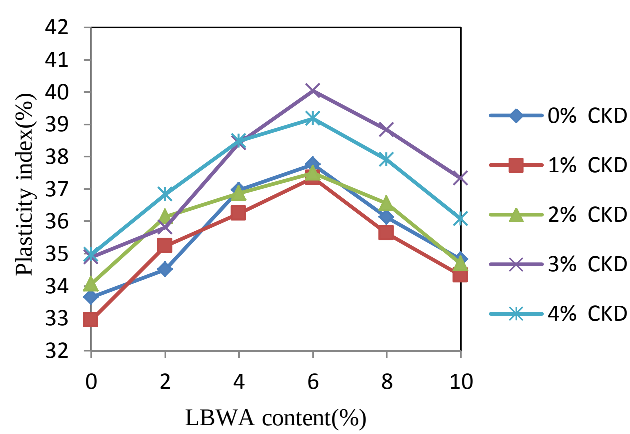

Fig 5. Plot of plasticity index of soil – CKD mixtures with LBWA content

3.4 Compaction Characteristics

3.4.1. Maximum Dry Density

The Plot of MDD of soil with increase in LBWA/CKD content is shown in Fig. 6. The results show a trend of decrease in MDD with increase in LBWA content. MDD values of 1.68, 1.67, 1.66, 1.65, 1.63 and 1.61 were recorded at 0, 2, 4, 6, 8 and 10% LBWA content. Similar trend was observed for 1, 2, 3 and 4% CKD. The decreased with rise in percentage of LBWA may be due to flocculation and accumulation of the soil. Also low specific gravity of LBWA (i.e 2.4) may be responsible for the decrease in MDD of the treated soil. No specific trend was established for MDD with increase CKD content. CKD contents appears to have little effect on the MDD of the treated soil.

Two–way analysis of variance (ANOVA) test on the MDD result for compaction shows that the impact of CKD and LBWA on BCS were relevant statistically (F_{CAL} = 14.33 > F_{CRIT} = 2.87) for CKD and (F_{CAL} = 58.74 > F_{CRIT} = 2.71) for LBWA. The impact of LBWA on the MDD result was is more noticeable when put into comparison to that of CKD.

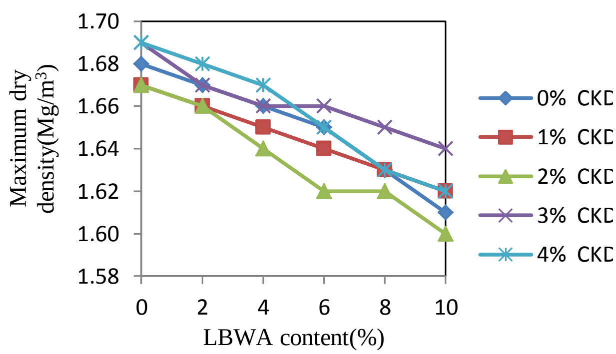

Fig 6. Plot of MDD of soil – CKD mixtures with LBWA content

3.4.2. Optimum moisture content

Fig 7. Show the change in OMC of soil with increase in CKD and LBWA concentrations. The graphs show an increase in OMC with progressive increment in LBWA content. OMC increased from its natural value of 17.2 to 21% when treated with 10% LBWA content. OMC values of 17.2, 18.6, 18.8, 20, 20.5 and 21% were recorded at 0, 2, 4, 6, 8 and 10% LBWA content. Similar trend was noted for 1, 2, 3 and 4% CKD. CKD contents appear to have little effect on the OMC of the natural soil. This trend may be due to greater need for water to provide more OH- needed for CER. Also, another reason may be due to increment in the needed specific surface area, resulting from the additional additives requiring additional water to loosen the entire soil matrix. The increase in OMC with increasing LBWA and CKD content agrees with the findings of Osinubi [26], Stephen [27], George [28], Akinmade [30] and Osinubi et al., [29, 31].

Two–way analysis of variance (ANOVA) test on the OMC results for compaction reveal that the impact of CKD and LBWA on OMC result were statistically relevant (F_{CAL} = 32.79 > F_{CRIT} = 2.87) for CKD and (F_{CAL} = 18.19 > F_{CRIT} = 2.71) for LBWA. The influence of CKD on the OMC result is more noticeable when put into comparison to that of LBWA

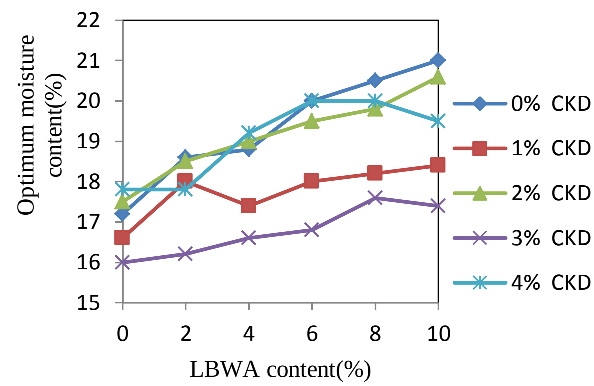

Fig 7. Plot of OMC of soil – CKD mixtures with LBWA content.

3.5 Shear Strength Parameters

3.5.1. Cohesion

Result of cohesion test is presented in Fig. 8. Cohesion of soil decreased with increase in LBWA content. The least cohesion values were recorded at 6% LBWA content. A value of 140, 110, 95, 60, 120 and 180 kN/m^2 was recorded at 0, 2, 4, 6, 8 and 10% LBWA content. Similar trend was recorded for 1, 2, 3 and 4% CKD. It was evident that increase in LBWA led to decrease in cohesion. The decrease in cohesion may be association with the breaking of particles of clay in the soil into honey comb, coarse-grained arrangements in the soil. Also, reduction may be due to flocculation and CER that break the bonds between clay particles and the reduction in voids due to compaction. Related statement was mentioned by Osinubi et al., [25].

Two–way analysis of variance (ANOVA) test on the Cohesion result reveal that the impact of CKD and LBWA on BCS were statistically relevant (F_{CAL} = 18.06 > F_{CRIT} = 2.87) for CKD and (F_{CAL} = 7.07 > F_{CRIT} = 2.71) for LBWA. The impact of CKD on the cohesion test result is more noticeable when put into comparison to that of LBWA.

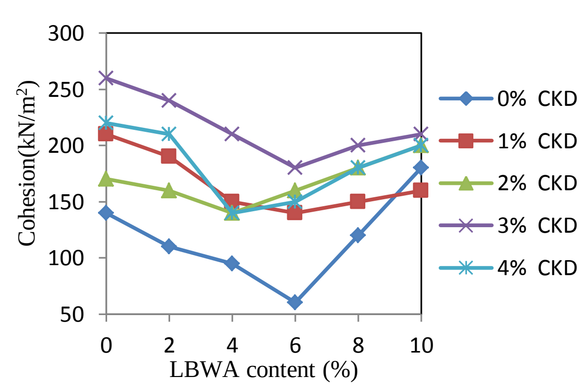

Fig 8. Plot of cohesion of soil – CKD mixtures with LBWA content

3.5.2. Angle of Internal Friction

Effects of additives concentrations on angle of internal friction test are presented in Fig. 9. Results show that angle of internal friction improved from its natural value up to 10% LBWA content. The natural soil recorded an angle of internal friction of 3° which increased to peak values of 10, 16, 18, 13 and 9° at 2, 4, 6, 8 and 10% LBWA content. Similar trend was recorded for 1, 2, 3 and 4% CKD with exceptions in some cases. The increase in frictional angle and decrease in cohesion may be linked to the breaking of particles of clay in the soil into honey comb, coarse-grained skeleton structures, development of pozzolanic reaction compounds [22]. Also, such trend may be linked to flocculation and CER that break the bonds existing among clay particles and the lessening in voids due to compaction. Similar statement was mentioned by Osinubi et al., [25]. In general, shear strength as well as bearing capacity of soil are affected by the angle of friction and cohesion of the soil. Results show that addition of LBWA and CKD have negative effect on the shear strength and bearing capacity of the treated soil, and this is in contrast to what is aimed from any soil stabilization process. However, an optimal blend of 2% CKD/10% LBWA recorded some level of improvement.

Two–way analysis of variance (ANOVA) test on the angle of internal friction result disclosed that the impact of CKD and LBWA on BCS were relevant statistically (F_{CAL} = 26.24 > F_{CRIT} = 2.87 for CKD and F_{CAL} = 12.40 > F_{CRIT} = 2.71) for LBWA. The impact of CKD on the angle of internal friction test result for BCS is more noticeable when put into comparison to that of LBWA.

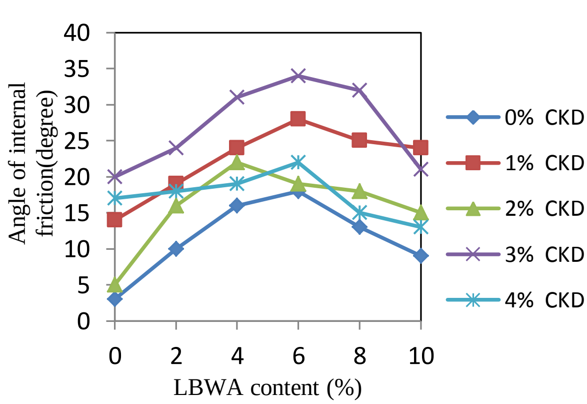

Fig.9. Plot of angle of internal friction of soil – CKD mixtures with LBWA content

4. Conclusions

The effect LBWA and CKD on black cotton soil (BCS) was studied. Based on the results, the following conclusions were drawn:

1. BCS is fine-grained, with greyish-black colour, 68.5% passed sieve 0.075 mm sieve size.
2. The CEC increased with increase in both the LBWA and CKD contents with deviations in few cases. Liquid limit generally increased with increase in LBWA content while plastic limit generally decreased. In the case of plasticity index, values increased with increase in LBWA content. Peak values were recorded at 6%LBWA content.
3. The MDD decreased with increase in LBWA content. MDD values of 1.68, 1.67, 1.66, 1.65, 1.63 and 1.61 were recorded at 0, 2, 4, 6, 8 and 10% LBWA content, . Similar trend was observed for 1, 2, 3 and 4% CKD. OMC increased with increase in LBWA content.
4. Cohesion of soil decreased with increase in LBWA content. Values of 140, 110, 95, 60, 120 and 180 kN/m^2 was recorded at 0, 2, 4, 6, 8 and 10% LBWA content, while angle of internal friction improved from its natural value up to 10% LBWA content.
5. Statistical study by means of two–way analysis of variance (ANOVA) revealed CKD and LBWA has effect on the modified soil properties
6. Based on the result obtained, the modified soil altered to some level the consistency, compaction and shear strength parameters of BCS at optimally 2% CKD/10% LBWA blend, and can be used as sub-base materials for lightly trafficked roads construction

Conflict of Interest

The authors declare that they have no conflict of interest

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