Improvement of properties of black cotton soil subgrade through lime kiln dust and sand stabilization

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ABSTRACT: The soil sample was blended with varying proportions of sand alone, and a combination of sand and Lime Kiln Dust (LKD). The laboratory results were analyzed based on the effect of the additives on the engineering properties of the soil sample. From the test results on neat soil sample, it was observed that black cotton soil had a high plasticity index, high swelling potential, and low bearing strength. The addition of sand-LKD to black cotton soil sample exhibited a significant improvement in strength, and reduction in the plasticity index and swelling potential. The application of 30% sand and 3% LKD increased the CBR value of the neat sample from 5% to 18%, reduced the PI value of the native soil from 49% to 10.2%. This combination satisfied all the Ministry of Works and Transport subgrade specification requirements and was considered as the optimum stabilizer content for black cotton subgrade soils.

1 INTRODUCTION

Black cotton (BC) soils are inorganic clays characterized by exceptionally low bearing capacity, high compressibility, low permeability, and high-volume change under changing moisture conditions (Amadi & Osu 2018, Kollaros & Athanasopoulou 2016). BC soils exhibit high swelling and shrinking due to changes in moisture content (Dalal et al. 2017). The soil is extremely hard when dry and loses its strength further upon wetting. The alternate wet and dry conditions in the soil bring about severe movements of the soil mass, thus structures built on BC soil experience recurring cracking and progressive damage in the form of settlement, unevenness, etc. (Dalal et al. 2017, Verma & Marv 2013). In Uganda, BC soils are mainly found in the semi-arid Karamoja subregion in the North East.

The high swelling and shrinkage properties of BC soil can be attributed to the presence of a considerable amount of montmorillonite clay mineral (Etim et al. 2017). It has an expanding lattice that easily adsorbs water, hence expanding. Montmorillonite is also associated with more surface area per unit mass than other clay minerals (Alshameri et al. 2014, Salima & Abdelhak 2013). Roads constructed on expansive subgrade soils have not fulfilled their intended functions of accessibility and mobility due to being in poor condition, to which the nature of the soil contributes to some extent (Ikeagwumi et al. 2019). At the same time, gravel roads with expansive subgrade soil, such as BC soil, have failed to perform their intended function of providing satisfactory ride quality due to deteriorations like cracks, bumps, slipperiness, and impassability, especially in wet conditions (Verma & Marv 2013, Etim et al. 2017, Al Fouzan & Dafalla 2014). This is exactly the situation of the roads in North-Eastern Uganda, where most of the roads are almost impassable during rainy season, hence bringing businesses to a standstill. There is, therefore, a need for improvement of such problematic subgrade soil before it is built upon.

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Different techniques have been adopted to enhance the engineering properties of black cotton soils and these include substitution and chemical stabilization, such as the use of lime. The optimal selection among the various methods is guided by various economic, practical, and environmental considerations. According to Ground Engineering Magazine (2009) & Edil et al. (2006), the reutilization of materials found on-site has proved to be more sustainable and environmentally positive than the conventional method of substitution (dig and dump) by dealing with unsuitable subgrade materials. Though stabilization is an economical and popular way of reusing on-site materials, the use of lime, either in isolation or with other stabilizing agents, has been found to be expensive, especially in third world countries (Zami & Lee 2009). Recent research has successfully utilized other effective and environmentally sustainable additives either in isolation or in combination with lime, including groundnut shell ash, bagasse ash, iron ore tailings, ground granulated blast furnace slag, and wood powder, to improve the properties of black cotton soil (Dalal et al. 2017, Ikeagwuani et al. 2019, Etim et al. 2017, Kang et al. 2015, Sreekrishnavilasam et al. 2007).

Research has shown that stabilization of locally available problematic soil by utilizing industrial and construction waste materials along with natural poorly graded river sand provides improved compaction and strength characteristics and reduces the cost of construction substantially (Kollaros & Athanasopoulou 2016, Kang et al. 2015, Gupta & Sharma 2016, Jjuuko et al. 2011, Schanz & Elsawy 2017). Lime kiln dust (LKD), a by-product from the manufacturing process of quick lime with high lime content, has potential in the stabilization of soils as a direct substitute for hydrated lime (Arulrajah et al. 2017).

This study investigated the potential use of lime kiln dust (LKD) and sand together as additives in the modification of BC soil in Uganda. Approximately, over 3600 kg of lime kiln waste dust is generated daily during lime production at Tororo Cement Limited. In addition, sand is naturally occurring and is one of the materials that are readily available in Uganda. Its constituents can easily be controlled. According to Adam & Agib (2001), in order to achieve higher quality and production cost reductions, proportions between soil, stabilizer, and compaction pressure need to be optimized, taking into consideration the specific characteristics of the soil. In spite of all this, little work has been done to determine the requirements of LKD and sand for stabilizing BC soil in Uganda to obtain optimum results. The work concentrated on the characteristics of BC soil, sand, and LKD samples, and on the effect of stabilizing BC soil by mixing it with dry sand and LKD.

2 MATERIALS AND METHODS

2.1 Black Cotton (BC) soil

Samples of black cotton soil were obtained from Nakapiripirit district (Namalu-Kaiku Road). The required amount of soil was obtained at depths of about 0.5 m below the ground level. Sufficient care was taken to ensure that the collected soil samples were fairly homogenous. The topsoil was ignored since it was more likely to contain organic matter and other foreign materials. The tests conducted on BC soil indicated a poorly graded material with a 99% proportion of fines passing sieve No. 200. It was classified as A-7-6 (55) according to AASHTO, an inorganic clay with a high plasticity index. A group index of 55 was greater than the required maximum of 20, indicating a poor subgrade material. The chemical constituents of the obtained BC soil sample were tested in Makerere University, Department of Geology and Petroleum Studies laboratory. The results obtained were CaO at 0.63%, MgO at 2.32%, Fe₂O₃ at 3.82%, Al₂O₃ at 17.29% and SiO₂ at 34.71%. Perkin Elmer Analyst 400 equipment was used in the analysis.

2.2 Lime Kiln Dust (LKD)

LKD is a waste product from the production process of quick lime. It is estimated that about 3600 kg of LKD is generated daily during lime production at the Tororo Cement Limited plant alone. LKD is suitable for stabilizing a wide range of soils, both cohesive and non-cohesive. This is also a cost-effective way of reusing it. LKD has been successfully used to
stabilize subgrade soils. It has been found to enhance values of the California Bearing Ratio, resilient modulus, and unconfined compressive strength, and lower the plasticity index (Kang et al. 2015, Heckel & Wahab 1996, Burnham et al. 1992, Daita et al. 2001, Solanki et al. 2010, Cetin et al. 2010). LKD used in the study was sourced from Tororo Lime Plant. It was packed in sacks and transported to the Geotechnical Engineering laboratory in Makerere University. The chemical constituents of LKD were determined in the laboratory of Tororo Lime Plant. Its chemical properties, as determined in the laboratory, included CaO at 71.52%, MgO at 2.66%, Fe$_2$O$_3$ at 1.47%, Al$_2$O$_3$ at 0.73% and SiO$_2$ at 2.38%. The values indicated high quantities of CaO, hence suitable for stabilization of BC soil with high amounts of SiO$_2$ and Al$_2$O$_3$.

2.3 Sand
Sand was obtained from River Lolachat in Nakapiripirit district. The grading curve for sand from the sieve analysis test was fitting in the grading envelope defined by the grading limits in the Ministry of Works and Transport (MoWT) specifications. The grading curve indicated uniformly graded sand with both coarse and fine particles. According to the Unified Soil Classification System (USCS), it was classified as Silty Sand, which bonds well with clay particles.

2.4 Sample preparation
The samples for laboratory testing were prepared in accordance with BS 1377 Part1:1990. It has been reported that some tropical soils are sensitive to pretest drying methods [44]. Therefore, all the samples of black cotton soil were air-dried. Other pretest sample preparation methods included pulverization using a rubber mallet, sieving, and sub-sampling (coning, quartering, and riffling). After air-drying, index property tests were carried out for classification.

In order to investigate the effect of sand and lime kiln dust on the properties of black cotton soil, specimens with specified amounts of sand, lime kiln dust, and soil were prepared in different mixes. The soil was blended with varying percentages of sand in the proportions of 0%, 20%, 30%, 40%, and 50%. Black cotton soil was further blended with lime kiln dust by keeping 30% sand constant and varying lime kiln dust in proportions of 3%, 4%, 5%, and 6% by mass. Most specifying bodies permit the use of recycled materials as a portion of the road improved subgrade. According to BS 6543 for waste materials and industrial by-products, a maximum of 50% LKD by weight of total mass could be used. The mixing was done mechanically on a metal tray. For consistency, soil was mechanically blended before mixing with sand and LKD. Tests of physical properties of the different blends/mixes were conducted.

2.5 Initial consumption of lime kiln dust
The method developed by Eades and Grim to measure the pH of soil stabilized with various percentages of lime or any other pozzolanic stabilizer was utilized. The quantity of lime kiln dust necessary to maintain the pH of 12.40 in the soil–LKD–water mix after one hour is considered to be the initial consumption of LKD of the material. It is the required minimum content of LKD that will stimulate the pozzolanic reactions to achieve a permanent gain in strength of the subgrade material. Samples of black cotton soil were mixed with distilled water and different proportions of LKD. The pH values for the different proportions of LKD were then read from the pH meter and recorded. The graph of pH against LKD content was then plotted and the minimum content of LKD needed to give a pH value of 12.40 was read from the graph. The initial consumption of lime kiln dust was determined as 5.6% at a pH value of 12.4. For adequate stabilization, an excess of lime kiln dust has to be added to black cotton soil.

2.6 Laboratory tests
Laboratory tests were carried out on the natural soil sample and blended soil mixtures. The tests were carried out to determine the index and strength properties of the native and blended soil samples. The results were analyzed based on the effect of the stabilizer in comparison with
the properties of the neat soil sample and stabilized soil samples. They were then compared against the MoWT specification requirements for subgrade construction. The tests were conducted in accordance with British Standards, Indian Standards, and American Society for Testing and Materials Standards, as shown in Table 1.

Table 1. Summary of laboratory tests.

<table>
<thead>
<tr>
<th>Material to Be Tested</th>
<th>Tests</th>
<th>Standard Test and Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black cotton soil</td>
<td>Particle size distribution (wet sieving and hydrometer)</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>Moisture content</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>Liquid limit</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>Plastic limit</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>Linear shrinkage</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>Compaction test</td>
<td>BS 1377: Part 4: 1990</td>
</tr>
<tr>
<td></td>
<td>CBR Three-point method</td>
<td>BS 1377: Part 4: 1990</td>
</tr>
<tr>
<td></td>
<td>Free swell test</td>
<td>IS 2720: Part 40: 1977</td>
</tr>
<tr>
<td>Sand</td>
<td>Particle size distribution</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td>Lime Kiln Dust</td>
<td>Optimum LKD Content</td>
<td>ASTM D6276</td>
</tr>
<tr>
<td>Blended mix of BC soil, Sand, and Lime Kiln Dust</td>
<td>Particle size distribution</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>Liquid limit</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>Plastic limit</td>
<td>BS 1377: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>Compaction test-stabilized materials</td>
<td>BS 1924: Part 2: 1990</td>
</tr>
<tr>
<td></td>
<td>CBR Three-point method</td>
<td>BS 1377: Part 4: 1990</td>
</tr>
</tbody>
</table>

3 RESULTS

3.1 Effect of sand on the index and strength properties of black cotton soil

3.1.1 Effect of sand on the gradation of black cotton soil
The grading curves of the blended mixes improved with addition of sand. In addition, the group index of the blended mixes decreased with an increase in sand content. This was evidenced by an increase in the amount of particles retained on sieve No 200. The finer particles of BC soil were replaced with coarser particles of sand, resulting in uniform gradation of particles in the blended mixes (Kollaros & Athanasopoulou 2016).

3.1.2 Effect of sand on atterberg limits of black cotton soil
There was a reduction in the liquid limit, plastic limit, and shrinkage limit and plasticity index with increasing percentages of sand content in the black cotton soil as indicated in Table 2. The liquid limit decreased from 70.5% to 29.4% with increasing proportions of sand. The plastic limit slightly decreased from 21.5% to 12.4%, whereas the linear shrinkage decreased from 15% to 6.4%. There was also a general reduction in the plasticity index of the modified black cotton soil from 49% to 17.0%. These results agree with those of several researchers (Gupta & Sharma 2016, Jjuuko et al. 2011, Babu et al. 2016). This can be attributed to a reduction in the fine proportions needed for bonding of the clay particles, and the changes in soil texture on addition of sand from fine-grained clay to the increasingly coarse-grained nature of the black cotton soil–sand mix. Addition of more non-cohesive sand minimizes the binding ability of the mixes and their ability to retain moisture. The reducing plasticity automatically results in less swell ability, hence low susceptibility to cracking. All the blends were associated with liquid limits less than 50%. Such soil materials are suitable for pavement layers (Jjuuko et al. 2011).

3.1.3 Effect of sand on the free swell ratio of black cotton soil
From Table 2, it was observed that, as more sand was added to the soil, the free swell ratio of the blended mixes decreased and thus a reduction in the swell potential of the soil resulted. The same behavior was reported by Babu et al. (2016), and it follows the obtained results. This was due to
the reduction in the proportion of clay particles, which are responsible for its high swelling potential. This changed the nature of subgrade soil from swelling to non-swelling.

3.1.4 Effect of sand on the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of black cotton soil

As more percentages of sand were added to black cotton soil, the maximum dry density slightly increased with increasing sand percentages. Similarly, the optimum moisture content decreased with increasing percentages of sand, Table 2. The same trend was reported by Gupta & Sharma (2016), Babu et al. (2016), Ningthoujam & Pramod (2018), and it is in accordance with obtained results. According to Jjuuko et al. (2011), soil type is a major variable in the resulting moisture density relationships. The alterations can be attributed to the variations in plasticity index and specific gravity of the mixes. Reduction in plasticity index minimizes the binding and moisture retention abilities of soil specimens. Well-graded soils exhibit higher MDDs than poorly graded soils, while finer soils exhibit higher OMCs and lower MDDs than coarser soils. Usually soils with MDDs greater than 2 Mg/m³ and OMCs less than 15% are easier to compact.

The increase in the maximum dry density is attributed to the addition of the coarse sand particles into fine-grained black cotton soil. This is explained by the fact that addition of coarse-grained sand particles to fine-grained soil occupies the void spaces between the soil particles. Furthermore, the addition of sand particles to fine-grained clay results in a coarse-grained skeleton-like structure and the voids between the particles are filled with fine-grained or clay particles. This enhances the compaction properties of the material and hence results in higher densities. Therefore, an increase in sand content leads to a reduction in void spaces in the soil sample, thus resulting in an increased density.

The decrease in the optimum moisture content is due to the reduction in the volume of voids as more sand is added to fill the void spaces between black cotton soil particles. The fact that clay has a high voids ratio due to its high proportion of fines, means the addition of sand particles to it reduces its capacity to hold water. In addition, the sand particles have a coarse-grained texture with a less specific surface area and thus a lesser amount of water is required to slide the particles together to achieve the desired density.

Table 2. Laboratory test results of black cotton soil-sand mixes.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Atterberg Limits</th>
<th>Free Swell Ratio</th>
<th>MDD</th>
<th>OMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neat BC</td>
<td>70.5</td>
<td>21.5</td>
<td>2.3</td>
<td>15.0</td>
</tr>
<tr>
<td>20% SD</td>
<td>43.8</td>
<td>10.4</td>
<td>2.0</td>
<td>10.0</td>
</tr>
<tr>
<td>30% SD</td>
<td>39.4</td>
<td>14.3</td>
<td>1.8</td>
<td>8.6</td>
</tr>
<tr>
<td>40% SD</td>
<td>36.8</td>
<td>13.8</td>
<td>1.5</td>
<td>7.1</td>
</tr>
<tr>
<td>50% SD</td>
<td>29.4</td>
<td>12.4</td>
<td>1.3</td>
<td>6.4</td>
</tr>
</tbody>
</table>

3.1.5 Effect of sand on the California Bearing Ratio (CBR) of black cotton soil

The soaked CBR values increased appreciably with an increase in percentages of sand. The CBR value of neat black cotton soil increased from 5.0% to 23.0% with the addition of sand content. The modified soil samples had CBRs of 7.0%, 13.0%, 16.0%, and 23.0% with addition of 20%, 30%, 40%, and 50% of sand, respectively. The same behavior was reported by Babu et al. (2016). The CBR values increased with addition of sand content due to the rearrangement of the soil particles from fine-grained soil to an increasingly granular nature having an interlocked structure between the soil particles. This improves the strength properties of the material by increasing the density of the material. Replacement of fine particles of BC soil with coarser sand particles results in uniformly graded blends with enhanced cohesion and friction parameters. Therefore, the higher the density of the material, the greater resistance to penetration force, thus resulting in an increase in the CBR value. If properly mixed, placed, and compacted in the field, the composite mixes exhibit improved load-bearing capacity.
3.1.6 Selection of the BC soil–sand optimum mix to be blended with LKD

On the basis of the above results, the optimum mix for the BC soil–sand mix was decided based on:

- Plasticity index and CBR value in compliance with the MoWT specifications. A mix of 30% sand was considered as the optimum mix to be blended with varying proportions of lime kiln dust, as it proved to be the minimum mix and economical for use. This had a PI value of 25.1%, which was close to the required maximum of 25%, and a CBR value of 13.0%, which was above the required minimum CBR of G7. However, this did not satisfy all the MoWT requirements because of its swelling in nature, with a free swell ratio of 1.8 and plasticity index value that was greater than required. Therefore, further modification was necessary to satisfy all the required standards;

- Economic reasons. 30% sand may be more economical for use as it would require:
  - Less imported material,
  - Less in-situ material wastage,
  - Less energy consumed in site preparation (excavation to spoil),
  - Less site operation costs (transportation costs).

3.2 Effect of Sand–Lime Kiln Dust (SD-LKD) combination on the physical and strength properties of black cotton soil

3.2.1 Effect of SD-LKD combination on the atterberg limits of black cotton soil

The Atterberg limit results for the black cotton soil–sand–lime kiln dust (BCS-SD-LKD) mix are presented Figure 1. It can be seen that a slight increase in the plastic limit values was noticed with the addition of 3% and 4% LKD content, whereas the addition of 5% and 6% LKD content in BCS-SD mix altered the composite mix to a non-plastic condition. The results showed that the liquid limit values were not consistent with the increasing LKD content. The liquid limit gradually increased from 39.2% to 43.5% with the addition of 3% to 5% LKD content, respectively, and further addition of 6% LKD content slightly reduced the liquid limit to 42.6. The general reduction in the plasticity index of the composite mix was observed with the increasing LKD content. The plasticity index reduced from 10.2% to 0% with the addition of 3% to 6% LKD, respectively. The same trend was observed with the shrinkage limit values with the increasing percentage of LKD.

The reduction in the plasticity index may be attributed to the aggregation of clay particles from fine clay to an increasingly granular nature induced by cation exchange and flocculation and agglomeration reactions. The increase in liquid limit is attributed to flocculation and agglomeration of the clay soil particles due to the addition of lime kiln dust. This results in aggregation of the clay soil particles from a fine-grained nature to increasingly coarser aggregates (Bell 1996, Al-Rawas et al. 2005, Nalbantoglu & Tuncer 2001). These have the ability to increase the water-retaining capacity of the flocculated aggregated structure and hence increase the liquid limit as well as the plastic limit of the soil. The decrease in liquid limit is attributed to the effect of cation exchange reactions between the cations of the soil and those of lime kiln dust, which depress the thickness of the diffuse double layer due to the increase in cation concentration. The addition of 6% LKD induced a reduction in the water-holding capacity of the soil and hence a decrease in liquid limit. The same behavior was reported by Bessaim et al. (2018) and it follows the above results.

3.2.2 Effect of SD-LKD combination on the MDD and OMC of black cotton soil

From Figures 2 and 3, as higher percentages of LKD content were added to the BCS-SD mix, the maximum dry density slightly decreased, whereas the optimum moisture content increased. These results follow the results of several researchers (Makandar 2016, Achampong et al. 2013). The variations in the MDD and OMC of the soil are attributed to flocculation of the soil particles, as indicated by the Atterberg limits (Al-Rawas et al. 2005, Nalbantoglu & Tuncer 2001). The increase in the optimum moisture content is attributed to the increase in the shearing resistance of the soil particles. As more LKD content is added to the BCS-SD composite, the soil
particles are gradually cemented, increasing the particle resistance to compactive effort. This cementation of the soil particles induces a higher water-holding capacity and thus an increase in optimum moisture content and a corresponding decrease in the maximum dry density. In addition, the increase in OMC is due to the larger specific surface area of LKD particles and hence more water is required for sufficient lubrication of the blended mixture to obtain MDD. The increase in OMC may also be attributed to the flocculated and agglomerated clay particles, which tend to agglomerate, thus occupying larger spaces and leading to an increase in water content. The decrease in MDD is due to the fact that LKD has a lower specific gravity as compared to the BCS-SD composite. This is attributed to flocculated structure aggregation formed by the addition of LKD having a lower specific gravity and hence a reduction in MDD (Kang et al 2015). The MDD and OMC of all blends was greater than that of the neat soil sample. This can be attributed to the high lime content of LKD facilitating faster consumption of water in the mixes. Similarly, the higher specific area of LKD leads to higher water absorption and quicker reaction, hence dense matrix of hydrated LKD (Bernard et al. 2010).

3.2.3 Effect of SD-LKD combination on the CBR of black cotton soil

The CBR results presented in Figure 4 show that the CBR value of the BCS-SD composite blended with LKD increased with addition of LKD content. The same trend was reported by Achampong et al. (2013). The increase in CBR values is attributed to the cation exchange reaction and flocculated structure aggregation of the soil particles (Bell 1996, Al-Rawas et al. 2005, Nalbantoglu & Tuncer 2001). In addition, the increase in CBR values may be related to the pozzolanic reactions, which are responsible for the strong cementing bond between the clay soil particles. These reactions resulted in the formation of cementitious compounds, i.e., calcium silicate hydrate.
(CSH) and calcium aluminate hydrate (CAH) (Al-Rawas et al. 2005). The formed compounds crystalize with time and thus result in changes in clay plasticity, increase in shear strength, and changes in swelling properties. Therefore, addition of LKD to the BCS-SD composite resulted in the bonding of clay particles together, which increases the resistance to penetration and thus results in an increase in the CBR value.

4 CONCLUSIONS

- The black cotton soil used in this study had the following physical properties: liquid limit of 70.5%, plastic limit of 21.5%, plasticity index of 49%, and free swell ratio of 2.3. For the strength properties: a CBR value of 5% at 95% compaction, MDD of 1.571 g/cm³ and OMC of 18.6%.
- There was a general reduction in the Atterberg limits with increasing percentages of sand. The liquid limit and plastic limit of the soil blended with sand decreased from 70.5% and 21.5% to 29.4% and 12.4%, respectively. The same trend was observed with plasticity index and linear shrinkage values from 49% and 15% to 17.0% and 6.4%, respectively.
- The variations in the free swell ratio of black cotton soil blended with sand show that black cotton soil had a free swell ratio of 2.3, which was reduced to 1.3. This implies that the black cotton soil changed from its swelling nature to a non-swelling nature after blending with sand.
- There was a reduction in OMC values and a corresponding increase in MDD with increasing proportions of sand. The maximum dry density of black cotton soil increased from
1.571 g/cm³ to 1.905 g/cm³ for the BCS-SD mix, whereas the optimum moisture content of the black cotton soil decreased from 18.6% to 11.4% of the blended mix. More so, the CBR of black cotton soil increased relative to increasing percentages of sand. The CBR values increased from 5% to 23% for sand content of 0% to 50%, respectively.

- BC soil treated with a combination of lime kiln dust and sand exhibited a general decrease in plasticity index and linear shrinkage values to levels lower than those achieved with sand content alone. The plastic limit values slightly increased with the addition of 3% and 4% LKD content, whereas further addition of 5% and 6% rendered the mix non-plastic. In addition, the liquid limit gradually increased from 39.2% to 43.5% with the addition of 3% to 5% LKD content, respectively, and furthermore, addition of 6% LKD slightly reduced the liquid limit to 42.6%.

- The compaction test results showed a reduction in the maximum dry density with a corresponding increase in the moisture content with the addition of LKD content. The MDD of black cotton soil increased from 1.571 g/cm³ to 1.689 g/cm³ for the final optimum mix, whereas the OMC of black cotton soil increased from 18.6% to 19.0% for the final optimum mix.

- The CBR results of the composite treated with LKD increased with the addition of various percentages of LKD. The soil treated with a combination of LKD and sand showed more strength gain than black cotton soil treated with sand alone. The CBR of black cotton soil increased from 5% to 18% for the final optimum mix. From the above results, the modified black cotton soil can be successfully used for subgrade construction.

REFERENCES


