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The effect of Groundnut Shell Ash and Metakaolin on Geotechnical Properties of Black Cotton Soils

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Abstract. Groundnut shell ash (GSA) and metakaolin (MK) were investigated for their stabilizing prospects in highly expansive clay soils due to the rising cost of traditional stabilizers and the need for cost-effective utilization of waste materials for useful engineering applications (black cotton soil). The natural soil's index qualities revealed that it belongs to A-7-6 in the AASHTO classification system and CH in the USCS classification system. This means that the soil is unsuitable for most engineering purposes. The natural soil's liquid limit and plasticity index values of 60.2% and 30.1%, respectively, indicate that the sample were malleable. The soaked CBR for natural soil is 1.67%, but it rises to 3.26% when 10% GSA and 10% MK are added. This value fell short of the recommended CBR values for pavement materials. The samples' durability measured based on their resistance to strength loss, fell short of the recommended strength by 80%. This concludes that the groundnut shell ash and Metakaolin cannot be used as standalone for stabilization of black cotton soil. However, when compared to the un-stabilized soil, the strength of UCS increased from 128.03 kN/m^2 to 482 kN/m^2 after 28 days of curing.

Keywords: Groundnut Shell Ash, Metakaolin, Black Cotton Soil, California Bearing Capacity.

1 Introduction

Black cotton soil (BCS) are problematic soils which are not good for engineering use, such as road and building construction. In other words, they are very good and fertile for all agricultural purposes. Expansive soils are widespread in semi-arid climatic zones around the world, when yearly evaporation surpasses precipitation, and can be seen anywhere on the planet [1]. In some regions of the world, these soils are termed "black cotton soil". Cotton grows well on them, hence the name and black cotton soils come in a variety of colors. The prevalence of montmorillonite, according to Osinubi [2], dominates the mineralogy of this soil, which is marked by considerable volume changes from wet to dry seasons and likewise. In the summer, black cotton soil deposits reveal a common pattern of fissures. Cracks that measured 70 mm broad and over 1 m deep have been recorded, with high deposits extending up to 3 m or more. Bitumen, lime, and cement are the three most used stabilizers for expanding clays [3].

In 21st centuries, attentions of researcher have been shifted from the use of traditional stabilizers (cement, lime, bitumen etc.) to the use of huge agricultural waste generated from the processing of agricultural products that constitutes problem in the environment. Waste utilization from agricultural material is aimed at reducing the cost of procuring cement and other traditional stabilizers and for the advancement of engineering practice [4]. Some researchers [2, 5-8] look into the possibility of using agricultural waste to stabilize the qualities of expansive problematic soils. Their findings reveal that wastes have a desired effect when used alone or in combination with lime or cements.

Groundnut is one of the economic crops produce in Nigeria since 1950. It ranked the sixth in the world's oil seed crops producing 48-50% oil contents followed by protein of 26- 28% and lastly carbohydrate, minerals and vitamins of 11 – 27%. India produces the most groundnuts in the world, followed by China and Nigeria [9]. Globally, 20 million hectares of land are utilized for groundwater farming each year and 10% of that are situated in Nigeria. All six north eastern states, four largely populated north western states, and three north central states are among Nigeria's biggest producers [10].

The use of solid waste (Groundnut Shell Ash) dumping for soil stabilization is an important practice that has a number of environmental benefits [11]. All solid and semi-solid materials abandoned by the community are referred to as solid waste. Indiscriminate solid waste management has negative consequences for the environment, perhaps leading to infectious disease outbreaks and epidemics. The excessive reliance on industrially made soil enhancing chemicals (cement, lime, and bitumen, for example) has maintained the cost of stabilizing a road high. This has hampered the ability of developing countries to provide roadways to suit the needs of its rural areas, who make up a substantial proportion of their population. Furthermore, the World Bank has invested on research targeted at reutilizing industrial by-products [12].

According to [13], groundnut shell ash (GSA) can be used as a soil remediation agent, particularly in engineering projects with unstable soil, where it can be used as an alternative for deep/raft foundations, saving money and energy. The utilization of agro-based wastes as raw materials has served as an option to reduce environmental pollution levels. Field residues and processing residues are two types of agricultural residues. Field residues are leftovers from crop harvesting that remain on the field. Leaves, stalks, seed pods, and stems make up this group. Process residues, on the other hand, are residues that remain after the crop has been processed into substitute precious resources. Groundnut shells are agricultural wastes derived from groundnut milling [14]. Metakaolin [15] is a highly pozzolanic substance made by calcining kaolin at 700 degrees Celsius. As a result, the goal of this research is to investigate the viability of agricultural wastes (Groundnut Shell Ash GSA) in variable percentages and Metakaolin in a constant percentage to stabilise black cotton soils.

2 Materials and Methods

2.1 Materials

2.1.1 Soil

The black cotton soil utilized were sourced from Kwandon town in Deba Local Government Area of Gombe State, which is located in North-Eastern part of Nigeria, using a disturbed sample method during the rainy season. The soil was excavated to a depth of 1 m, a portion of the excavated material was wrapped in nylon to acquire the natural moisture content of the soil, and the leftover soil was stored in bags and taken for laboratory analysis. The soil was air dried first before pulverizing.

2.1.2 Groundnut Shell Ash

The groundnut shell ash was sourced locally in Minna, Niger State, Nigeria. It was oven dried at room temperature and then burned at 600 to 700^{o}C to produce the ash (GSA). The ash produced was sieved with sieve No. 212 µm. The oxide composition groundnut shear ash (GSA) of Alabadan et.al, [16] was adopted as shown on table 1.

Table 1: Oxide Composition of Groundnut Shell Ash

Oxide	Concentration (%)
CaO	**8.66**
SiO_2	**15.92**
Al_2O_3	**6.73**
Fe_2O_3	**1.93**
MgO	**4.72**
K_2O+Na_2O	**6.12**
SO_3	**6.40**
CO_3	**6.02**

Source: [16]

2.1.3 Metakaolin

Kaolin for production of metakaolin was obtained from Alkaleri L.G.A of Bauchi State. It was burned at temperatures ranging from 600 to 700°C in a kiln at industrial design department at A.T.B.U. Bauchi, the metakaolin was allow to cool before grinding and was sieved using sieve no. 212 µm. The oxide composition of metakaolin of Umar et. al [15] was adopted (Table 2).

Table 2: Oxide Composition of Metakaolin

Property	Concentration (%)
Al_2O3	**34.2**
SiO_2	**53.7**
K_2O	**0.932**
CaO	**0.513**
TaO_2	**5.97**
V_2O_3	**0.23**
Cr_2O_3	**0.057**
MnO	**0.061**
Fe_2O_3	**3.84**
NiO	**0.071**
CuO	**0.030**
ZnO	**0.009**
Ga_2O_3	**0.088**
Total	**100**

Source: [15, 17]

2.2 Methods

Laboratory test on the Black Cotton soil and groundnut shell ash/metakaolin mixture was done in accordance with BS1377 [18] standard. Various proportions of 2%, 4%, 6%, and 8% of GSA and 10% Metakaolin were mixed with BCS and the subsequent experiments carried out on the blended mix.

2.2.1 Atterberg Limits Test

The Laboratory test were carried out in accordance with Osinubi et al., [19], the liquid limit (LL), plastic limit (PL), and plasticity index (PI) of SSA/Lime stabilized BCS were determined in the laboratory. With varying percentages of SSA (2%, 4%, 6% & 8%) with 10% fixed Metakaolin were added to BCS by dry weight of soil.

2.2.2 Soil Compaction Test

The soil compaction test was done in accordance with British Standard 1377 [18]. The goal was to assess how compacted dry density and soil moisture content were related. The typical proctor light weight compaction efforts were used for this study (BSL). The soil was compacted in a mould of volume 100 cm^3 with 2.5 kg rammer weight and a drop of 304.8 mm in three layers with twenty-seven (27) blows for each layer. The related OMC and MDD were calculated using a graph of moisture content vs dry density. The method was repeated by adding 2 %, 4 %, 6 %, and 8% SSA to the natural BCS, along with 10% Metakaolin.

2.2.3 Strength

California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) values were determined using strength tests on a black cotton Soil-Groundnut Shell Ash-Metakaolin mixture. For curing, the compacted CBR specimens were tightly sealed in plastic bags to prevent moisture loss owing to evaporation. The composites Optimum Moisture Content was used to cast and cured by enclosing every sample in polythene material bags to thwart moisture loss prior to actual testing in full compliance with the Nigerian General Specification (1997), while specimens for unconfined compressive strength (UCS) were prepared at their respective Optimum Moisture Content and curing by wrapping each sample in polythene material bags to prevent moisture loss. In the instance of UCS, the sample was cured for 7, 14, and 28 days. Another set of soil sample was cured for 7 days under comparable circumstances before being properly withdrawn, de-waxed, and totally submerged in water for seven (7) days before being tested for UCS.

2.2.4 Durability

The soil stabilized specimens' durability was assessed using a dip in water test to determine resistance to loss of strength, instead of the wet-dry and freeze-thaw tests recommended by ASTM [20], which are ineffective in tropical circumstances. The resistances to loss of strength were calculated as a ratio of the 14-day UCS value of cellophane-cured specimens to the 7-day UCS value of cellophane-cured specimens, opened and submerged in water for further 7 days.

3 Results and Discussions

3.1 Index properties

Table 3 summarizes the results of index properties performed on natural soil. The black cotton soil was classed as an A-7-6 clayey soil by the AASHTO Classification System. According to the Unified Soil Classification System, USCS [20], the soil was classed as inorganic clay soil of High plasticity "CH" with LL and PI values of 60.2 and 30.1%, respectively. As a result, the outcomes obtained fall short of the industry norm for most engineering projects.

Table 3: Properties of untreated black cotton soil.

Property	Value/Description
Natural moisture content	**30.57%**
Specific gravity	**2.28**
Percentage passing BS sieve No. 200	**83.85%**
Liquid limit	**60.2%**
Plastic limit	**30.1%**
Plasticity index	**30.1%**
Linear shrinkage	**17.86%**
AASHTO classification	**A-7-6**
Unified soil classification system	**CH**
Maximum dry density (MDD)	**1.40 Mg/m^3**
Optimum moisture content (OMC)	**27.5%**
Unconfined compressive strength	**128.03 kN/m^3**
California bearing ratio soaked	**1.67%**
California bearing ratio (unsoaked)	**2.20%**
Colour	**Dark grey**

3.2 Atterberg Limit

3.2.1 Liquid Limit

Figure 1., depicts the effects of GSA and MK on the black cotton soil's LL. After an initial drop at 2% GSA and 10% MK content, the LL increased as the groundnut shell ash and metakaolin concentration increased. The conclusion is consistent with [13]. When the structure of a soil at its LL undergoes a change that results in a marked decline in repulsive forces, its strength increases to the point where more moisture is required to bring the soil to its dynamic shear strength. This did tend to raise the LL of the soil-GSA ash and MK mixture from 60.2% at no GSA and MK content to 58.4 % at 10% GSA and MK content each. The first decline in the LL could be attributed to the influence of dilution of clay content in the mix, along with a decrease

in the diffused double layer. The rise in the LL between 2% GSA and 10% MK and 10% GSA and 10% MK could be consistent with the observation that each increase in GSA and MK introduced more Pozzolanic chemicals from the ash, which required more water to complete hydration.

3.2.2 Plastic Limit

Figure 1., depicts the variance in the BCS's PL as a function of GSA and MK concentration. The addition of GSA and MK led to the reduction in the PL of treated soils. The study by [13] obtained results contrary to the trend in this research. According to the report, the PL of the BCS rose due to flocculation attributed to the prevalence of free lime in the fly ash. However, the free lime level in GSA and MK is insufficient to exceed the PL, and so no such change was detected. Sharp reduction in the PL (24.29%) was observed at 2% GSA and 10% MK. That's because the amount of soil to be flocculated dropped as the proportion of GSA and MK in the mix rose, and the finer particles of GSA and MK may be assimilated in the voids of flocculated soil. As a result, the amount of water trapped in the pores decreased, lowering the PL.

3.2.3 Plasticity Index

Figure 1., depicts the variation in plasticity index of the samples after addition of varied percentages of GSA and a fixed proportion of MK. The inclusion of GSA and MK raises the BCS's plasticity index, as shown in the graph. The plasticity index at no GSA content was 30.1% and as stabilizer content was increased to 4% GSA and 10% MK, a peak value of 30.61% was recorded. The rise in PI was most likely caused by a lack of Ca2+, which is needed to replace the weakly bound ions in the clay structure, and therefore flocculation did not take place as reported by [13]. Instead, there was an increase in the fine fraction which absorbed more water and became more plastic.

3.2.4 Linear Shrinkage

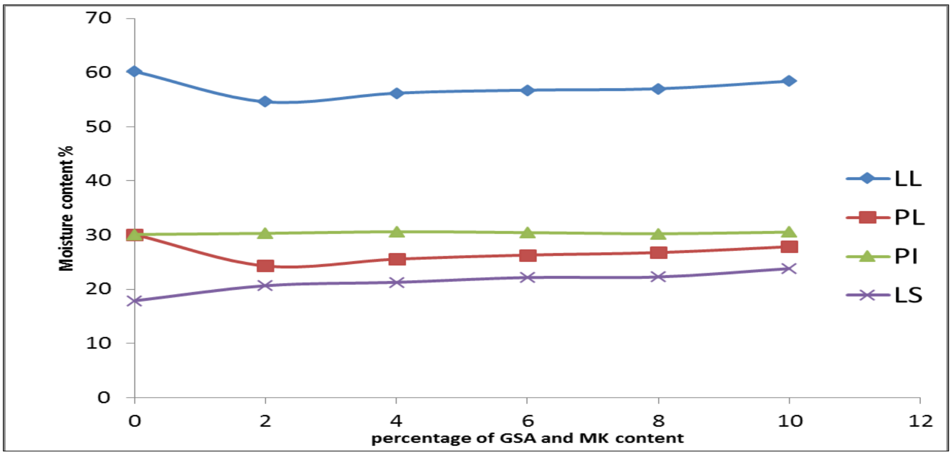
The soil natural linear shrinkage was 17.86%; a rise was observed to a peak value of 23.81 % as depicted in Fig 1. The rise in the linear shrinkage after adding GSA and MK could be attributed to lack of flocculation and agglomeration as explained earlier and hence the mixture contained finer materials which exhibited more shrinkage characteristics.

Figure 1: Variations of Atterberg limit with GSA and MK content

3.3 Compaction Parameters

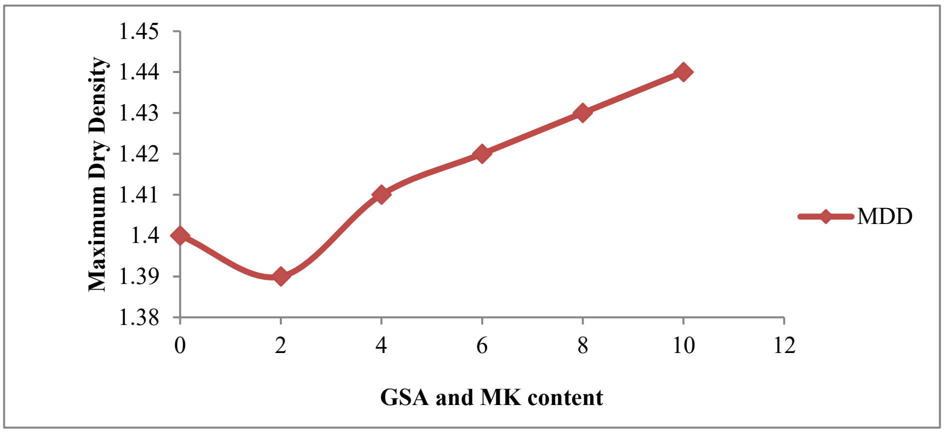
3.3.1 Maximum Dry Density

On the Black Cotton Soil, the fluctuation of the maximum dry density (MDD) with GSA and MK content is displayed in Fig 2. For 0 % GSA, the maximum dry density was 1.4 Mg/m^3 and on addition of GSA and MK, a decrease in MDD was observed to a value of 1.39 Mg/m^3 at 2% GSA and 10% MK. Further increase in GSA content led to rise in MDD to a maximum of 1.44 Mg/m^3 at 10% GSA and 10% MK as reported by [13]. The initial decrease in MDD could be attributed in part to the flocculation and agglomeration of clay particles filling larger areas, resulting in a



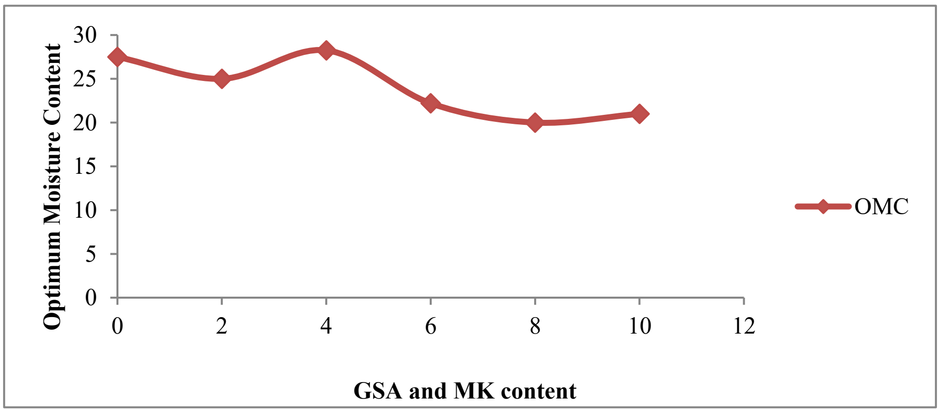
reduction in MDD [21]. The subsequent increase in MDD is predominantly related to ion exchange.

Figure 2: Variation of MDD with GSA and MK content



3.3.2 Optimum Moisture Content

The OMC for sample without GSA is 27.5%, and consecutive increases in OMC to a value of 28.25% at 4% GSA and 10% MK content, as shown in Fig 3. Further addition of groundnut shell ash and metakaolin led to a reduction in the OMC to 20% at 8% GSA and 10% MK as explained by Moses and Osinubi [22] and finally, increase of OMC to 21% was observed at 10% GSA and 10% MK blend mix. The first increases in OMC could be attributed to the different cations and clay mineral particles' increased desire for water to conduct hydration process. The decrease in OMC from 8% GSA to 10% MK was due to self-desiccation, in which all available water molecules were used up in the hydration reaction, resulting in decreased hydration and incomplete hydration, which harmed the OMCs.



3.3.3 California bearing ratio

Figure 4., depicts the variation in CBR with GSA and MK content. According to Ijimdiya, the addition of GSA and MK content resulted in an increase in CBR [13]. Although the increase is still required this could also be linked to the insufficient quantity of CaO present in the GSA and MK. The peak soaked CBR value of 3.26% was obtained at 10% GSA and 10% MK this value fell short of the specification requirement for base and sub base materials [23]. The peak CBR value was attained at 10% GSA and MK content each with a CBR value of 7.5% for the unsoaked condition depicted in Fig 4.6. Notably, it has very little effect on the CBR value of Black Cotton Soil, which is in line with the findings of other studies [12, 24].

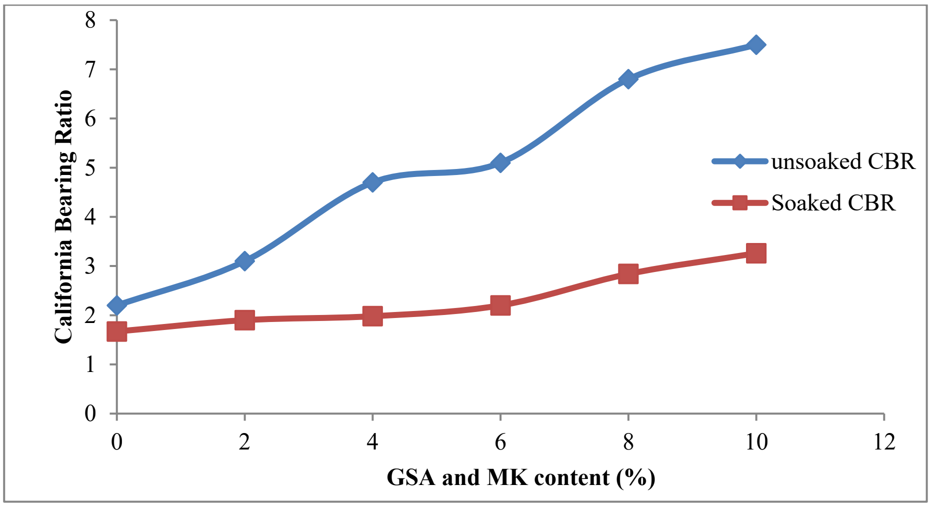


Figure 4: Variation of CBR with GSA and MK content

3.3.4 Unconfined compressive strength

Figure 5., shows the effect of adding groundnut shell ash and Metakaolin to black cotton soil, as well as their UCS values and the fluctuation of UCS with increasing curing time. It is observed in Fig 5 that on addition of 4% GSA and 10%MK, there was a decrease in the UCS of the mixture. The reasons for the decrease could be as a result of insufficient CaO in the GSA which is required for the stabilization of the BCS. However, at 10% GSA and 10% MK, there were increased values of UCS recorded. It's possible that the higher UCS is due to the existence of enough calcium oxide for stability. At curing periods of 7, 14 and 28 days, UCS values at 10% GSA and 10% MK mixture increased to 254, 295 and 482 kN/m2 respectively. The time-dependent strength gain action and pozzolanic reactivity of the free lime content of GSA and MK are responsible for the increasing trend of compressive strength with curing time. The increase in compressive strength is due to adequate water, which aided the hydration process linked to the reaction of Black Cotton soil, groundnut shell ash, and metakaolin. These results in secondary cementitious compounds [25].

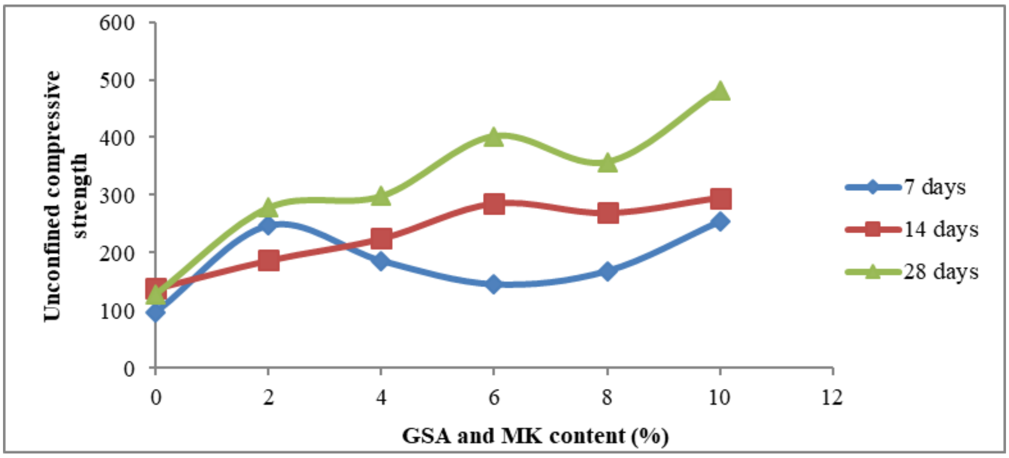


Figure 5: Variation of USC with GSA and MK content

3.3.5 Durability

Figure 6., depicts the effect of adding groundnut shell ash and metakaolin on soil durability. At 10% GSA and 10% MK content, the maximal durability value for resistance to strength loss was 18.8%. The soil stabilized specimens' durability was assessed using a dip in water test to determine resistance to strength loss, instead of the wet-dry and freeze-thaw tests mentioned in [20], which are ineffective in tropical conditions. The resistances to strength loss were calculated as a ratio of the 14-day UCS value of cellophane-cured specimens to the 7-day UCS value of unsealed cellophane-cured specimens submerged in water for further seven (7) days. According to George and Karibo, the GSA failed to meet the minimal durability criteria for application in pavement construction [26].

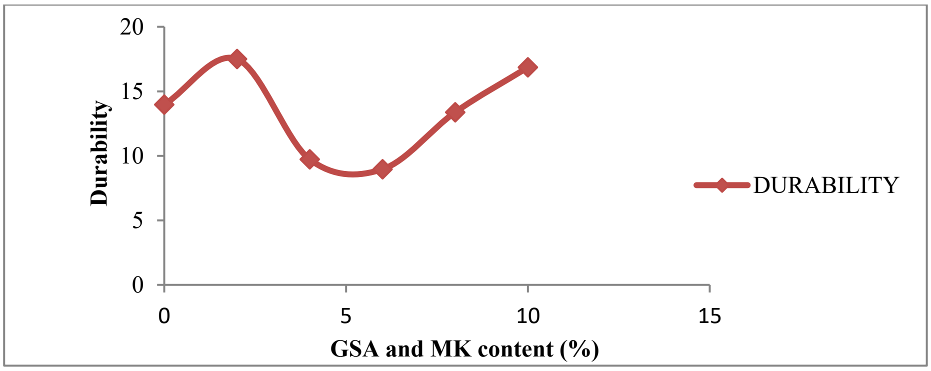


Figure 6: Variation of durability with GSA and MK content

4 Conclusions

The results obtained from this study, have led to the following conclusions.

The soil is highly plastic and classified as A-7-6 subgroup of the AASHTO classification. Adding GSA and MK significantly improves the index properties, compaction and strength characteristics of black cotton soil examined. It increases the MDD of the soils with decrease in the corresponding values of optimum moisture content

The plastic limit of the soils decreases while linear shrinkage increases with the addition of GSA and MK. The UCS of these soils increases upon the addition of GSA and MK. Soil properties were enhanced at 28 days curing period.

The peak CBR (soaked) value at 10% GSA and 10%MK failed to satisfy the country's specification for base and sub-base materials. Conversely, GSA and MK cannot be used as a standalone stabilizer for road construction work. However, it is recommended that GSA and MK can be used more profitably as an admixture with conventional or traditional stabilizers such as lime and cement.

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