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Effect of Compactive Effort on Strength Characteristics of Black Cotton Soil Admixed with Eggshell Powder- Gum Arabic

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Abstract— *The effect of compaction energy of the British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH) on black cotton specimens treated with 5, 10, 15, 20 and 25% eggshell powder (ESP) and 2, 4, 6, 8 and 10% gum-Arabic (GA) was studied. Atterberg's limits, compaction California bearing ratio (CBR) and unconfined compressive strength (UCS) tests were performed on the specimens. The soil was classified as A-7-6 (13) by the American Association of States Highway and transportation Officials (1) and CH by the Unified Soil Classification System (2). The 7day unconfined compressive strength (UCS) Values of the natural soil using BSL, WAS and BSH compaction energies increase from 387, 451 and 324kN/m^2 respectively, while peak values of 644, 475 and 400kN/m^2 where recorded at 2%GA/5%ESP, 2%GA/15%ESP and 2%GA/5%ESP Treatments respectively were less than the UCS value of 1710kN/m^2 requirement specified by road Note 31 (4). The soaked California bearing ratio (CBR) values of the ESP/GA stabilized soil increased from 9.4, 10.6 and 11.3% to a peak value of 10.1, 17.9 and 17.6% at 25%ESP/2%GA, 10%ESP/2%GA and 10%ESP/2%GA for BSL, WAS and BSH compaction energies respectively. An optimal blend of 10%ESP/2%GA is recommended for treatment of expansive black cotton soil for use as sub-grade material.*

***Keywords*—Eggshell powder, gum Arabic, California bearing ratio, Compaction, Unconfined compressive strength**

1. INTRODUCTION

Black Cotton soil mostly found in Africa and Asia are considered as Shrinks and swells soils. These types of soils are prone to failure of pavement, building and waste containment facilities in the north-eastern part of Nigeria and some regions of the world. (6). Black cotton soils shrink when they lose their moisture, but swell when they absorb water. It is typical to use modifiers or treatment agents such as additives to low-quality materials, which brings about improvement in the soil properties including decreased rate of subsidence, decreased adhesion coefficient in soils with high cohesion (clay), increased adhesion coefficient in soils with low cohesion (sand), reduced percentage of water absorption and prevention of soil expansion, reduced cost of earth structures (transport), speeded road construction operations, resistance to frost and defrost, improved ductility, reduced rigidity of earth structures, lack of weed growth in the surface of earth structures such as roads and reduced thickness of bearing layer (7). The Expansive soils mostly found in the north-eastern part of Nigeria are dominantly referred to as "black cotton soils "it derives its name from some part of the world like India where cotton plant thrives well on them (5). Black cotton soils have colours ranging from light grey to dark grey and black.

Two groups of parent rock materials that have been associated with the formation of expansive soils, comprises sedimentary rock of volcanic origin, which can be found in North America, South Africa and Israel, and the second group of parent materials basically entail the igneous rocks found in India, Nigeria and South Western U.S.A (5). The mineralogy of this soil is dominated by the presence of montmorillonite, which is characterized by large volume change from wet to dry seasons and vice versa. Deposits of black cotton soil in the field show a general pattern of cracks measuring up to 70mm Wide and over 1m depth during the dry season (5). One of the most common methods of improving fine soil is stabilization using additives that enhances the soil properties causing physical and chemical changes. It is, however, worth noting that fine soils behavior should be well studied before deciding on the method of soil improvement. (12).

1.1 Gum Arabic

Gum Arabic is a Biopolymer obtained from leguminous tree species that is well adapted to Sudan and sahellian agro-ecology of Africa, and it produces a natural gum made of hardened sap(17). Generally, there are two main types of gum Arabic used as hydrocolloids: Acacia Senegal and Acacia Seyal. The gum Arabic consists of a mixture of polysaccharides and glycoproteins which gives it the properties of glue binding that is edible by humans. The gums are sought after by the intentional buyers as Grade 1 (Acacia Senegal), Grade 2 (Acacia seyal), Grade 3 (Acacia Combretum) and Special Grade (Acacia Polycantha). (17).

Nigeria currently produces 20,000 metric tons of gum Arabic annually that made it the second leading producer of gum Arabic in the world with Sudan as the leading producer, and Chad being next to Nigeria as the third largest producer of the product whose world production has been estimated at 70,000 metric tons annually. From available data, Africa produces about 98% of the world requirement of gum Arabic. Gum Arabic producing states in Nigeria includes Adamawa, Bauchi, Borno, Yobe, Jigawa, Gombe, Taraba, Plateau, Sokoto, Kebbi, Katsina, Nasarawa, Niger and Zamfara.. This research utilizes gum Arabic waste obtained from Gombe state gum Arabic depot.

1.2 Eggshell

The eggshell (ES) is a waste material from domestic birds such as poultries, hatcheries, homes and fast foods or indomie joints; which could result to enviromental pollution, but if subjected to adequete scrutiny it could be an alternative for soil stablization(11). Egg-shell powder contains 99.8% of CaO and remaining consists of AI_2O_3, SiO_2, CI, Cr_2O_3, MnO, and CuO (10) . In 2013, Nigeria has the highest record of Egg consumption of 650,000MT in which the Shell is 11%, Egg white 58%, and Yolk 31% (18). That means

Eggshell waste = 650,000MT/yr * 0.11 gives 71,500MT Trailer load= 71500/30 which is approx. 2,383/Annum by 2013.

2. INDEX PROPERTIES

The results of the preliminary test classified the soil as A-7-5 According to the American Association of States Highway and transportation Officials (1) and CH in accordance with the Unified Soil Classification System (2). The liquid limit, plastic limit and plasticity index of the natural soil were observed to be 66.80%, 35.20% and 31.60% respectively, which confirmed that the soil is highly plastic and not suitable for any engineering works.

Table -1: Index Properties of Black Cotton Soil

Property	Value
Natural moisture content (%)	25.32
Liquid limit (%)	66.80
Plastic limit (%)	35.20
Plasticity index (%)	31.60
Linear shrinkage (%)	18.90
Free swell (%)	73.00
Specific gravity	2.54
Percentage passing BS No. 200 sieve	99.00
Percentage sand fraction	65.00
Percentage silt fraction	23.00
Percentage clay fraction	10.00
Activity	3.16
AASHTO classification	A-7-5 (13)
USCS classification	CH
Group Index	13

3. COMPACTION CHARACTERISTICS

3.1 Maximum Dry Density

The variation of maximum dry density (MDD) with eggshell – gum Arabic content are shown in figs. 1, 2 and 3 for BSL, WAS and BSH compaction energies. The MDD increases with an increase in eggshell-gum Arabic content for the BSL compaction energy. The peak value of 1.94Mg/m^3 was observed at 10%GA15%ESP, which corresponds to an increase of 21.05% when compared with the untreated soil. However, the increase in eggshell – gum Arabic content decreases the MDD of the treated soil for both WAS and BSH compaction energies. This is in agreement with findings reported by (9) and (8)

In general, the higher the MDD, the better the soil for construction works, but for expansive soil, a higher MDD is an indication of high swelling potential. (8). Therefore 25%ESP/10%GA gives better result with WAS and BSH compaction energies.

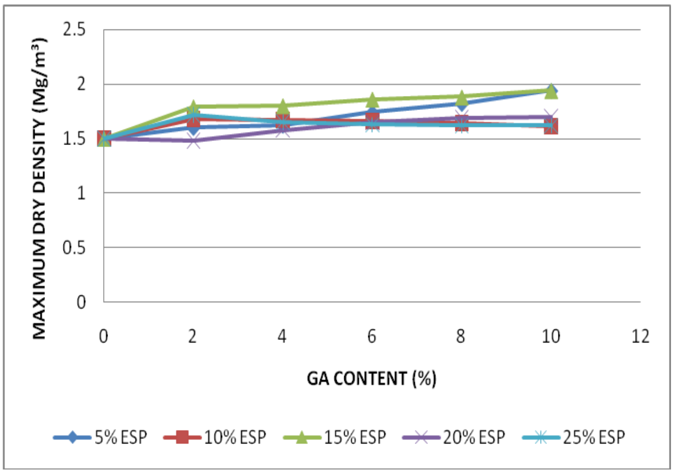

Fig -1: Variation of MDD with ESP-GA treated soil using BSL compactive effort

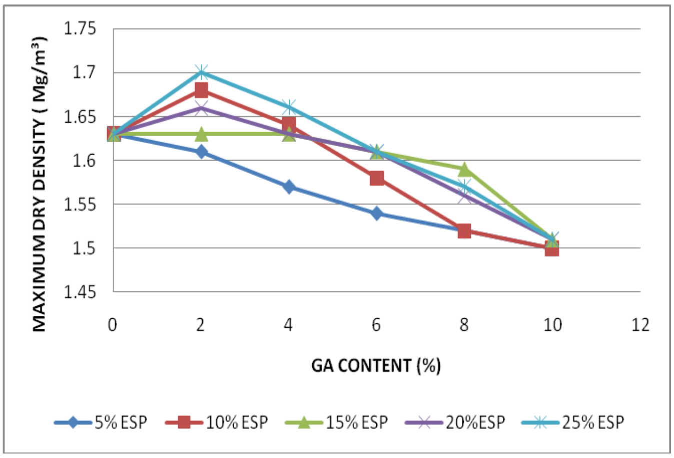

Fig -2: : Variation of MDD with ESP-GA treated soil using WAS compactive effort

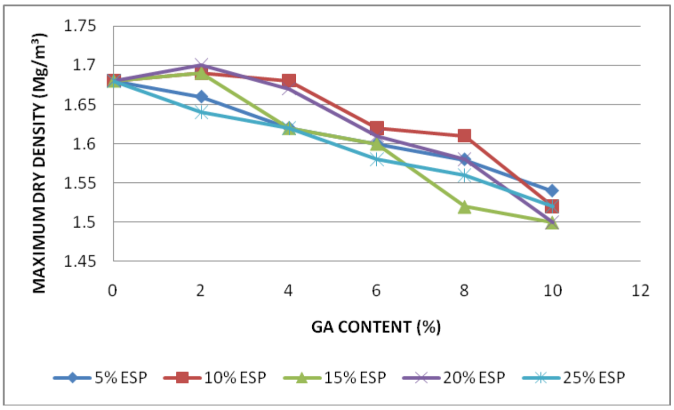

Fig -3: : Variation of MDD with ESP-GA treated soil using BSH compactive effort

3.2 Optimum Moisture Content

The variation of optimum moisture content (OMC) with eggshell – gum Arabic content for BSL, WAS and BSH are shown in figs. 4, 5 and 6 respectively. The OMC increases with the increase in the eggshell – gum Arabic content. This increase was as a result of the pozzolanic of action eggshell powder and soil, which require more water (10).

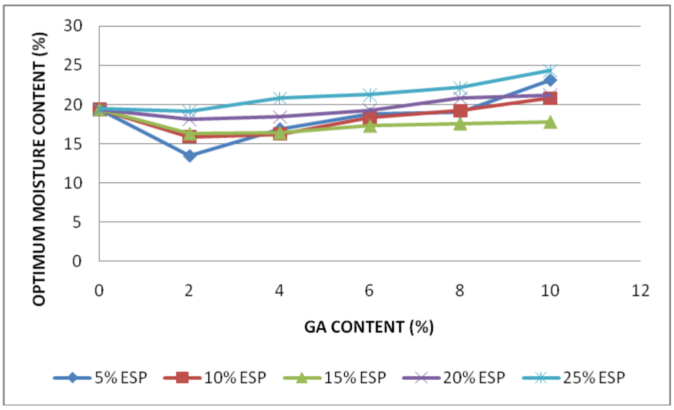

Fig -4: : Variation of OMC with ESP-GA treated soil using BSL compactive effort

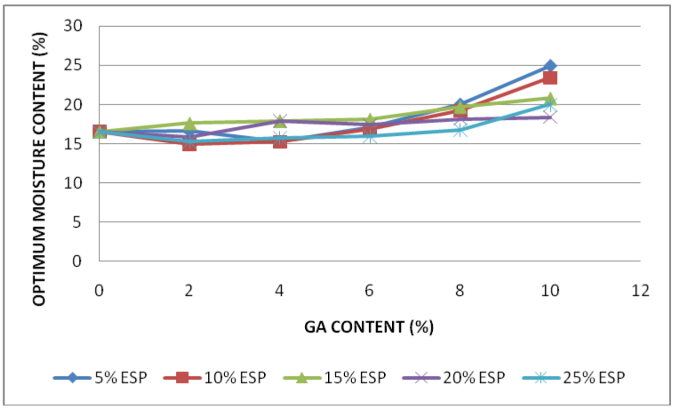

Fig -5: : Variation of OMC with ESP-GA treated soil using WAS compactive effort

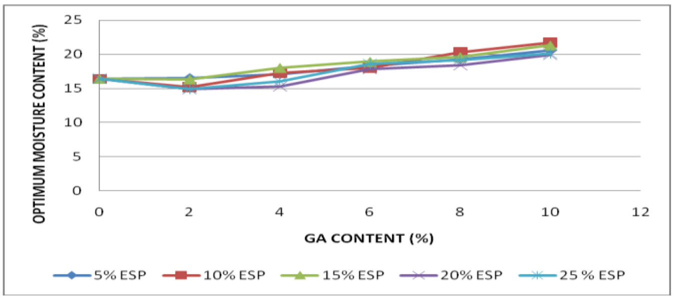

Fig -6: : Variation of OMC with ESP-GA treated soil using BSH compactive effort

4. STRENGTH CHARACTERISTICS

4.1The unconfined compressive strength

The unconfined compressive strength (UCS) test has been recommended for determining the require amount of additive to be use for stablization of soil (13).The 7day UCS test results show peak values of 694.02, 475.76 and 400.20kN/m^2, for BSL, WAS and BSH compactive effort at 2%GA5%ESP, 2%GA/15%ESP and 2%GA/5%ESP treatment respectively as presented in Figs.7-9. The optimal blend of eggshell and gum Arabic treated black cotton soil was attained at 2%GA/5%ESP using BSL compaction energy with a peak 7day UCS value of 694.02kN/m^2. The 694.02kN/m^2 meets the requirement of 687-1373kN/m^2 for sub- base as specified by (15), as against these below 1710kN/m^2 value specified for base stablization with OPC (14)

The variation of 14 and 28days curing period UCS for BSL,WAS and BSH compaction energies for different percentages of eggshell and gum Arabic contents are shown in Figs. 10-16. The peak 14 day UCS values for BSL, WAS and BSH compaction energies are 1336.63, 559.72 and 961.12kN/m^2 all at 2%GA/5%ESP content treatment respectively. The peak 28 day UCS values for BSL, WAS and BSH compaction energies are 1809.31, 1387.62 and 1507.97kN/m^2 at 2%GA/5%ESP, 2%GA/25ESP and 2%GA/5%ESP contents treatments, respectively. This showed that at best blend could be 2%GA/5%ESP using the BSL compaction energy.

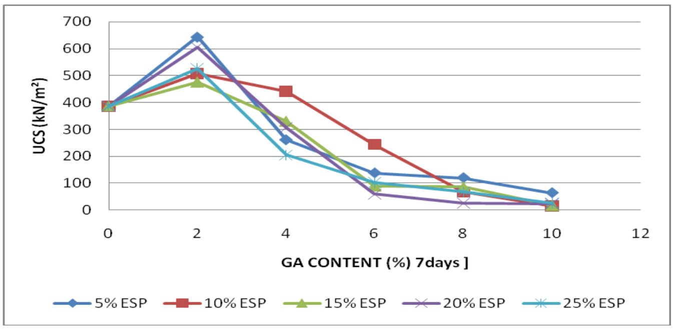

Fig. 7 Variation of UCS for 7days curing with ESP-GA mixtures using BSL compactive effort

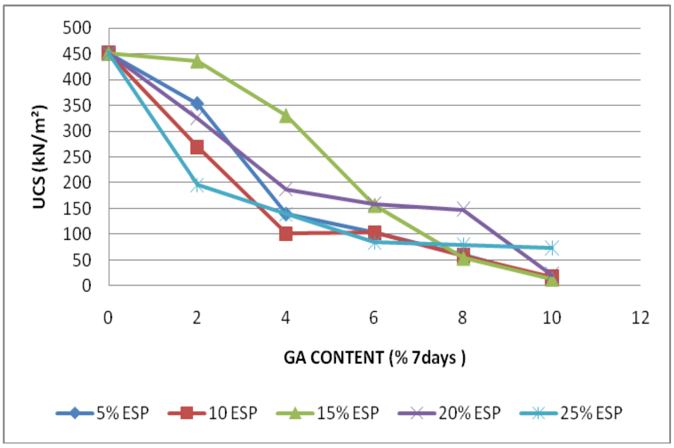

Fig. 8 Variation of UCS for 7days curing with ESP-GA mixtures using WAS compactive effort

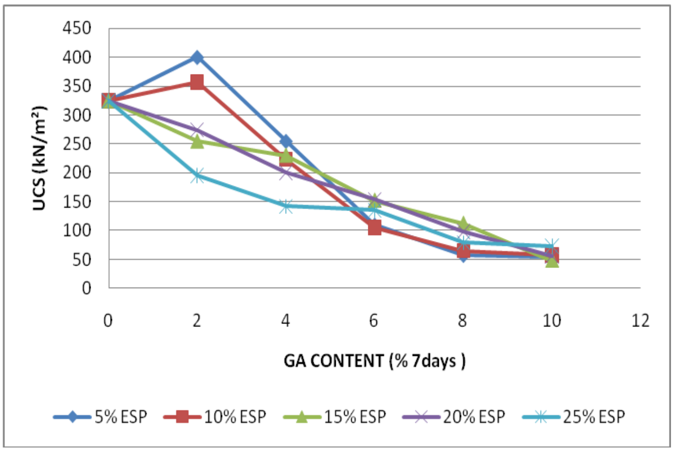

Fig. 9 Variation of UCS for 7days curing with ESP-GA mixtures using BSH compactive effort

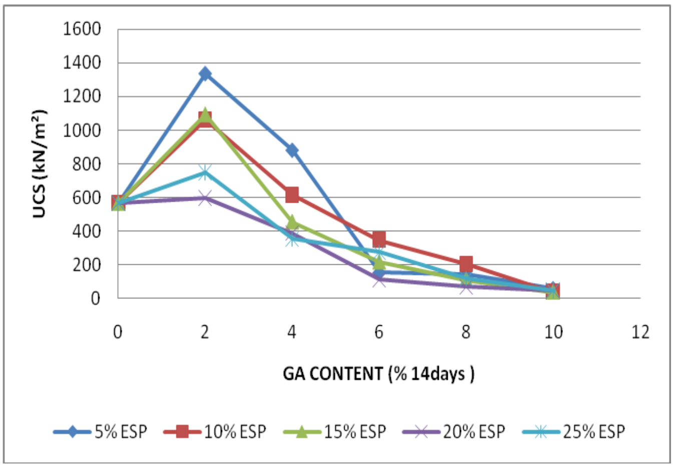

Fig. 10 Variation of UCS for 14days curing with ESP-GA mixtures using BSL compactive effort

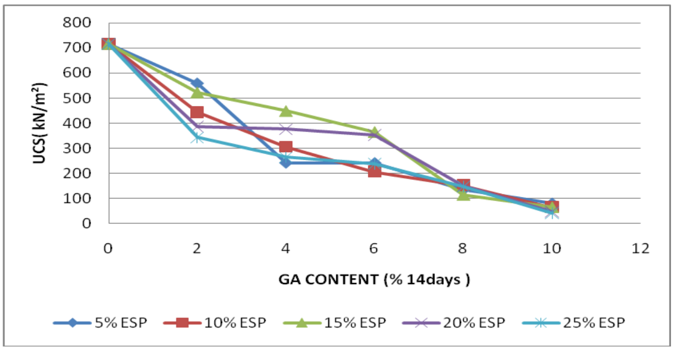

Fig.11 Variation of UCS for 14days curing with ESP-GA mixtures using WAS compactive effort

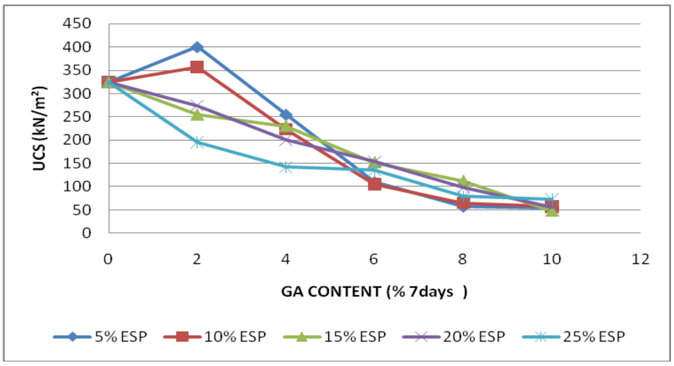

Fig.12 Variation of UCS for 14days curing with ESP-GA mixtures using BSH compactive effort

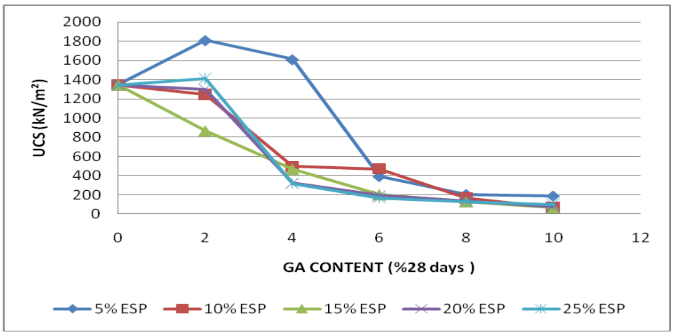

Fig.13 Variation of UCS for 28days curing with ESP-GA mixtures using BSL compactive effort

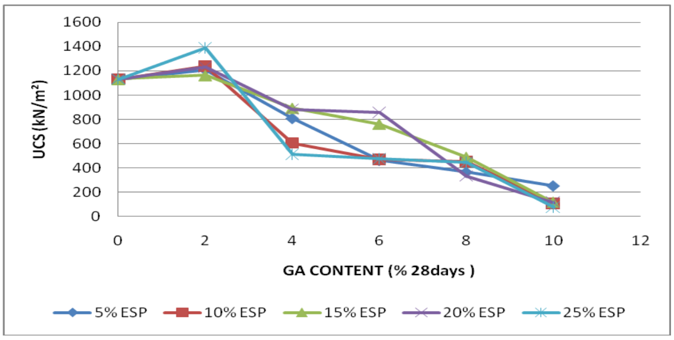

Fig.14 Variation of UCS for 28days curing with ESP-GA mixtures using WAS compactive effort

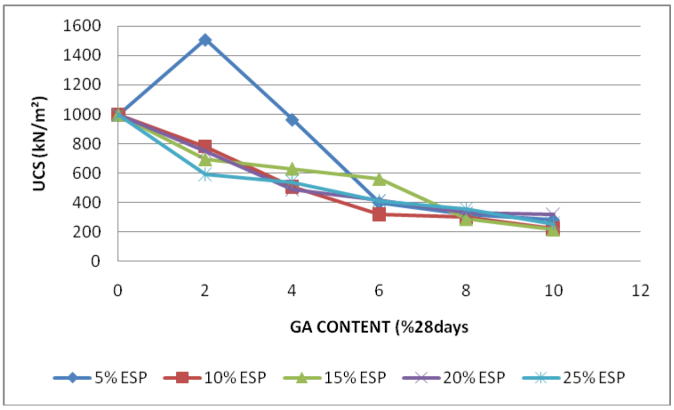

Fig.15 Variation of UCS for 28days curing with ESP-GA mixtures using BSH compactive effort

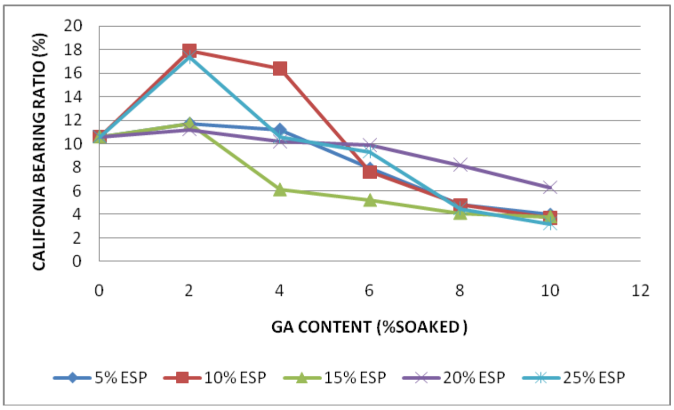

Fig.16 Variation of soaked CBR with ESP-GA mixtures for WAS compactive effort

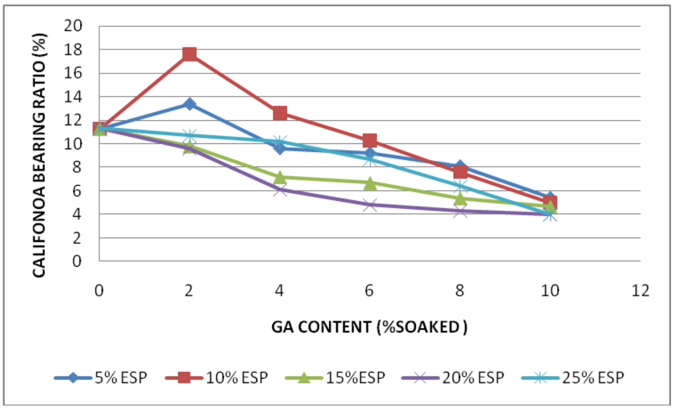

Fig.17 Variation of soaked CBR with ESP-GA mixtures for BSH compactive effort

4.2 California bearing ratio

The California bearing ratio (CBR) value of the stabilized soils is an important parameter in assessing suitability for use as a construction material it gives an indication of the strength and bearing ability of the soil; which will assist the designer in recommending or rejecting the soil as suitable for sub-grade, sub-base and base for a flexible road pavement. (5)

The peak CBR values of 10.1, 17.9 and 17.6% at treatment level of 2%GA/25%ESP, 2%GA/10%ESP and 2%GA/10%ESP for BSL, WAS and BSH compaction energies respectively could be observed in Figs.16-19. All the specimens were short of 80% and 30% requirement for base course and sub-base but meets the 10% requirement for subgrade material (3)

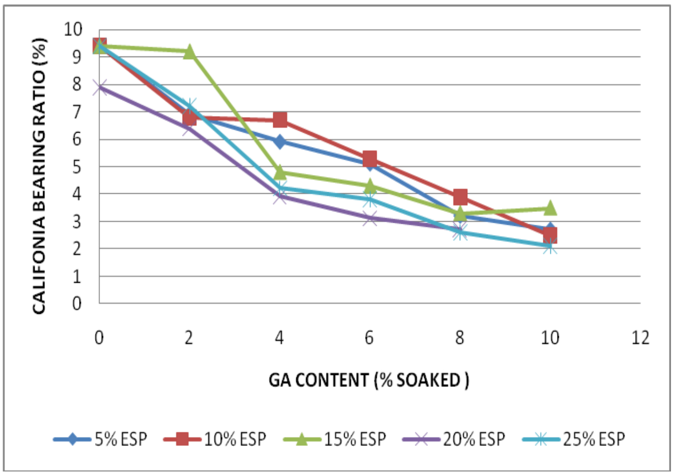

Fig.15 Variation of soaked CBR with ESP-GA mixtures for BSL compactive effort

5. DURABILITY ASSESSMENT OF SPECIMENS

In order to simulate some of the worst conditions that could be attained in the field for any soil to be used for any engineering purposes, immersion of the cured specimen in water before testing its compressive strength is necessary to ensure that the stabilized material does not fail under adverse field conditions. The UCS values obtained under these conditions are analyzed in conjunction with the UCS values for 14days curing period. The specimens are normally soaked for 7 days prior testing to obtain the percentage resistance to loss in strength of the stabilized material as recommended for tropical countries by [16].

The peak resistance to loss in strength values for BSL, WAS and BSH compactive effort are 57.0, 28.5 and 16.0% at 10%GA/10%ESP, 10%GA/20%ESP and 10%GA/10%ESP respectively as showed in Figs. 18-20. It could be observed that tested specimens fell short of the acceptable conventional 80% required minimum resistance to the loss in strength [16]. However, 57.0% resistance to loss in strength for BSL compactive effort at10%GA/10ESP content seems almost acceptable since limiting value of loss in strength was obtained based on 4day soaking period and not the 7 days soaking period that the specimens were subjected to in this work.

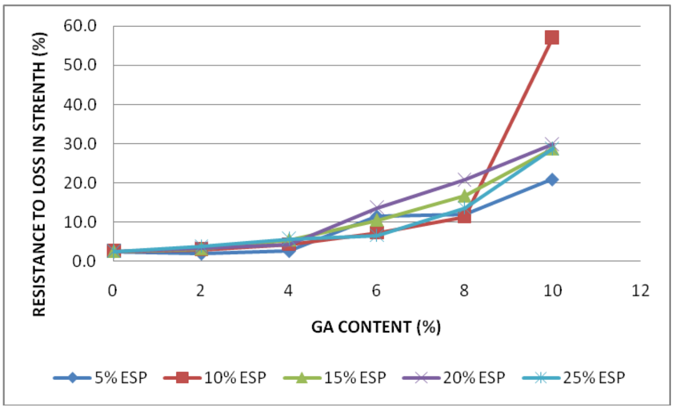

Fig.18 Variation to resistance to loss in strength with ESP-GA mixtures for BSL compactive effort

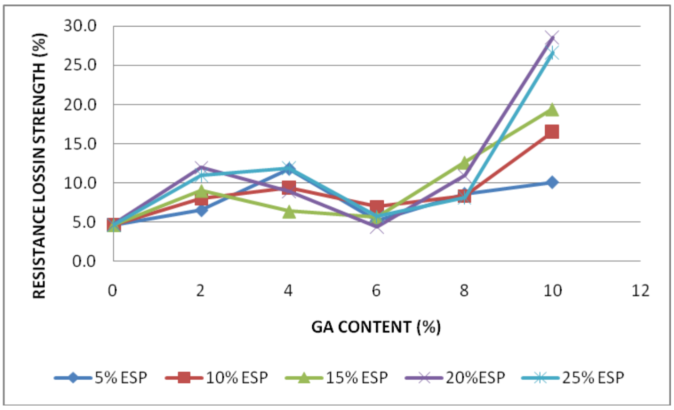

Fig.19 Variation to resistance to loss in strength with ESP-GA mixtures for WAS compactive effort

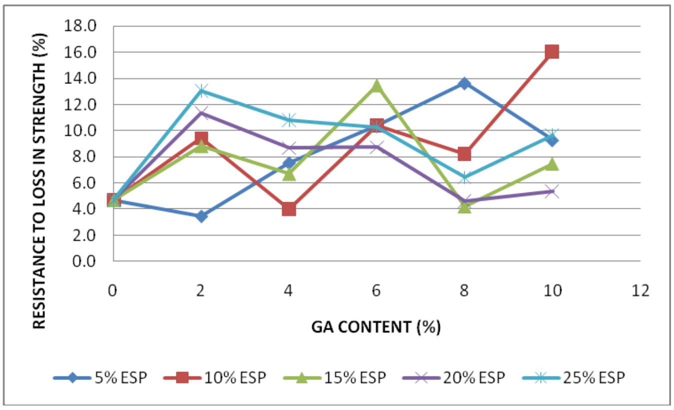

Fig.20 Variation to resistance to loss in strength with ESP-GA mixtures for BSH compactive effort

6. CONCLUSIONS

The natural black cotton soil was classified as A-7-5(13) using the AASHTO and CH using the Unified Soil Classification System (USCS), respectively. The soils under these groups are called problematic soil due to shrink and swell properties which makes it unsuitable for any engineering construction. The soaked CBR values showed increase in strength of 6.9%, 41.0% and 36% at 2%GA/25%ESP, 2%GA/10%ESP and 2%GA/10ESP for BSL, WAS and BSH compaction energies respectively. The OMC also showed increase with increase ESP-GA contents for all compactive efforts with the lowest values of 13.5, 15.2 and 15.5% at 2%GA/5%ESP,4%GA/10ESPand2%GA/5%ESP respectively. The peak 7 days UCS values of 694.02, 475.76 and 400.20kN/m^2 where attained at 2%GA/5%ESP, 2%GA/15%ESP and 2%GA/5%ESP for BSL, WAS and BSH compaction energies respectively. This falls below the specified value of 1710kN/m^2 stipulated by (14) for base material stablization. However, this value conformed to the UCS values of between 687-1373kN/m^2 requirements for the sub-base at 2%GA/5%ESP using the BSL compaction energy. The soaked CBR values of 10.1 17.9 and 17.6% met the specification for sub-grade materials as recommended by (3).The durability of the specimen at 10%GA/10ESP, 10%GA/20%ESP and 10%GA/10%ESP content is acceptable on the bases of the result of 7 days soaking period obtained from the resistance to loss in strength test. Thus, higher compactive effort does not impact positively on the strength and durability assessment of the black cotton soil (16). Even though, high strength is expected when soils are compacted at higher compactive effort [20, 21]. Thus, an optimal blend of 2%GA/5%ESP using BSL compaction energy is recommended for use as sub-grade material.

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