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## PERFORMANCE OF BLACK COTTON SOIL TREATED WITH BITUMINOUS EMULSION

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### ARTICLE INFO

### ABSTRACT

#### Keywords:

*Spatial Variation, Black Cotton Soils, Bituminous Emulsion, Compaction And Unconfined Compressive Strength*

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*An experimental study was conducted to determine the performance of black cotton soil while treated with bituminous emulsion. Experiments were carried out with two natural soil samples in which 0% to 10% of the bituminous emulsion by weight of the soil was added at an interval of 2%. The tests carried out include the followings; determination of natural moisture content ( $W_p$ ), particle size distribution (PSD) and Atterberg limits (liquid limit ( $W_L$ ), plastic limit ( $W_p$ ) plasticity index (PI) and linear shrinkage (LS), compaction and unconfined compressive strength (UCS). It was found out that the application of the bituminous emulsion made the soil more firm by achieving maximum dry density at lower optimum moisture content. The emulsion was found to have significantly reduced the swelling potential of the soil at the Optimum percentage of 10. The bituminous emulsion was proved to be effective in increasing the unconfined compressive strength of the black cotton soil to the extent that it was suitable for low cost and low load bearing construction works. It is recommended to investigate the effects of bituminous emulsion in excess of 10% on the properties of the material. And also, to study the performance of bituminous emulsion with appropriate addition of additives (such as lime) to improve the quality of the selected soil*

### INTRODUCTION

Black Cotton Soils are expansive soils which swell or shrink excessively due to changes in moisture content. These soils have an appreciable plasticity in the clay fraction. They

are dark gray to black in colour with a high content of clay usually over 50 percent; in which montmorillonite is the principal clay mineral.

The Lake Chad Basin is known to be the only location having extensive lacustrine deposits of black clayey soils in West Africa (Osinubi et al, 2009). Black cotton soils are soft and highly compressible, and have unacceptable consistency indices, low strength, and are highly impermeable. These undesirable properties make them unfit for use in infrastructural development projects; hence they have to be stabilized. However, though clay soil materials have poor engineering properties and are generally not suitable for construction purposes, they are used beneficially as barriers in containment of contaminants as an integral part of environmental protection strategy and as buffer materials for waste disposal. This application of expansive soils is due to the possession of a remarkable swelling due to water intrusion and therefore restriction of the water and contaminant migration through them. Stabilization makes it possible for soils to support themselves and other imposed loads. In the case of black cotton soils, stabilization could be achieved by means of chemical additives. This is because pulverization is difficult to achieve with black cotton soils but chemical additives facilitate flocculation making densification possible which is one of the essence of stabilization. Stabilization of clay (black cotton) soils must improve the swelling potential for strength gain to be attained. Most studies on montmorillonite clays focused on the index, physical and chemical properties while strength properties are often ignored due to the low strength of clay soils when in contact with water. The Nigerian expansive soils are formed from basic igneous rock parent material. The name black cotton soil is derived from the fact that cotton plants thrive well on it. The black cotton soils from north eastern Nigeria derived their origin from basalts of the upper Benue which covers a wide area

extending to the north and eastern parts of the Jos plateau and also from quaternary sediments (Osinubi et al, 2009). Montmorillonite and Kaolinite are the two predominant clay minerals found in black cotton soils. Black cotton clays and most expansive soils contain more of the montmorillonite than Kaolinite (Morin, 1971; Osinubi & Medubi, 1997)a. The predominance of montmorillonite is due to the weathering of the basic constituents (Ola, 1983). Chen (1988) observes that clay mineral containing montmorillonite (a smectite) generally exhibits a swelling tendency in the presence of water. On the other hand, Kaolinite is relatively inactive clay mineral. Its structure is made of repeating layers of elemental silica-gibbsite sheets in a 1:1 lattice (Braja, 1998). Its inactivity is attributed to the presence of hydrogen and Van der Waal's forces that give an overall unit of enhanced strength. Ola (1983) and NBRRI (1983) reported that the black cotton soils of Nigeria have been laid during the late tertiary and quaternary periods as the Chad formations and are composed of sequence of lacustrine and fluvial clays and sands of Pleistocene age. According to Ola (1983), black cotton soils with montmorillonite as the predominant clay mineral are the most troublesome soils in Africa. In Nigeria they occupy an estimated area of 104,000km<sup>2</sup>. Usually there is less or no presence of organic material in the soil, but the occurrence of black colour is probably due to presence of iron or titanium (Jha and Sinha, 1993). It has been recognized in geotechnical engineering field that the swelling of black cotton soils caused by moisture changes may result in excessive heave resulting to severe damage to overlaying structures or pavements. The damage caused by these soils is enormous and manifests in the cracking masonry fences, reinforced concrete gates and road pavements (Sahel, 1993).

Gromko (1974) described the heaving of an expansive foundation soils to be in the following ways; (1) a general upward movement shortly after the start of construction and finishes some years after the completion of the structure, (2) a seasonal cyclic expansion-contraction which occurs

around the structure and primarily related to the amount and frequency of rainfall and the rate of evaporation, and (3) local heaving, which may result from the breakages of water line or poor site drainage.

The main factors involved in the heaving phenomenon are as follows:

- soil type (including the proportion of clays and mineralogy)
- dry density and soil structure
- moisture content which is related to suction for a given soil
- time to heave is a function of permeability
- thickness and depth of the expansive soil stratum
- in-situ stress conditions both vertical and horizontal
- externally applied loads and appropriate stress path
- Source of moisture variation, climate position and variation of the water table, drainage leakage and vegetation

The research is aimed at improving the engineering properties of Black Cotton Soil using Bituminous Emulsion.

## 2. MATERIALS AND METHODS

### 2.1 Location

The soil samples used for this study were collected from Gari area, 9km from Dumbulwa-Galda province in Fika Local Government Area of Yobe State, North-Eastern Nigeria. The area lies between longitude  $11^{\circ} 7' 00''$ N and latitude  $11^{\circ} 28' 0''$ E.

### 2.2 Geology of the Study Area

The area is underlying a soil which is typical dark grey in colour and very difficult to handle as visitation was made during the dry season. The area is extensively covered by black cotton soil formed from the weathering of shale and clay sediments and basaltic rocks. The soil contains montmorillonite as the predominant material. The region is a tropical region with seasonal rainfall and less percolation due to the nature of the ground soil, not all crops grow on that soil. The locals living in this area face difficulties in building their houses and also in accessing the

neighbouring villages in rainy seasons using their only earthed road.

### 2.3 Bituminous Emulsion

This is liquid asphalt cement emulsified in water. It is composed of water and an emulsifying agent, which is composed of large molecules. Emulsifiers are often supplied in a water-insoluble form to the emulsion producer and need to be neutralized with acid or alkali by the emulsion manufacturer to generate the anionic or cationic water-soluble form used to prepare the soap solution. The choice of the acid or alkali and the final pH of the emulsion influence the emulsion properties. Hydrochloric acid and occasionally phosphoric acid are the acids used, and sodium and potassium hydroxide are the most common alkalis. Cationic emulsions are usually acid, and anionic emulsions are typically alkaline. Hydrochloric acid was used in this research.

**2.4 Sample Collection**

Two disturbed samples (sample 1 and sample 2) were collected from two different pits at a depth of 1.0m below the ground surface.

**2.5 Sample Preparation**

Samples were prepared by adding bituminous emulsion at varying percentages. The percentages adopted were 0%, 2%, 4%, 6%, 8%, and 10%. The quantity of the soil was kept constant while the percentage by weight of the bituminous emulsion was added to the soil. Experiments were conducted on varying sets of mixtures.

**2.6 Curing Condition**

Curing was carried out on the un-soaked samples and the curing periods were 7, 14 and 28 days. However, the soaked samples were only cured for 7 days.

**2.7 Laboratory Tests Conducted**

The laboratory experiments conducted in this research work were done in accordance with the British standards BS 1377 (1990). The following experiments were conducted: (1) determination of the physical/index properties

of the natural and modified black cotton soil for the purpose of identification and classification of the soil through particle size distribution (PSD) and Atterberg limits, (2) determination of moisture-density relationship for the natural soil sample, and (3) surcharge pressure under which swelling is measured for the natural and modified soil samples. The detailed tests include the determination of natural moisture content ( $W_n$ ), particle size distribution (PSD) and Atterberg limits (liquid limit ( $W_L$ ), plastic limit ( $W_P$ ) plasticity index (PI) and linear shrinkage (LS). The engineering property tests conducted were; compaction and unconfined compressive strength (UCS).

**3.0 RESULTS AND DISCUSSION**

The index and engineering properties determined in the laboratory are presented in tables 1 and 2 below. The percentage passing number 200 sieve was 95.14% for sample 1 and 94.85% for sample 2, while the natural moisture content values ( $W_n$ ) are 9.72% and 13.20% for samples 1 and 2 respectively

**Table 1: Soil Properties at Location 1**

Bituminous Emulsion Content (%)	Atterberg limits (%)				Compaction Parameters		Swelling Pressure (N/mm <sup>2</sup> )	Unconfined Compressive Strength (7 days) (kN/m <sup>2</sup> )	
	W <sub>L</sub>	W <sub>P</sub>	PI	LS	MDD (Mg/m <sup>3</sup> )	OMC (%)		Unsoaked	Soaked
BEC							SP		
0	84.9	35.9	49.0	23.6	1.86	8.97	54.3	420.65	20.00
2	68.4	40.4	28.0	21.7	1.67	9.00	51.6	543.40	21.33
4	63.8	38.9	24.9	18.5	1.76	9.00	50.9	657.34	24.64
6	61.2	33.3	27.9	16.4	1.77	8.25	48.8	656.78	20.33
8	54.5	26.8	27.0	12.8	1.78	6.80	42.6	658.72	29.65
10	48.1	21.2	26.9	9.67	1.82	6.66	33.5	745.23	33.44

**Table 2: Soil Properties at Location 2**

Bituminous Emulsion Content (%)	Atterberg limits (%)				Compaction Parameters		Swelling Pressure (N/mm <sup>2</sup> )	Unconfined Compressive Strength (7 days) (kN/m <sup>2</sup> )	
	W <sub>L</sub>	W <sub>P</sub>	PI	LS	MDD (Mg/m <sup>3</sup> )	OMC (%)		SP	Unsoaked
0	66.9	37.2	29.7	26.1	1.54	9.34	55.6	533.32	22.0
2	61.8	44.8	17.0	22.3	1.68	9.17	53.2	590.42	24.45
4	57.7	36.7	21.0	18.2	1.72	9.23	44.9	621.54	28.47
6	54.9	28.7	26.2	15.2	1.68	8.97	38.3	626.74	34.26
8	49.2	26.8	22.4	10.5	1.82	7.24	32.1	719.34	28.34
10	42.1	22.5	19.6	8.17	1.84	6.99	27.5	645.12	39.67

**3.1 Atterberg Limits**

Figures 1 to 4 show Atterberg limits in the two samples. In each figure, two curves are shown; one representing sample 1 and the other sample 2. The effect of bituminous emulsion content (BEC) on liquid limit of the two soil samples was studied and the results are presented in tables 1 and 2, and figure 1. It can be observed that as the emulsion content is increased, the value of the liquid limit decreased. At 0% emulsion, the W<sub>L</sub> value is 84.9% in sample 1 and it decreased to 68.4% with 2% addition of the emulsion. This decrease continued up to a value of 48.1% when 10% of the emulsion was added. Similar pattern was observed in sample 2 though with lower values. It can be observed that the liquid limit is 66.9% with 0% emulsion. This value decreased to 61.8% when 2% emulsion was added and the decrease continued up to 42.1% with 10% emulsion. The variations in plastic limit with added bituminous emulsion can be observed in figure 2. The values for the control soil samples are 35.9% for sample 1 and 37.2% for sample 2 respectively. Figure 3 shows the variations in plasticity index with addition of bituminous

emulsion. For sample 1, it can be observed that PI value decreased from 49.0% in the control sample to 28.0% with an addition of 2% emulsion. It then continued to decrease up to a value of 26.9% with 10% addition of the emulsion. The pattern of decrease in PI was the same in sample 2. The control sample has a value of 29.7% and it decreased to 19.6% with 10% addition of the emulsion. The linear shrinkage is not an exception; it also decreased from its control value of 23.6% to 9.67% with 10% addition of the emulsion in sample 1 and from 26.1% to 8.17 in sample 2. This can be observed in figure 4. In general, the Atterberg limits decreased with an addition of the bituminous emulsion. This phenomenon could be explained as an improvement in the soils' index properties. The changes that resulted in the expansive soils could apparently be linked to the increase in clay sized fractions from coagulation caused by the bituminous emulsion. The increased clay-size could suggest a partial breakdown of the cemented soil aggregates of the stabilized black cotton soil samples.

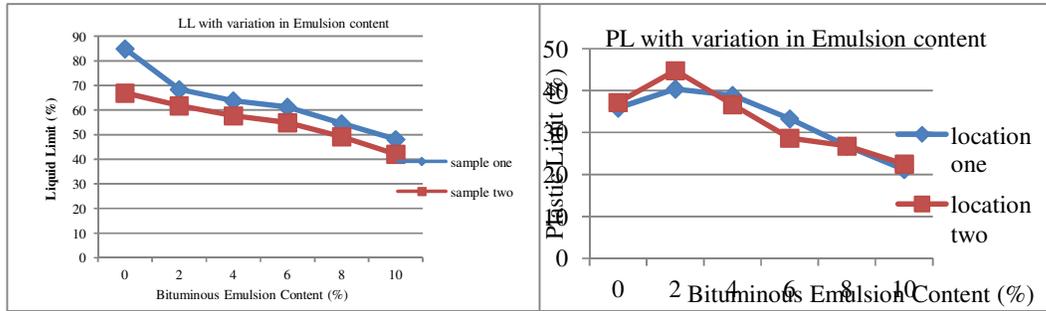


Fig.1: Variation of  $W_L$  with BEC

Fig. 2: Variation of  $W_P$  with BEC

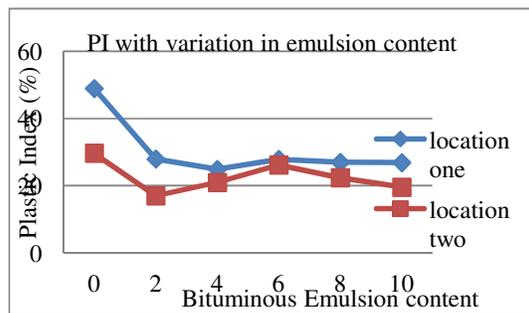


Fig. 3: Variation of PI with BEC

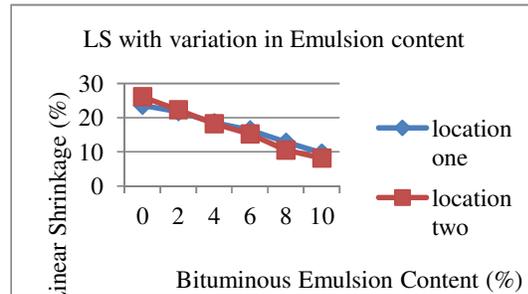


Fig. 4: Variation of Linear shrinkage with BEC

**3.2 Compaction Characteristics**

Figure 5 shows the variation of MDD with percentage of Bituminous emulsion. For the first sample the MDD of the untreated soil was found to be 1.86Mg/m<sup>3</sup>, the value decreased to 1.76Mg/m<sup>3</sup> upon addition of 2% bituminous emulsion. When the amount of bituminous emulsion was increased to 4%, the MDD slightly increased, it continued in such a manner up to 10% of the stabilizer where it reached 1.82Mg/m<sup>3</sup>. As for the second sample the MDD of the untreated soil was 1.54Mg/m<sup>3</sup>, it continued to

increase for the increase in the emulsion up to 4% where it reached 1.72Mg/m<sup>3</sup>, it then slightly dropped to 1.68 Mg/m<sup>3</sup> at 6%. It then raised with increase in the stabilizer until it attained MDD of 1.84 Mg/m<sup>3</sup> at 10%. The initial decrease and increase in MDD for the compactive effort recorded can be attributed to the flocculation and agglomeration of the clay particles due to the ion exchange or due to the flocculation and agglomeration of the clay particles occupying larger spaces leading to corresponding increase in the MDD (O’Flaherty, 1988).

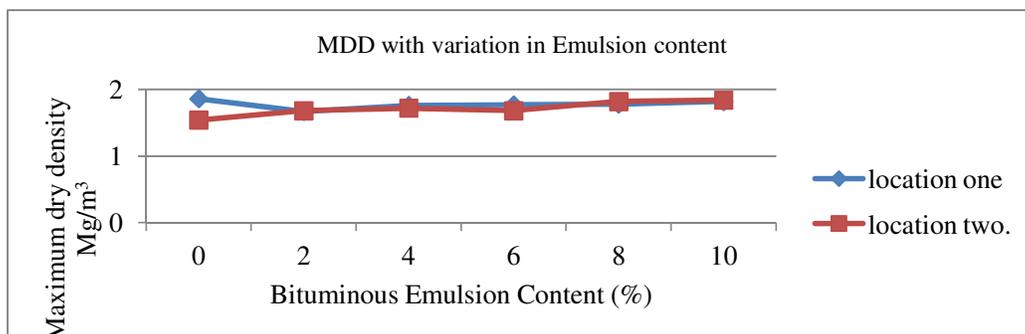


Fig. 5: Variation of MDD with BEC

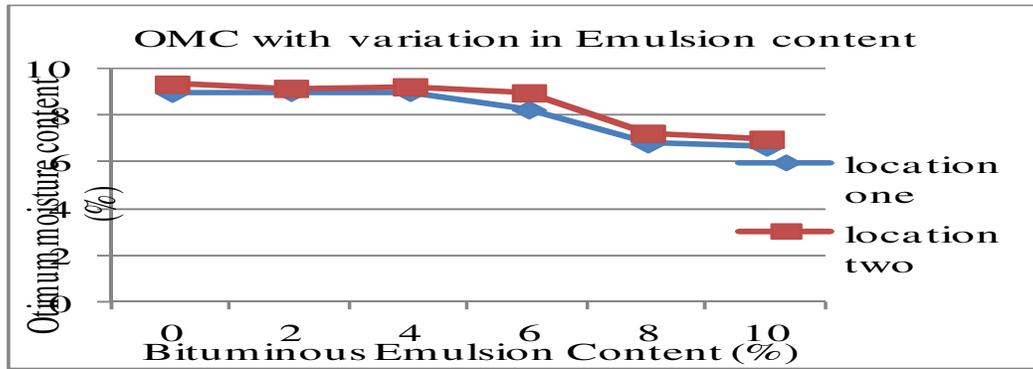


Fig. 6: Variation of OMC with BEC

From Figure 6 above, there was no appreciable difference in OMC between untreated and 2 to 4% bituminous emulsion treated soil. The OMC for the untreated soil was 9% and that of 2 and 4% bituminous emulsion modified was 8.7%. When the emulsion was increased to 6%, 8% and 10% the

respective OMC dropped to 8.25%, 6.8% and 6.66%. Similar trend was observed with the second sample.

A reduction in the value of the OMC makes the soil more rigid which is an indication of improvement in the material engineering behaviour

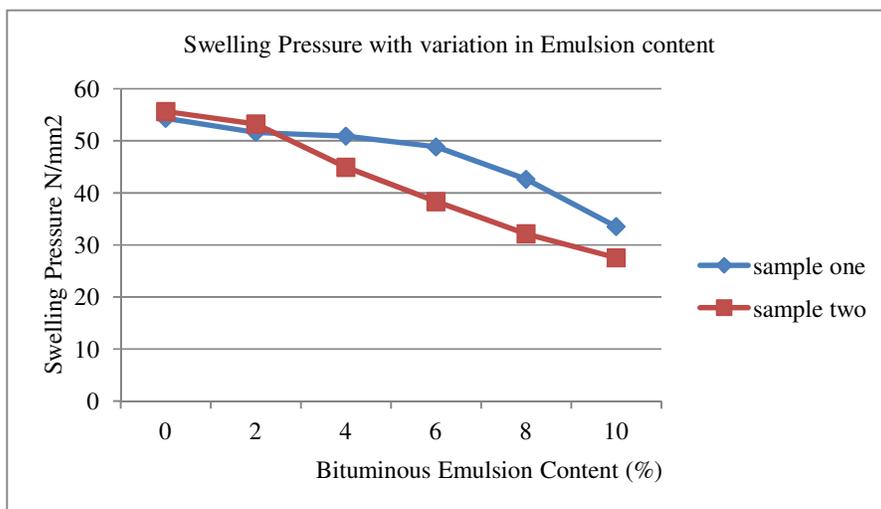


Fig. 7: Variation of swelling pressure with BEC

### 3.3 Swelling Pressure

It was observed from figure 7 that the swelling pressure would decrease with increase in the emulsion for both samples. The pressure reduction can be attributed to the presence of Si and Al ions in the emulsion. According to Anand et al, 2005, the silicates and aluminates compounds dissolved in an environment to a

pH of above 10 and react with Ca<sup>2+</sup> to produce the cementitious compounds which causes a decrease in the negative charges or the lowering of the zeta potential and this led to flocculation and consequently decrease in the pressures (O’Flaherty, 1988).

### 3.4 Unconfined Compressive Strength

The variation of the UCS with the percentage of bituminous emulsion for soaked condition was shown in Figure 8. The value of UCS for the soaked sample was too low but it was increasing with increase in the percentage of the emulsion. It was found to be 20KN/m<sup>2</sup> for the untreated sample and it reached the maximum of 33.4 KN/m<sup>2</sup> at 10% of the

emulsion. The same pattern was observed with sample two, where at 0% of the stabilizer, the UCS value was observed to be 22 kN/m<sup>2</sup>, and at 2% of the emulsion the value was observed to have increased to 24.45 kN/m<sup>2</sup>, it reached a maximum value of 39.67 kN/m<sup>2</sup> at 10%.

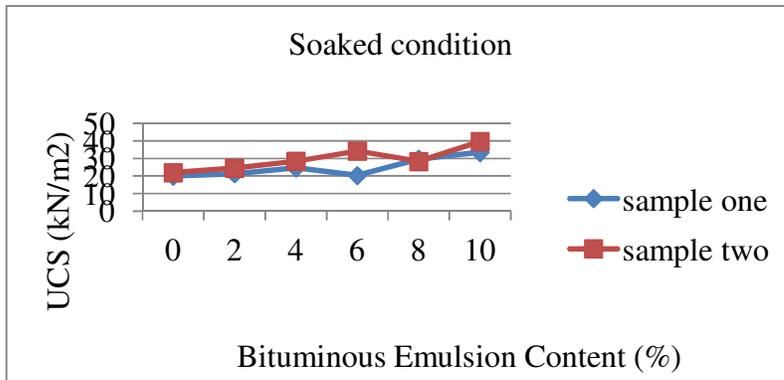


Fig. 8: Variation of UCS with BEC (Soaked Sample)

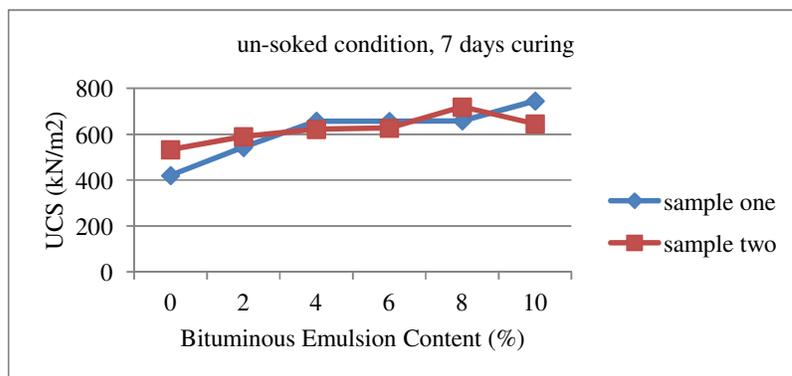
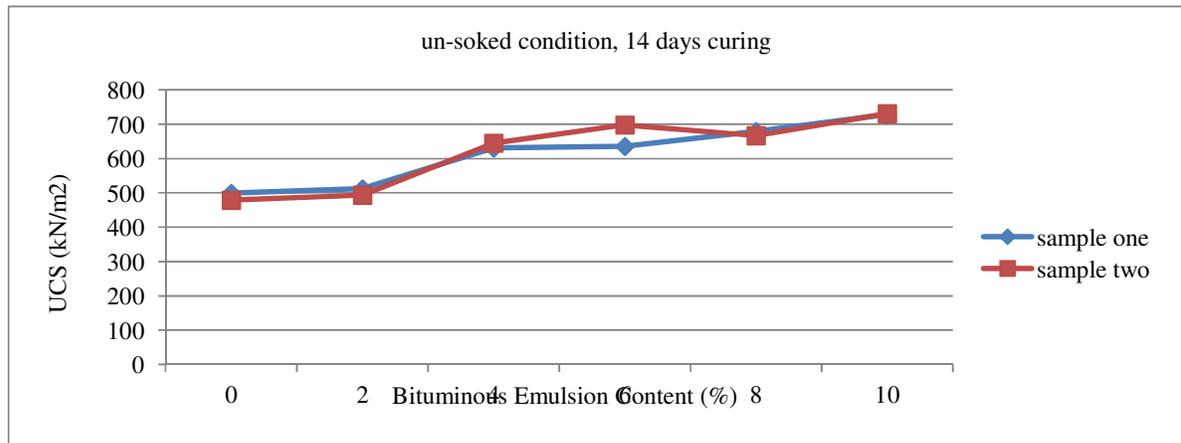


Fig. 9: Variation of UCS with BEC (Un-Soaked Sample)

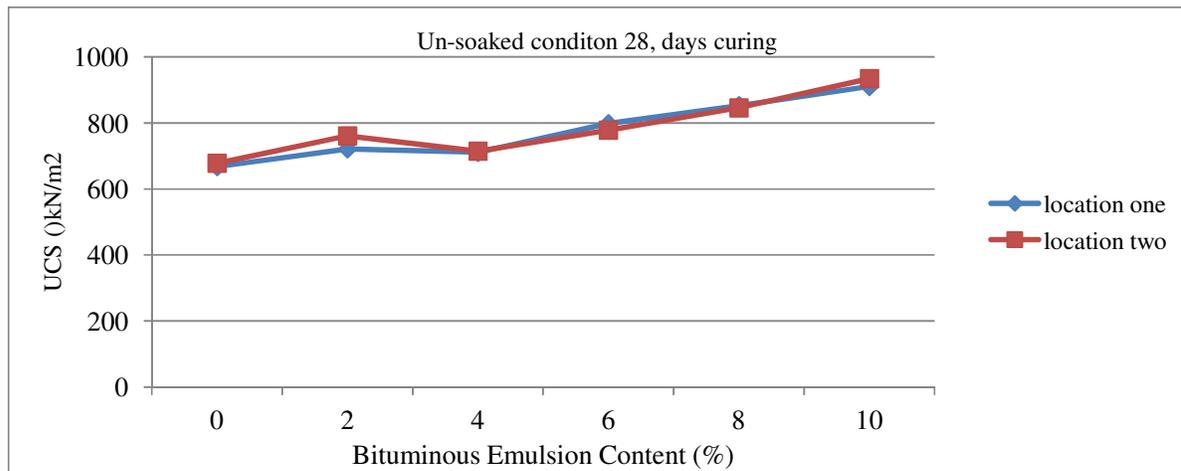
Figure 9 shows the variation of the UCS with amount of bituminous emulsion for the two samples in an un-soaked condition but cured in air tight bags for 7days. The values for the UCS at 0% emulsion for the first sample was 420.65 KN/m<sup>2</sup>, it kept increasing with increase in the stabilizer up to the maximum value of 745.23kN/m<sup>2</sup> at 10% of the emulsifier. For the

second sample the value of the UCS at 0% of the emulsifier was 533.32 KN/m<sup>2</sup>, it followed the same trend with the first sample up to 8% of the emulsifier where it reached a maximum value of 719.34 KN/m<sup>2</sup>, upon increasing the amount to 10%, the value dropped to 645.12 KN/m<sup>2</sup>



**Fig. 10: Plots of UCS with variation in bituminous emulsion for the two samples cured in air tight poly-bags for 14 days (un-soaked condition)**

It was also observed in Figure 10, when the untreated sample was kept for 14 days in air tight poly the UCS was observed to be 499.76kN/m<sup>2</sup>. When the sample was stabilized with 2% of the emulsion the UCS raised to 512kN/m<sup>2</sup>. It kept increasing up to a value of 728.46kN/m<sup>2</sup> at 10% emulsion. Similarly, sample two also followed the same trend



**Fig. 11: Plots of UCS with variation in bituminous emulsion for the two locations cured in air tight poly-bags for 28 days (un-soaked conditions)**

Figure 11 above represent plots for UCS of the sample at 28 days curing. It was observed that the UCS value for the untreated sample, was found to be 667.65 KN/m<sup>2</sup> and after addition of 2% emulsion the value rose to 721.23 KN/m<sup>2</sup> and it increased with the increase in the amount of bituminous emulsion up to 10% emulsion where it reached a value of 910 KN/m<sup>2</sup>, similar trend was observed with sample two. The increase in the value of UCS with an increase in bituminous emulsion may be due to increase in strength in the weekly formed bonds between the clay minerals surface and the water molecules. The formation of these bonds resulted in an increase in strength with the passage of time.

However, the increase in strength can also be attributed to the presence of iron oxide (goethite) which dehydrates with time to yield higher strength in agreement with Nixon & Skipp, (1957), Little (1967) and Osunubi (2001).

### CONCLUSIONS

The application of the bituminous emulsion made the second sample more firm by achieving maximum dry density of 1.84 Mg/m<sup>3</sup> and lower moisture content of 6.6 at 10% BEC. The potential of the soil to swelling was found to have reduced significantly after treatment with the bituminous emulsion. This shows that problems caused by the soil (black cotton soil) due to swelling will be minimized when stabilized with 10% (Optimum value) of the admixture.

The bituminous emulsion was found to increase the unconfined compressive strength of the black cotton soil steadily. From the results obtained, increment in the value of the UCS was observed with the increase of

bituminous emulsion. Even though the strength found at the optimum value is lower than the strength of 1720KN/m<sup>2</sup> specified by the Federal Ministry of Works and Housing specifications for roads and bridges (1997). But it was found to be suitable for low cost and low load bearing construction works.

The bituminous emulsion was found to be suitable for improving engineering properties of tropical black cotton soils within the context of low load bearing facilities.

### RECOMMENDATIONS

It is recommended that:

1. More than 10% addition of bituminous emulsion can be investigated to find out whether or not the treated soil will meet the Nigerian Standard for base and sub-base materials.
2. An additional additive (such as lime) can be used with bituminous emulsion for better results.

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