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Improvement Of Geotechnical Properties Of Road Pavement Subgrades Using Coir Fibre

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Abstract: *This paper presents a laboratory study conducted to determine the effect of coir fibre (CF) on stabilization of soil for road pavement subgrade application. Two soil samples were used for the experiments and varied proportions of the coir fibre was added. Series of tests were carried out on the soil samples which includes the particle size distribution analysis, Atterberg limit test, compaction test using British Standard Light (BSL) methodology, and the California Bearing Ratio (CBR) test. Based on the test carried out on the two soil samples, the samples were found to belong to the A-2-6 subgroup of A-2 group of the AASHTO soil classification and the SC (clayey sand) group of the USCS classification system. Based on the compaction test, the Maximum Dry Unit weight (MDUW) of the two soil samples were 18.8 kN/m^3 and 18.3 kN/m^3 , but on addition of coconut coir fibre of 0.5% - 8% by weight of the soil, the MDUW's of the two soil samples increased to 20 kN/m^3 and 22 kN/m^3 respectively. From the California bearing ratio test (48 hours soaked) carried out on the soil samples, the CBR values were found out to be 4% and 15%, respectively, but on addition of coconut coir fibre of 0.5% - 8%, the CBR values were increased to 16% and 22% respectively. This shows a significant impact on the compaction properties and the CBR of the two soil samples with the addition of CF. It was therefore concluded that coir fibre can be used to stabilize weak subgrades at an optimum content of 5% of the weight of the soil.*

Keywords: *California Bearing Ratio, Coir fiber, compaction, subgrade, pavement*

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1. INTRODUCTION

The most suitable approach available to the geotechnical engineer is to improve the existing soil for better use in construction. Reinforcing of soil mass is geared towards reducing the tensile strain which may occur under gravity and surrounding forces. Civil engineering researchers are constantly in the search for alternate materials that are readily available and cost effective for soil improvement Mezie et al., 2023; Ubani et al., 2023). To this effect, variety of materials are being used as reinforcing materials such as metallic elements, geosynthetics and others (Bhuiyan et al., 2024; Prashant, et al., 2016). In the present paper, an attempt has been made to study the effect of coir fibre (CF) on stabilization of laterite.

Many studies have shown that fibre reinforcement can significantly improve the engineering properties of soil (Dasaka and Sumesh, 2011; Mwasha, 2009; Babu and Vasudevan, 2008; Lekha and Sridevi, 2006; Rao et al, 2005). There are instances where a laterite may contain substantial amount of clay minerals that its strength and stability cannot be guaranteed under load, especially in the presences of moisture. These types of laterites are also common in many tropical regions including Nigeria where in most cases sourcing for alternative soil may not be an economically viable option. The over dependence on the utilization of industrially manufactured soil improving additives (cement, lime etc), have kept the cost of construction of stabilized road financially high. This, therefore, has continued to deter the underdeveloped and poor nations of the world from providing quality and accessible roads to their locals and residents. Thus the use of natural fibre (such as coir fibre) will considerably reduce the cost of construction as they are cheap and locally available and as well reducing the environmental hazards constituted by industrially manufactured soil additives. According to Freitag, 1986, randomly distributed fibre in a compacted fine-grained soil could result in greater stiffness. The primary advantage of these randomly distributed fibre are the absence of potential planes of weakness that can develop parallel to oriented reinforcement (Maher, and Gray, 1990).

The Use of coir fibre as a natural fibre for soil improvement has been studied and found to be a good option. Coir fibre is a natural fibre extracted from the fibrous husk that surrounds coconut. The fibres are tough, strong and extremely resistant to fungal and bacterial decomposition. Coir fibre length varies from 0.3 mm to 250 mm; but to an average ranges from 100 mm to 200 mm and are usually obtained manually with the use of knives. The coir is then soaked in water for a minimum of 24 hrs so as to aid the removal of the organic material binding the fibre. After which, dried by mechanical or natural means. Coir cross sections are highly elliptical and non-uniform with average diameter of 0.25 mm in spite of low cellulose content, coir fibre has a very close fibre structure which accounts for its better durability compared to other fibres. Mwasha (2009) reported that coir fibres have good strength characteristics and are resistant to bio-degradation over long period of time. Sebastian et al. (2011) outlined that randomly distributed fibres offer strength isotropy and limit potential planes of weakness that could possibly develop parallel to a reinforcement oriented in reinforced soil. Compaction study carried out on soil reinforced with coir fibre by Lekha and Sridevi (2006) reported an increase and decrease respectively in the maximum dey unit weight and optimum moisture content with an increase in coir fibre content. Babu and Vasudevan (2008) reviewed that the strength and stiffness of tropical soils were increased with the inclusion of 1-2% discrete coir fibres by weight. Ramesh et al. (2010) discussed that the unconfined compressive strength of a black cotton soil reinforced with bitumen-coated coir fibres shows a marginal variation in strength. Dasaka and Sumesh (2011) reported that varrying the length of coir fibres and content in soil results in an improvement in the strength characteristics. These reveal a need for further studies towards utilization of coir fiber for soil improvement.

This study contributes to existing studies by analysing the geotechnical properties of subgrade soils reinforced with various amounts of coir fibre. The focus is on the applicability of this soil improvement method for Nigerian road construction. Locally sourced natural soils from Awka was used for the study and the result strengthened the hypothesis that coir fiber can effectively be used for soil stabilization.

II MATERIALS AND METHOD

2.1 Sampling

The samples were collected within the geological location of Anambra state. The soil samples used for this project were disturbed samples collected from burrow pits located in Agu-Awka and inside Nnamdi Azikiwe University, Ifite both towns within Awka capital territory in Anambra state.

2.2 Laboratory Test

The laboratory tests conducted include sieve analysis, Atterberg limits, specific gravity, compaction, and CBR tests. The summary of the test procedures are presented in this section.

2.2.1 Sieve Analysis

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles. The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil. The graph of percentage passing against sieve sizes plotted on logarithm graph and the coefficient of uniformity (Cu) and coefficient of curvature (Cc) of the two samples where determined thus:

$$C_U = \frac{D_{60}}{D_{10}}$$

$$C_C = \frac{(D_{30})^2}{D_{60} \text{x} D_{10}}$$

Where

C_U = Uniformity coefficient

C_C = Coefficient of curvature

D_{60} = Particle size such that 60% of the soil is finer than this size

D_{10} = Particle size such that 10% of the soil is finer than this size

D_{30} = Particle size corresponding to 30% finer

When $C_U < 2$, the soil is uniform and non uniform when $C_U > 2$.

Coarse grained soil is when more than half is larger than sieve number 200. Well graded sand (SW) is when the value obtained from C_U is greater than 6 and C_C is between 1 and 3. Poorly graded sand (SP) is when the sample is not meeting the entire gradation requirement of well graded sand (SW).

2.2.2 Atterberg Limits

The Atterberg limits consists of the liquid limit (LL), the plastic limit (PL) and the shrinkage limit (LS). A value frequently used in conjunction with these limits is the plasticity index (PI). The hydraulic conductivity of soil vary with the amount of water present, and results of the three consistency tests, expressed as moisture contents are arbitrarily used to differentiate between the various states of material. These tests were performed according to ASTM D 4318.

2.2.3 Specific Gravity

This laboratory test is performed to determine the specific gravity of soil by using a Density bottle. Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity of a soil is used in the phase relationship of air, water, and solids in a given volume of the soil. The mass of an empty clean and dry density bottle was weighed and recorded; (M1). 10g of a dry soil sample (passed through the sieve No. 10 (2mm) was poured in the density bottle. The density bottle containing the dry soil, M2, was weighed and recorded. Distilled water was added to fill about half to three-fourth of the density bottle. The sample was soaked for 10 minutes.

A partial vacuum was applied to the contents for 10 minutes, to remove the entrapped air. The vacuum was stopped and the vacuum line carefully removed from the density bottle. The density bottle was filled with distilled (water to the mark), the exterior surface of the density bottle cleaned with a clean, dry cloth. The weight of the density bottle and contents, M3 was determined. The density bottle was emptied and cleaned, then filled with distilled water only (to the mark). The exterior surface of the density bottle was cleaned with a clean, dry cloth and the weight of the density bottle and distilled water, M4, determined. The density bottle was emptied and cleaned. The specific gravity was then calculated as;

$$Specific gravity\ (Gs) = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$

Where:

M_1 = weight of empty density bottle

M_2 = weight of density bottle with dry soil

M_3 = weight of density bottle with soil and water

M_4 = weight of density bottle with water only.

2.2.4 Compaction

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. The compactive effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction. This laboratory test will employ the tamping or impact compaction method using the BSL method in accordance with BS 1377 (BSI 1990).

Each of the two soil samples were moistened to five different molding water content (4%, 8%, 12%, 16% and 20% by weight) by the increment of four percent (4%), after each molding water content. At each of the molding water contents, the soil samples were thoroughly mixed by hand and compacted thereafter using the BSL method. Subsequently the soil samples were also compacted with varying proportions of coir fibre; 0.5%, 0.75%, 1.25%, 3%, 5%, and 8%.

The Compaction Energy / Compactive Effort (CE) is equal to number of layers multiplied by number of blows, weight of rammer, height of fall and acceleration due to gravity (9,81 m/s^2) all divided by the volume of mold, mathematically expressed as:

$$CE = \frac{\text{No.of blows x No.of layers x wt.of rammers (kg) x Height of fall (m)x } 9.81 m/s^2}{\text{Volume of mold } (cm^3)}$$

For the British Standard Light (BSL) compactive energy the soil samples were divided into three layers with twenty seven blows per layer. The mould used here being the BS mould has the volume of 1000 cm^3, the weight of rammer used is 2.5 kg with a height of fall of 0.3048 m. CE for BSL is 0.605 MNm/m^3.

2.2.5 California Bearing Ratio (CBR)

The California bearing ratio (CBR) test was carried out to evaluate the bearing capacity of the soil samples for road pavement construction. The construction of highway road pavement requires a regulatory minimum California Bearing Ratio which should not be less than 80%, 30%, and 10% for base, sub-base and sub-grade material respectively, where the material for sub-base and sub-grade should be subjected to soaking for

48hours in order to analyze the behavior of the soil under the worst possible condition (rainy season).

After the optimum moisture content has been achieved from compaction test, the result is used to mix the sample for CBR test. The sample was dried and 6 kg of sample was weighed. 6 kg of sample was mixed using optimum moisture content (OMC) as determined by compaction test. The sample was thouroughly mixed and divided into 3 layers. The mould was filled in 3 layers, each layer was compacted with 27 blows using a 2.5 kg rammer. The collar of the mould was removed and the top of the mould was leveled with a spatula. A surcharge weight of 2.5 kN was placed at the top of the mould and the soil, and the whole arrangement was soaked for 48hours. After soaking for 48hours, the surcharge weight was removed, and then the mould and the sample were placed on the CBR machine. The dial gauges on the machine were set to zero and the sample was loaded. Dial reading was taking after every 30 sec till 7 mm penetration, it was calculated for both top and bottom and the average noted. The higher CBR value will be the CBR value for the material. A graph of force (load) against penetration was plotted.

$$\text{CBR} = \frac{Load\,(force)}{Standard\ load} \times 100$$

Where;
Force = dial gauge reading x 0.0294
Standard forces at 2.5 mm and 5 mm penetration are 13.24 kN and 19.96 kN respectively.

III. RESULTS AND DISCUSSION

3.1 Index Properties of the Soils

The result of the laboratory tests carried out on the two soil samples are summarized in Table 1. These are results of test conducted without inclusion of the coir fiber.

Table 1: Result of Index Properties of Soil Samples

Properties	SAMPLES	
	A	B
Liquid Limit(%)	28	30.9
Plastic Limit(%)	3.4	4.1
Plasticity Index(%)	24	26.8
Plasticity	Medium Plastic	Medium Plastic
Specific Gravity	2.52	2.7
%Passing 0.075 mm	28.96	31.78
%Retained On 0.075 mm	71.064	68.218
AASHTO Classification	A-2-6	A-2-6
USCS Classification	SC	SC
MDD (KN/m^3)	18.8	18.3
OMC (%)	17	16
CBR (48hrsSoaked)	4	14.8
General Rating As Subgrade	Poor	Good

The particle size analysis for the two lateritic soils shows that the cumulative percentage retained on BS sieve No. 200 were in the range of 71.06% and 68.218%, and also, the cumulative percentage passing through BS sieve No. 200 were in the range of 28.98% and 31.78% respectively. The samples are coarse grained soils since less than 35% passed through BS sieve No. 200. Fig. 1 is the particle size distribution plots for the two soil samples.

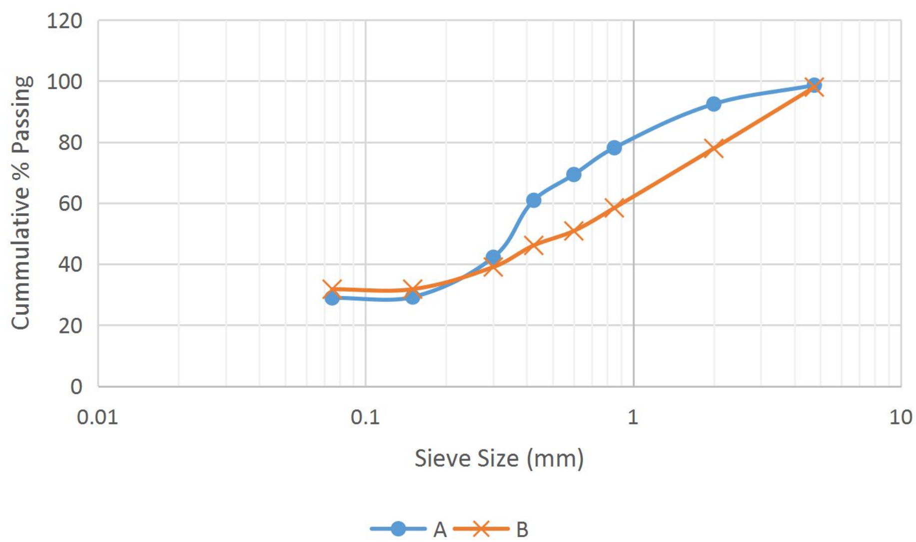

Fig.1 : Graph Of Grain Size Distribution curves for the Soil Samples

From Table 1, it is seen that the two soil samples have less than 35% of their particles passing BS sieve No. 200, their liquid limit is less than 40 maximum; while the plasticity index of the two samples is greater than 10 maximum. Liquid limit values of 28% (sample A) and 30.9% (sample B) were obtained and the plasticity indices of 24% and 26.8% respectively were also obtained.

According to the AASHTO system of soil classification, sample A is classified as A-2-6, while the sample B is also classified as A-2-6. The two soil samples are rated as excellent to good subgrade materials. The two soil samples are coarse grained soils, since they all have more than 50% of their particles retained on the BS sieve No. 200. According to USCS classification, sample A and sample B soil fall into the group symbol; SC and group name; Clayey Sand, since they both have their plasticity index greater than 7.

Generally, the soils are good subgrade materials. According to FMWH specifications for Road and Bridges (1997), the liquid limit and plasticity index of subgrade or fill material should not exceed 80% and 55% respectively. Therefore, the two samples satisfy the criteria for use as subgrade since they have their liquid limit and plasticity indices within the specified range. The specific gravity of 2.5 and 2.7 results obtained for the two samples also fall within the specification of FMWH.

3.2 Compaction Test Results

Soil compaction is a conventional mechanical approach to soil stabilization. The field compaction which is achieved by the use of rollers is estimated based on the laboratory compaction. The laboratory compaction gives the maximum dry unit weight of a soil subjected to a known compaction energy. The moisture content at which the soil attains the maximum dry unit weight is also observed and recorded as an indicator to how moist a compacted soil should be to achieve the best compaction. Fig.s 2 shows the compaction results of the soil samples without inclusion of coir fiber for BSL and BSH respectively.

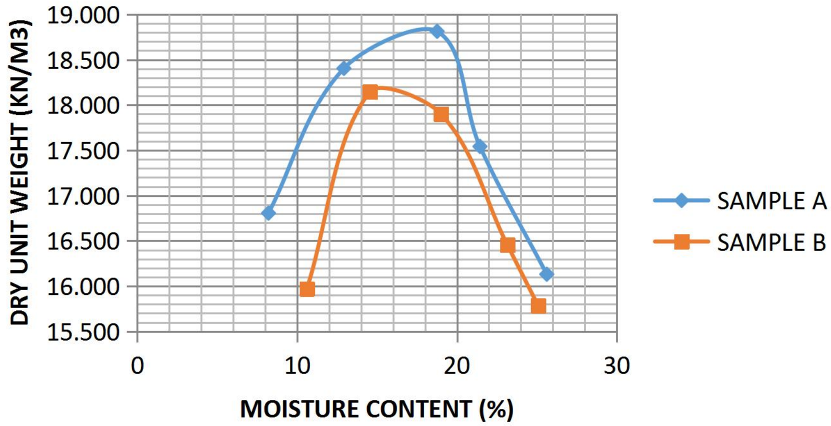

Fig. 2 : Compaction curves of the soil samples

Comparing the maximum dry unit weight (MDUW) and the optimum moisture content (OMC) of the two soil samples when plotted with the British Standard Light Compactive effort, it is noticed that the sample B soil has the lower maximum dry density (MDD). Sample B has the best compaction quality being that it achieved the highest dry density at the same compactive effort with the other soil sample. It was also noticed from the graphs that the OMCs of the samples decreased as their MDD increased, which is in line with Venkatramaiah (2006) and Rowe (2000).

BSL compaction was carried out for the two lateritic soil samples with varying percentages (0.5%-8%) of coir fibre (CF). This was done to understand the effect of the coir fibre on the MDUW and OMC of the soils. Fig.s 3 and 4 are the compaction curves for the two soil samples.

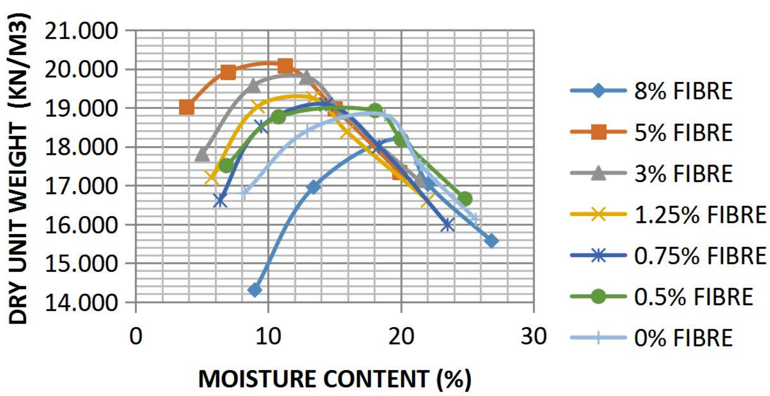

Fig. 3 : Compaction Curves for Sample A with varying amounts of CF

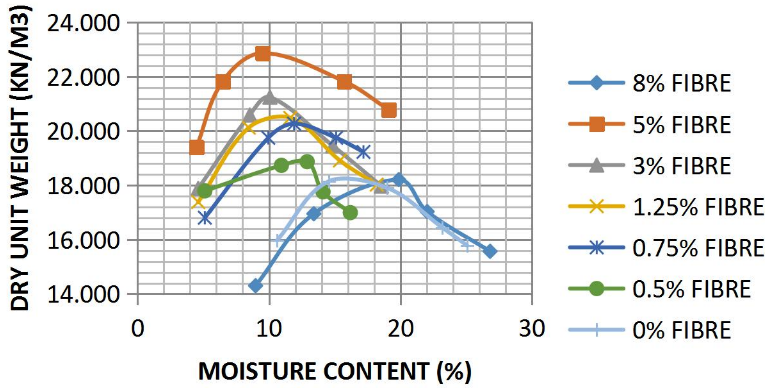

Fig.4: Compaction Curves for Sample A with varying amounts of CF

From a clear observation of the graphs, the maximum dry unit weights of the soils increased with higher amounts of fiber content up to 5% CF content. Beyond 5% of CF, there was a drop in MDUW. Consequently, the curves with higher MDUW's had lower OMC's. These are clearly shown in Fig.s 5 and 6.

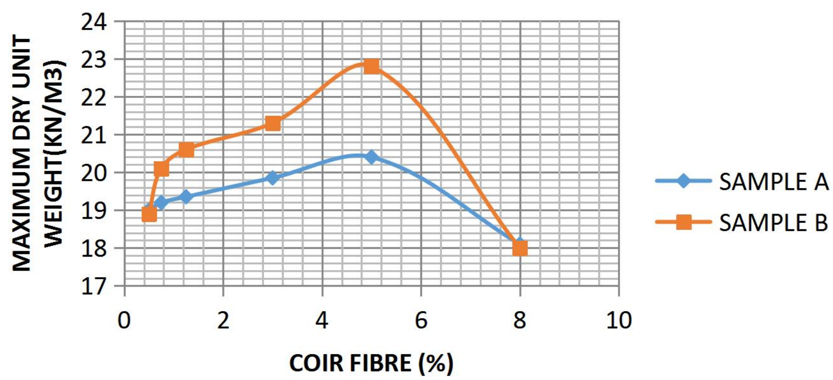

Fig.5 : Effect of CF on MDUW of the soil samples

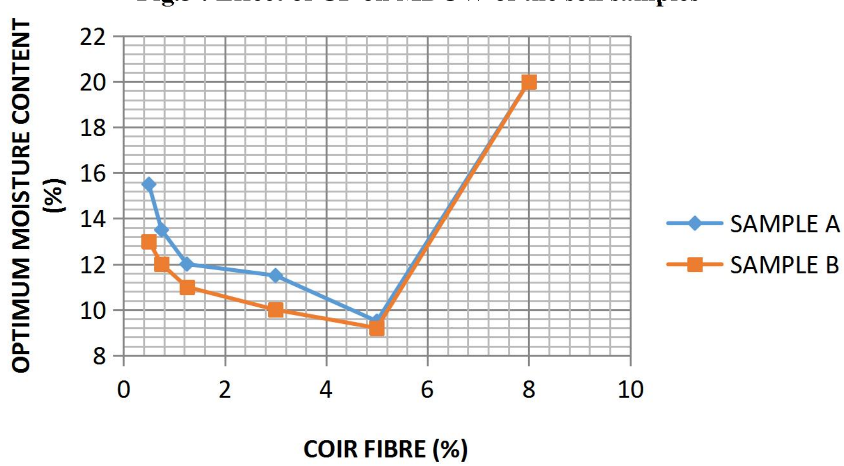

Fig.6 : Effect of CF on MDUW of the soil samples

The increase in MDUW with inclusion of coir fiber would be as a result of the water absorption of the coir fibre which increases its tensile strength. But at higher amounts of CF, the resulting decrease in MDUW would be as a result of the lower specific gravity of CF compared to soil. The optimum percentage of coir fiber observed is 5% for both samples.

3.3 Result of California Bearing Ratio Test

The results for the CBR tests conducted for the two soil samples with and without the addition of coir fibre is shown in Fig.7.

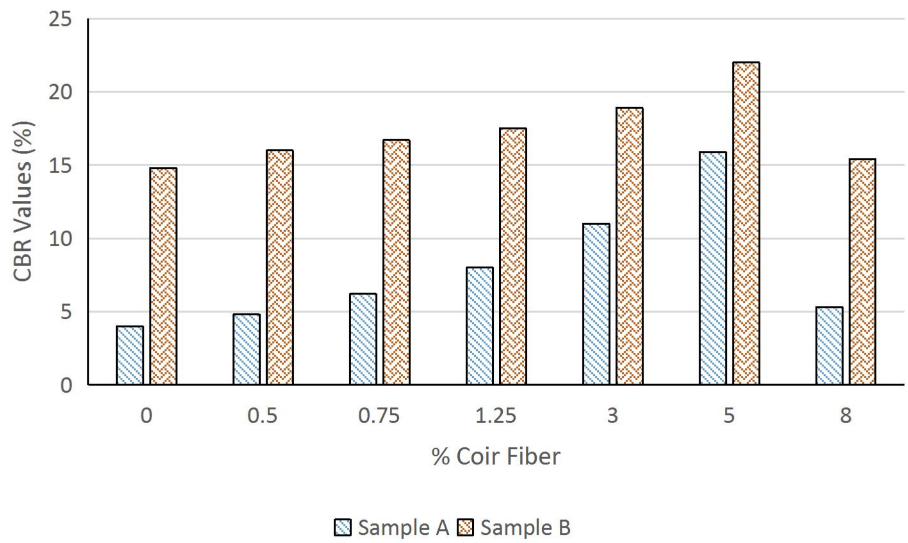

Fig. 7: Graph of CBR Values against % Coir Fibre

The CBR result follows a similar trend as the compaction results. Samples with higher MDUW's also achieved higher CBR. 5% of CF content exhibited the best performance based on compaction and CBR. It is therefore taken as the optimum amount of CF for subgrade improvement. At the optimum 5% CF, an increase in CBR of 48.6% and 297.7% was recorded for samples A and B respectively. These confirm the effectiveness of coir fiber as a natural reinforcement for subgrade improvement. It offers clear potentials both for stabilization of weak soils and for improving the properties of stable ones for road pavement applications.

IV. CONCLUSION

An investigation on the application of CF as a reinforcement for subgrade soil improvement was carried out. The test carried out on the two soil samples with inclusion of different amounts of CF revealed that CF is a good material for improvement of geotechnical properties of Soil. Based on the tests carried out on the two soils used for the study, it was observed that the MDUW of both samples kept on increasing at addition of varied amount of coir fibre until after the 5% fibre addition before a decrease in MDUW was observed, indicating that 5% fibre addition is the optimum. The CBR values of the samples were also observed to have increased progressively with the addition of varied amount of CF until 5%. The drop in MDUW and CBR at 8% inclusion of coir fiber suggests that usage of higher amounts of fiber beyond 5% would result in decrease in subgrade quality. Hence, the study recommends 5% as optimum dosage of coir fiber for subgrade improvement.

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