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(RESEARCH ARTICLE)

Effects of oil palm mesocarp fibers on the physical and mechanical properties of expansive soils

André Abanda [1], Ahoudou Ngamie Ndoukouo [2], Benjamin Bahel [1], Blaise Ngwem Bayiha [3], Fabien Kenmogne [3,*] and Moussa Sali [3,4]

[1] Department of Civil Engineering, National Advanced Polytechnical School of Douala, University of Douala, Cameroon.
[2] Department of Architecture and Engineering Arts, Fine Arts Institute, University of Dschang, Cameroon.
[3] Department of Civil Engineering, Advanced Technical Teacher Training College of the Technical education, The University of Douala, Douala, Cameroon.
[4] Laboratory of Materials, Mechanics and Civil Engineering, National Higher Polytechnic School of Maroua, University of Maroua, Cameroon.

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Abstract

Palm fiber is one of the favorable materials used in stabilization of soft soil in geotechnical engineering projects, nowadays due to its sustainability, less damage of environment, biodegradability, availability and cost-effectiveness in a context of widespread appeal to the world for return to nature by protecting the earth. On the other hand, expansive soils are renowned for their swelling-shrinkage property and these volumetric changes resultantly cause huge damage to civil infrastructures. Likewise, subgrades consisting of expansive soils instigate serviceability failures in pavements across various regions worldwide. This paper presents results of the laboratory evaluation of expansive soils stabilized with oil palm mesocarp fiber (OPMF), with a view to determine its suitability as flexible pavement construction material. The mixtures were subjected to British Standard heavy (modified Proctor) compaction energy to determine their strength characteristics. The samples were subjected to different tests to ascertain their index properties. Varying proportions of OPMF from 1% to 4% were incorporated into the soil samples and the effects were observed based on compaction and California Bearing Ratio (CBR) results. The control samples without inclusion of OPMF achieved the highest Maximum Dry Densities (MDD), the MDDs reduced linearly as the OPMF content increased. Consequently, the CBR values decreased with increase in OPMF. The reduction in MDD ranged from 20.28g/cm^3, 18.5 g/cm^3, 15.65 g/cm^3, 12.53 g/cm^3 as the OPMF increased from 1%, 2% to 3%, 4%. and the optimum moisture content remained almost unaffected due to high-absorbent nature of the fibers. With the inclusion of the OPMF, the CBR value under soaked conditions dropped from 5% to 1.8% rendering them very unsuitable for pavement subgrade. It was concluded that the presence of fiber depreciated the engineering properties of the earth materials. Direct application of OPMF in any part of road pavement has been dissuaded.

Keywords: Expansive Soils; Soil Stabilization; Oil Palm Mesocarp Fibers; Compaction; Density; California Bearing Ratio.

1. Introduction

Most building structures are held up in one way or another on the ground. In this way geotechnical engineers need to know the physical and mechanical properties of the soils in order to guarantee the structural stability of the works to be built [1]. Also, weak soils are often encountered in road construction sites, but where they are encountered as natural soils, they are either removed and substitute with a borrowed subgrade material or improved by addition of some soils

* Corresponding author: Fabien Kenmogne

stabilizer [2]. As clay soils being the weakest in one most cases with worst physical and mechanical properties in the presence of water, there are some clay soils characterized by considerable changes in one their volume when variations of water content occur, causing serious damage and deformations to structures built on them, particularly to building and light pavement and other not [3].

One of the problems that we frequently encountered in civil engineering is the soil's inability to withstand the structural loads; therefore, we are forced to find alternative methods for the improvement of their physical and mechanical properties, mainly shearing strength and bearing capacity. One of the methods to improve the mechanical behavior of soils is stabilization [4;5]. The most common method for improving the properties of clay soils is stabilization with the use of binder materials such as cement and lime as published by many researchers. Also, research published by other researchers shows that an alternative method of stabilizing the soil is with the use of natural fibers[1,6]. In this study we are using oil-palm mesocarp fibers (OPMF) for the improvement of the physical and mechanical properties of expansive soils. However, the use of these natural fibers is justified because is cheaper, in general since these are mainly residues of agro-industrial processes with abound in developing countries and Cameroon in particular [7,8]. The aim is to come out an approach of an essential principle of sustainable development, which is low-cost technique, less polluting, waste management instead of disposal of wastes (fibers) in landfills or by burning which causes environmental hazard such as emission of carbon dioxide.

The primary product of oil palm fruit processing is the palm oil [7]. As a result of palm oil production in some parts of the country, much waste is generated. This is because the oil milling produce of huge amount of several by-products in waste as OPMF. Inefficient disposal of this fibers waste can lead to environmental challenges. In areas where there is high production of palm oil, these wastes are already constituting landfill problems. OPMF is one of the major waste products after fresh palm oil fruit has been processed. If this fiber improves the CBR values of the expansive soil, it is implying soil reinforcement or soil improvement and solid waste reduction [9].

The following questions will be answered during this research:

1. Can OPMF as stabilizing material affect some physical properties (density and compactness) of expansive soils?
2. Can OPMF as stabilizing material affects some mechanical properties (California Bearing Ratio) of expansive soils, and if so, what is the minimum or maximum amount of OPMF required for stabilization?

The objectives of our research are as follows:

1. General objectives:

This research aims to determine the effects of oil palm mesocarp fibers on the physical and mechanical properties of expansive soils.

2. Specific objectives

To achieve our overall objective, the following specific objectives are pursued:

3. Evaluate the density and compactness of expansive soil stabilized with oil palm mesocarp fibers and determine the maximum amount of fiber required for stabilization.
4. Evaluate load bearing capacity (CBR) of soil reinforced with oil palm mesocarp fiber.

The research involves laboratory test by preparing samples of soils mixes containing varying proportion of OPMF and then carried out laboratory tests on density, compaction test and CBR test. Before to this, the grain size analysis of the aggregate will be carried in order to determine the percentage of silt, clay and sand in the sample, also water content, compaction test will be carried in other to determine the optimum water content, plasticity index of the soil. Then the different results will be interpreted and concluded. If the fibers increase the load bearing capacity of soft soil definitely the swelling potentials and volumetric shrinkage of soft soil will reduce. Thus, we will determine the maximum quantity of fibers needed to achieved the maximum dry density and the load bearing capacity (CBR) of the soil will be determine.

2. Materials and methods

This section describes all the methods and techniques used in the context of our research, as well as the materials and means used. It presents the test used in the classification of the soil type, as well as the test procedure, details and equipment used to assess the effects of palm fibers on expansive soils.

2.1. Materials

The materials used in the test program include natural fiber such as oil palm mesocarp fiber (OPMF) and expansive soils.

2.1.1. Oil palm mesocarp fibers

The natural fiber that are the subject of this manuscript was obtained from the oil palm, variety E Elaeis guinansis, of SOCAPALM located in Nkapa village (See Fig.1), Fiko sub division of the Moungo Division, central Region of Cameroon.

The fibers are extracted from oil palm mesocarp fiber and washed with caustic soda (as shown in Fig 2, c). A hydraulic press is used to extract oil from the OPMF. At the exit of the press, the oil cake is made of a very dense mixture of fibers and palm nut (Fig 2a). The fibers which are mechanically cleared from the nuts and some pulp particles, are washed at a temperature of 70% c and then dried (Fig 2c). figure 2 shows the pictures of the oil cake and the state of the fibers at different stages of extraction.

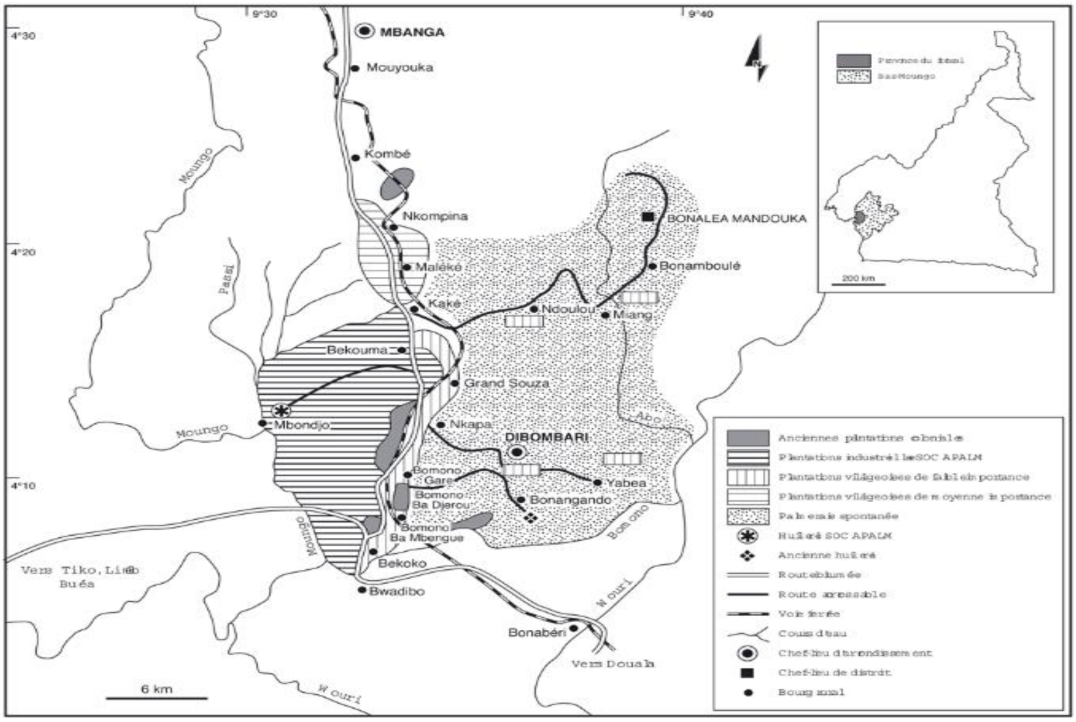

Figure 1 Geographical site for collecting of palm fiber (*www.maplandia.com>moungo*)

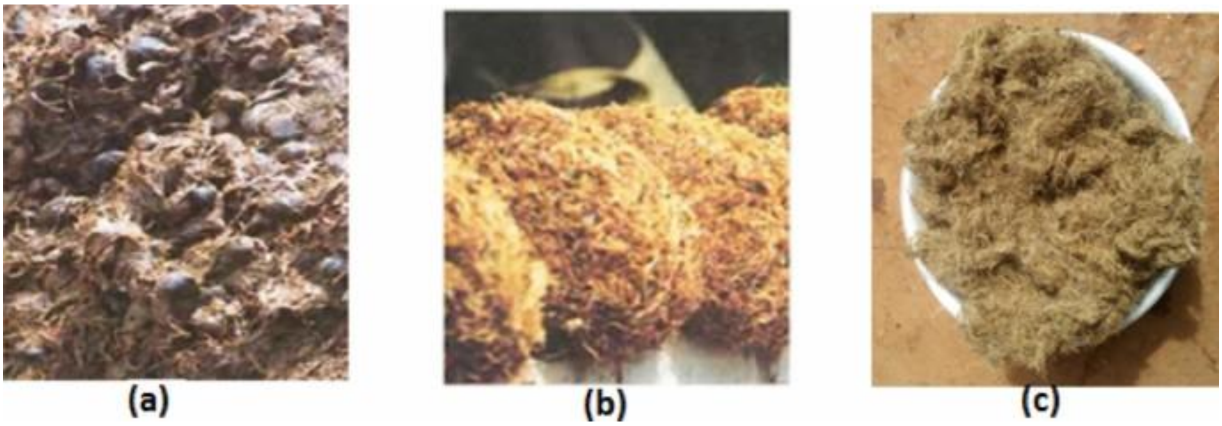

Figure 2 (a) oil cake, (b) clean fresh OPMF (c) dried OPMF

2.1.2. Expansive soil

The expansive clay soils used in this study were collected from a construction site in Loum. The locality of Loum is situated on national highway number 5, 40 km away from the town of Nkongsamba in the Moungo division, littoral region of Cameroon. Geographically, it is located between latitudes 4°30' and 4°43', and longitudes 9°35' and 9°54' E. From this city center also transits the regional road N°16 (R16) which connects Yabassi to Kumba. These two important roads (intersect) join at the Tombel junction, making the city of Loum a Cosmopolitan city. With the closure of the Mbanga-Nkongsamba railway line in the early 1990s, the road currently remains the only means of interconnection neighboring localities.

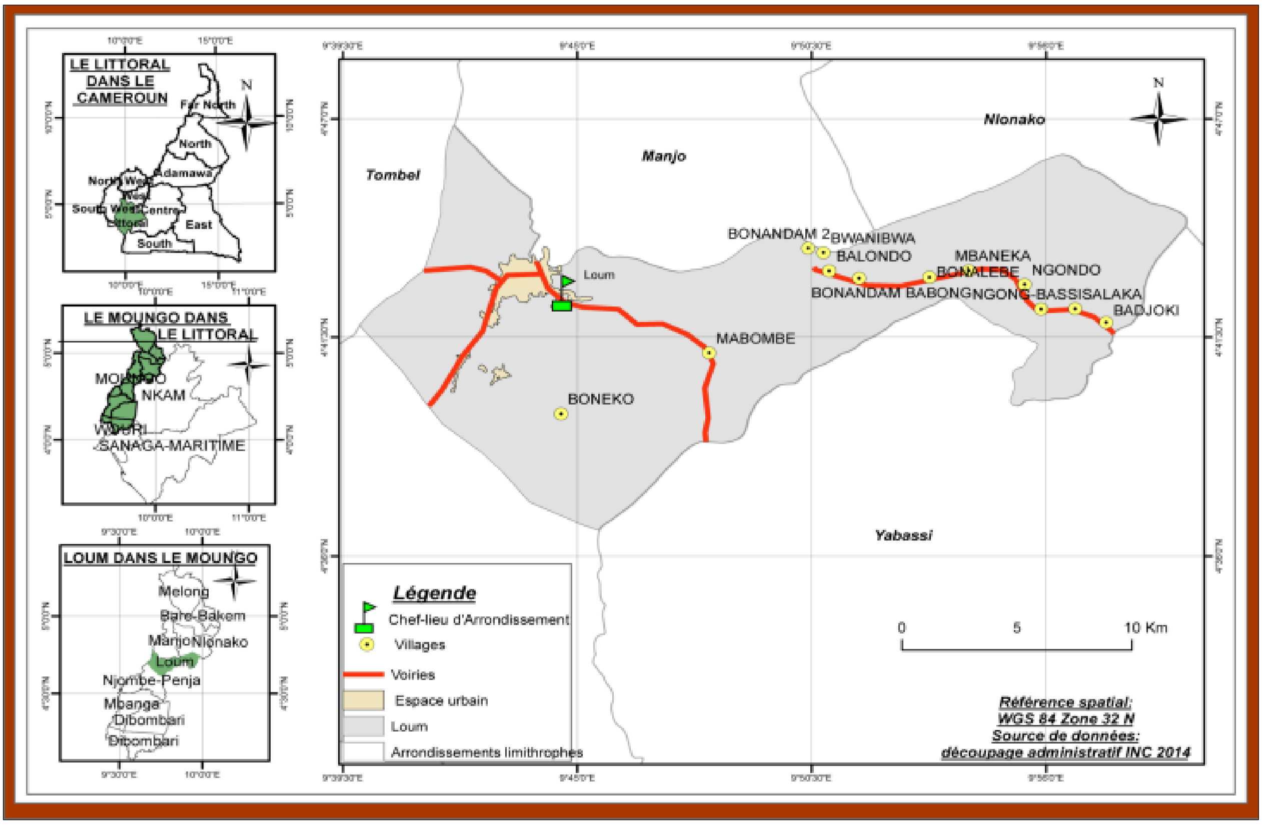

Figure 3 Location of Loum in the Littoral region of Cameroon (www.maplandia.com>moungo)

2.2. Methods

The following method was adopted for the mixing and sample preparation. Soil was air dried for 24 hours, followed by grinding of the soil to eliminate large grains. Sieving was done with a series of sieves ranging from 2.5mm down to 0.03mm. After that, Atterberg limits, Plasticity limits or consistency limits were used to characterized the behavior of the fine soils. The fiber was washed with caustic soda solution in other to eliminate the oil on it which might affect the bond between fiber and soil.

2.2.1. Treatment of the oil palm mesocarp fibers

1. To remove the adhered oil and contaminants associated with fiber, the fibers were washed with a detergent solution. In this research work, the detergent used was caustic soda (NAOH).
2. Water (10L) was boiled at a temperature of 105^{o}C and poured in a silver basin;
3. 500g of NAOH was poured inside and immediately the fibers were added and stirred with a stick;
4. It was allowed to stand for about 5 minutes;
5. The fibers were carefully removed from the solution and rinsed with distilled water;
6. It was air dried for 48hours;
7. Prior to mixing, the palm fibers were dried for 12 hrs in a hot air oven at 105^{o}C in order to remove the moisture content.

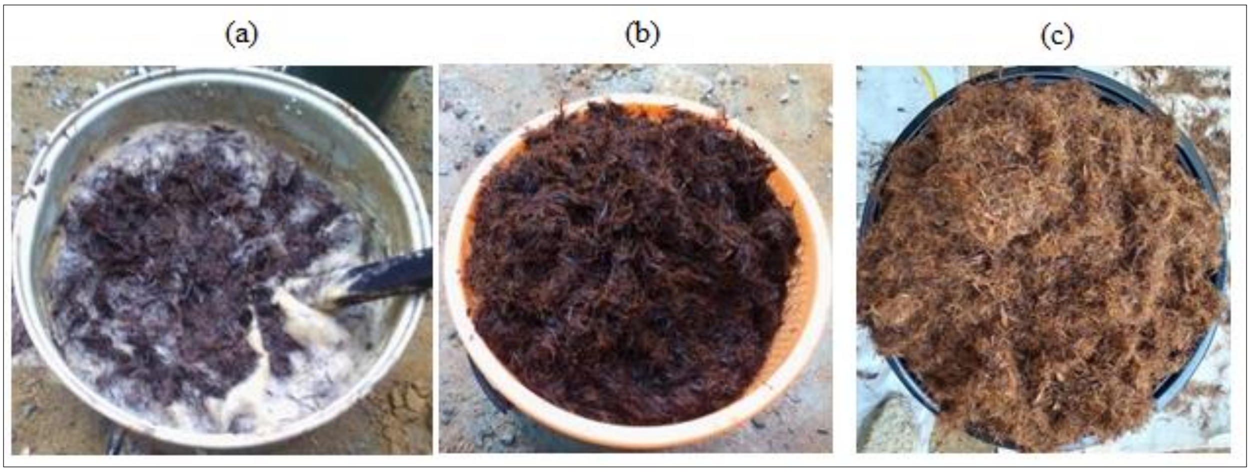

Figure 4 Treatment of OPMF, (a) OPMF in NAOH solution (b) OPMF on a drainer, (c) dried fibers

2.3. Calibration of the soil

The soil was air dried then grind and later carry on a sieve analysis as per IS: 2386

Figure 5 (a) pulverization of the soil, (b) weighing of the soil

2.4. Physical characteristics of the soil

To characterize the soils, the different limits of liquidity and plasticity were determined. The grains were classified according to their sizes and particles natures, and we determined the percentages of silt, clay and sand contained in the sample. The sample taken was ground at the laboratory until the particle size of less than 1mm was obtained. This consisted of doing the particle size analysis, Atterberg's limits and so on, in the laboratory.

2.4.1. Sieve analysis

The sieves used for making a sieve analysis conformed to (IS: 2386). The tests were carried out in accordance with the procedure given in (IS: 2386). The objective of the test was to determine the percentages of fines of the sample. The retained grains of the fine aggregate for each sieve weighed after the mechanical and manual agitation were recorded on table 1.

Table 1 Particle size distribution

Sieve sizes (mm)	Retained particles (g)
2.5	0.25
1.6	46.18
1.25	52.35
1	27.61
0.63	136.14
0.35	450.22
0.16	674.6
0.1	533.3
0.008	79.35

The grains size analysis curve brings information on the percentage of fine particles. From the gradation curve we will calculate the uniformity coefficient (Cu) and the concavity coefficient (Cc).

$$C_u = \frac{D60}{D10},\ C_C = \frac{D30^2}{D60 \times D_{10}}, \quad (1)$$

Where; Cu is the coefficient of uniformity; Cc, the coefficient of concavity; D60 the grain diameter at 60% passing; D10 the grain diameter at 10% passing and D30 the grain diameter at 30% passing.

2.3.2. Moisture content

The natural moisture content of a sample is the amount of residual water contained in the soil at the time of excavation. The calculation of water content is based on the following formular.

$$W\% = \frac{weight\ of\ water}{weight\ of\ oven\ dried\ soil} = \frac{W_n - W_d}{W_d - W_c} \times 100 \quad (2)$$

Where Wc: weight of Can; Wn: weight of natural soil + can; Wd: weight of oven dried soil + can; Wn-Wd = weight of water; Wd-Wc = weight of dried soil.

2.4.2. Equipment

The sensitive balance with precision of 0.01g; An oven and the weighing cans.

Procedure

1. Measure the soil and note its weight;
2. Fill the soil in the can and note the weight of can plus soil;
3. Place it in an oven for 24 hours at 105°C; Allow to get cold and take its weight;
4. Calculate the water content using the Equation (2).

2.4.3. Liquid limits and plastic limits of soil

The liquid and plastic limits of soils depend on the amount and type of clay in a soil and forms the basis for soil classification system [10,11].

Liquid Limit

The liquid limit of a soil is the minimum water content at which the soil is still in liquid state but has small strength against flowing which can be measured by standard procedure.

1. From prepared sample passing through 0.4mm sieve, take 120g in an evaporating dish;
2. Add distilled water to the soil sample and mix it thoroughly to form a uniform paste with the help of a spatula;
3. Allow to stand for 24hrs to allow uniform distribution of moisture;
4. Place a portion of paste in the cup of liquid limit device;
5. Squeeze down and spread paste in the cum with a spatula;
6. Clean the soil at the top so that the maximum depth of soil in the cup is 1cm;
7. Level the top and use a Casagrande grooving tool to divide the soil paste in the cup into two halves in the direction perpendicular to the direction of handle;
8. Lift and drop the cup by rotating the handle at the rate of 2 revolution per second till the two halves of the soil come in contact along a distance of about 12mm;
9. Count the number of blows required and record. Ensure that the number of blows range between 15 and 35;
10. From the flow portion take a portion of sample with a spatula into a known weight; then determine the moisture content of this sample as per standard procedure.
11. Redo the procedure with different water content 3 to 4 times. The results will be given after this part.

Note: If the number of shocks is less than 15, let it dry a bit, If the number of shocks is greater than 35, a little wet and mix again.

Plastic Limit

1. Plastic limit is the water content at which a soil just begins to crumble when rolled into a thread approximately 3mm in diameter.
2. Take about 50g of sample passing through a 425um sieve from prepared sample;
3. Add distilled water to soil sample and mix it thoroughly so that the soil mass is plastic and has to be remolded;
4. Prepare a ball weight about 8g out of this soil mass;
5. Place the ball on the glass plate and roll with fingers so that a tread of uniform diameter is form;
6. Continue rolling till the tread rich a diameter of 3mm by taking reference from the metallic rod;
7. Redo the process of rolling until the tread start crumbling just before attaining a diameter of 3mm;
8. Collect the pieces of known tread into a container of known weight;
9. Determine the moisture content using the formula (2) above;
10. Redo the procedure two more times and record the water content. The average of the water content is the plastic limit.

Plasticity Index

The plasticity index which is the difference between the liquid limit and its plastic limit, is given by the formula below:

Ip: plasticity index; WL: liquid limit; Wp: plastic limit.

Specific gravity of soil

1. The test is carried out to determine the specific gravity or relative density of the soil
2. Clean pycnometer, and dry it, find the mass of pycnometer (M1);
3. Introduce about 400g of oven dried soil in to the pycnometer and record mass of pycnometer plus soil (M2);
4. Fill pycnometer with distilled water to half its height, mix very well and allow to stand for 4hrs. later fill the pycnometer with water up to the top cap. Dry the pycnometer from the outside and record its mass (M3);
5. Empty the pycnometer and clean it thoroughly. Fill it with distilled water up to the top of cap. Dry the pycnometer from the outside and record the mass (M4);

Repeat step 2 and twice; Calculate the specific gravity of the soil at room temperature as well as at 27^{o}C.

The specific gravity is given by the formula below.

$$G_s = \frac{mass\ of\ soil}{mass\ of\ equal\ volume\ of\ water} = \frac{M_s}{M_w} \quad (3)$$

2.4.4. Modified proctor test (IS-2720: part 8).

Once the soil was prepared, the modified proctor test was applied using the reference IS-2720 (part 8). Using the different moisture content such as 5%, 10%,15% and 20%, It enables us to determine the values of the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD).

1. Take about 4.5kg of air-dried sample; Pass through the sieve;
2. Add about 5% water and mix thoroughly to turn a uniform mixture;
3. Determine the weight of the proctor mold with base plate (W1);
4. Attach the extension on top of the mold; Fill the mold in 5 layers, compacting each layer 25 times with the help of a proctor hammer;
5. Detach the top attachment and use a straight edge to trim the excess soil at the top;
6. Determine the mass of the mold plus soil (W2);
7. Using the jack to extrude the compacted soil; Determine mass of empty moisture can;
8. From the moist sample take samples in to the moisture can and determine its mass;
9. Place the soil sample into the oven and wait for 24 hours; Remove the soil and take the weight of oven dried soil;

The above steps are repeated 4 times with varying percentages of water then the graph is plotted between the dry density of the soil and moisture content.

calculation of bulk density γ_w

$$\gamma_w = \frac{M_2 - M_1}{V_m} \quad (4)$$

Where M1 = weight of mould with base plate; M2 = weight of mould with compacted soil;

Volume of mould in cm^3. Calculation of dry density γ_d , using the equation:

$$\gamma_d = \frac{\gamma_w}{1 + \frac{w}{100}} \quad (5)$$

γ_d = bulk density;   w = moisture content of natural soil.

2.5. California Bearing Ratio test (IS 2720: Part 16)

California bearing ratio is the percentage of stress a soil specimen can resist for a certain amount of penetration relative to the value of stress of which a standard soil could resist. Basically, the value is an indicator of the strength of the soil. It is the expression in percentage of force per unit area required to penetrate a soil mass with a standard circular plunger of 50 mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. The ratio is usually determined for penetration of 2.5 and 5 mm. When the ratio at 5 mm is consistently higher than that at 2.5 mm, the ratio at 5 mm is used.

2.5.1. Procedure for penetration test

Place the mould assembly with test specimen on the lower plate of penetration testing machine. To prevent upheaval of soil into the hole of the surcharge weights, 2.5 kg annular weight shall be placed on the soil surface prior to seating the penetration plunger after which the remainder of the surcharge weights shall be placed;

Seat the penetration piston at the center of the specimen with the smallest possible load, but in no case in excess of 4 kg so that full contact of the piston on the sample is established;

Set the load and deformation gauges to read zero. Apply the load on the piston so that the penetration rate is about 1.25 mm/min;

Record the load readings at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10 and 12.5 mm;

Raise the plunger and detach the mould from the loading equipment. Take about 20 to 50 g of soil from the top 30 mm layer and determine the moisture content.

Figure 6 Penetration test for CBR

If the initial portion of the curve is concave upwards, apply correction by drawing a tangent to the curve at the point of greatest slope and shift the origin. Find and record the correct load reading corresponding to each penetration.

$$C.B.R. = \left(\frac{PT}{PS}\right) \times 100 \quad (6)$$

Where; PT = Corrected test load corresponding to the chosen penetration from the load penetration curve. P_S = Standard load for the same penetration taken from the table above.

The C.B.R. values are usually calculated for penetration of 2.5 mm and 5 mm. Generally, the C.B.R. value at 2.5 mm will be greater than at 5 mm and in such a case/the former shall be taken as C.B.R. for design purpose. If C.B.R. for 5 mm exceeds that for 2.5 mm, the test should be repeated. If identical results follow, the C.B.R. corresponding to 5 mm penetration should be taken for design.

Table 2 Standard Load Values at Penetration

Penetration of Plunger (mm)	Standard Load (kg)
2.5	1370
5.0	2055

3. Result and discussions

In this section, we are going to present the result of the different test that was carried out. This test includes the physical characteristics of the soil (water content, Atterberg's limits, Specific gravity of soil, Granulometric analysis), physical characteristics of the composite sample (compaction test, swelling potential) and the mechanical characteristics of the composite material (CBR). We will also present the result of tests characterizing different materials that were carried out in the laboratory, followed by scientific discussions.

3.1. Moisture content of the soil

The natural water content of the soil was determined as recorded in the table 3.

Table 3 Natural moisture content of the soil

Sample number	**1**	$W\% = \frac{W2-W3}{(W3-W1)} \times 100 =$ **21.6%**
Weight of can, W1	63.1	
Weight of can + wet soil, W2	294.02g	
Weight of can + dry soil, W3	253.00g	
Moisture content, W%	$\frac{weight\ of\ water}{weight\ of\ oven\ dried\ soil} \times 100$	

The natural moisture content (w%) of the soil after extraction was found to be 21.6%

3.2. Particle size distribution

The particle size distribution for the soil sample is shown on table 10, which allows us to draw the curve as shown on figure 7. From the curve of the soil distribution, the uniformity coefficient, Cu and coefficient of concavity, Cu can be obtained thus, from Eq.(1), one has for D60=0.3, D10=0.1, D30=0.15, $C_u = 3$ and $C_c = 0.75$, the soil sample used in this study can be classified as poorly graded in terms of soil gradation.

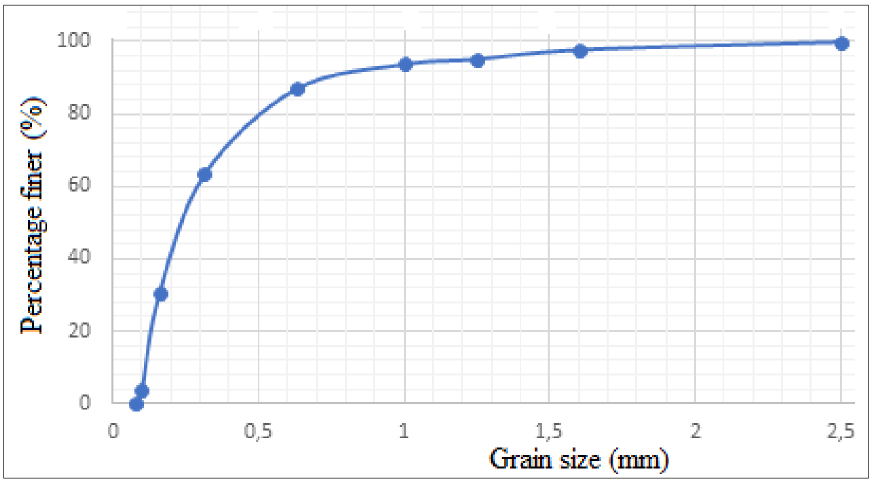

Figure 7 Particle size distribution curve

3.3. Atterberg's limit

3.3.1. Liquid limit (Wl)

Table 4 Liquid limit of the soil

NATURE	**Natural soil and soil plus fiber**				
Test number	1	2	3	4	5
Mass of can, w1 (g)	0	0	0	0	0
mass of wet soil, w2 (g)	8.65	6.85	5.35	7.2	8.64
Mass of dry soil, w3 (g)	5.75	4.6	3.8	5.15	5.9
Moisture content	50.43	48.91	40.78	39.8	46.44
Number of blows	18	17	16	34	28

Recall that our samples were tare before being weighed (i.e. they canceled the tare weight that is no longer involved in the weight of our materials when weighed). Based on test data obtained, the results are recorded on table 4. This data permitted us to plot the flow curve as seen on Figure 8. The moisture content corresponding to 25 blows from the flow curve is the liquid limit of the soil. Liquid limit (Wl) = 44%, *3.3.2. Plastic limit*

Table 5 gives the data that was collected during plastic limit experiment.

Table 5 Plastic limit of the soil

Test Number	**1**	**2**	**3**
Mass of can, w1 (g)	0	0	0
Mass of moist soil, W2 (g)	6.88	7.89	10.62
Mass of dried soil, W3 (g)	5.59	6.12	7.84
Moisture content W% = $\frac{W2-W3}{W3} \times 100$	23.08	28.92	35.46
Plastic limit = (w1+w2+w3)/3	PL = 29.15%		

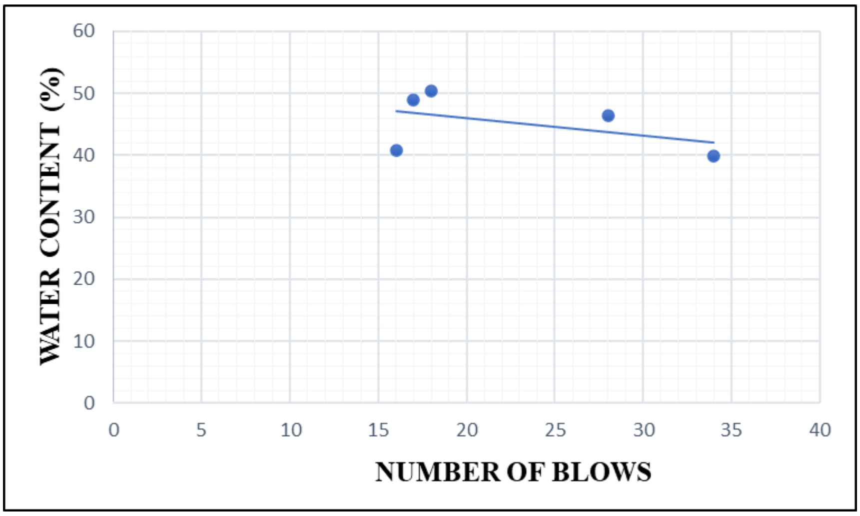

Figure 8 Flow curve of liquid limit

3.3.3. Plasticity index

PI = WL - Wp = 44 – 29.15 = 14.85% iP = 14.85%; 5 < Ip <15: So, we are in presence of a medium plastic soil

3.4. Specific gravity (relative density)

Table 3:3 gives data that was collected during the specific gravity test.

Table 6 Specific gravity of the soil

NO	**Description**	**Sample 1**
1	Weight of pycnometer (W1)	42.99
2	Weight of pycnometer + sample (W2)	129.31
3	Weight of pycnometer + sample + water (W3)	231.76
4	Weight of pycnometer + water (W4)	175.56
5	Specific gravity $= \frac{W2-W1}{(W4-W1)-(W3-W2)} = \frac{129.31-42.99}{(175.56-42.99)-(231.76-129.31)}$	SG = 2.86

The specific gravity of 2.86 indicate that our soil is clay or silty clay.

Table 7 Physical properties of the soil sample used in this study

Physical properties	
Specific gravity	2.86
Liquid limit	44
Plastic limit	29.15
Plasticity index	14.85
Soil description	Clay with medium plasticity

3.5. Effect of OPMF on compaction of the soil

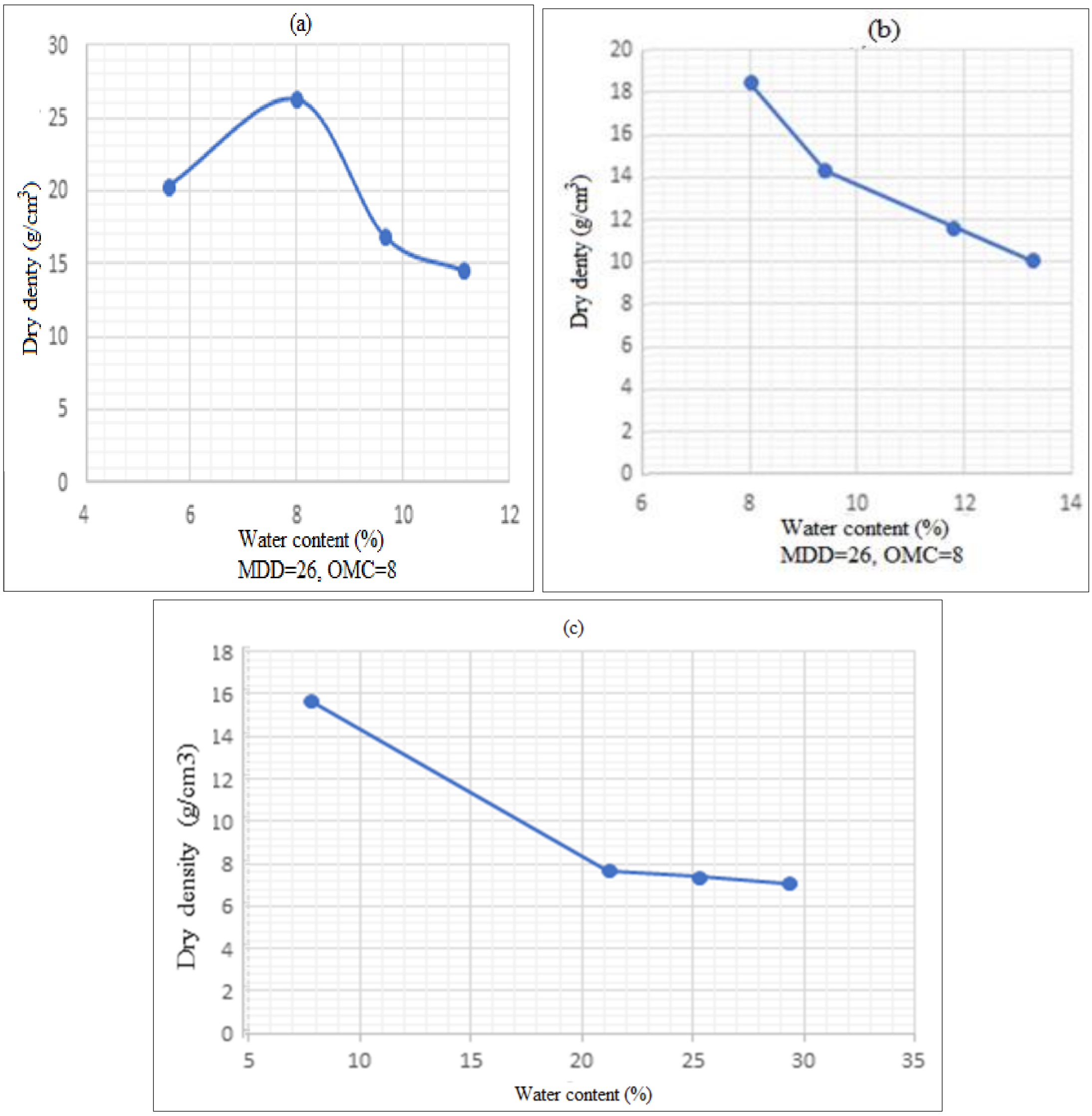

Figure 9 Maximum dry density and optimum water content (a): at 0% fiber content, (b) at 1% fiber content (c) at 2% fiber content

The compaction tests were performed to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for the soil sample. The result of the compaction of the soil with zero percent fiber (reference sample) and with varying proportion of fiber from 1%, 2% and 3% are shown on Tables 11, 12 and 13 of the appendix and the curves are presented on Figure 9. The percentage of the moisture content of the soil which is corresponding to the maximum dry density is reported as the optimum moisture content; The optimum moisture content of the soil is the water content at which the soil can be compacted to the maximum dense state. From figure 9, the maximum dry density (MDD) and the optimum water content (OMC) of the soil used in this study are 26 g/cm³ and 8 % respectively, without the inclusion of OPMF.

We observed that, as the fiber content increases, the MDD reduces, the highest MDD with inclusion of fiber is achieve at a lower water content. The highest OMC with or without fiber remain the same which is 8%. The relationship between the fiber content and maximum dry density is summarized on figure 10. From the figures it can be observed that the MDD decreases with increasing percentage of oil palm mesocarp fiber (OPMF). The MDD reduced from 20.28g/cm³ to 12.53 g/c³ as the OPMF increased from 1%–4%. The trend for the soils suggests that higher inclusion of the OPMF will lead to a much higher reduction in MDD. The MDDs decreased linearly with increase in OPMF.

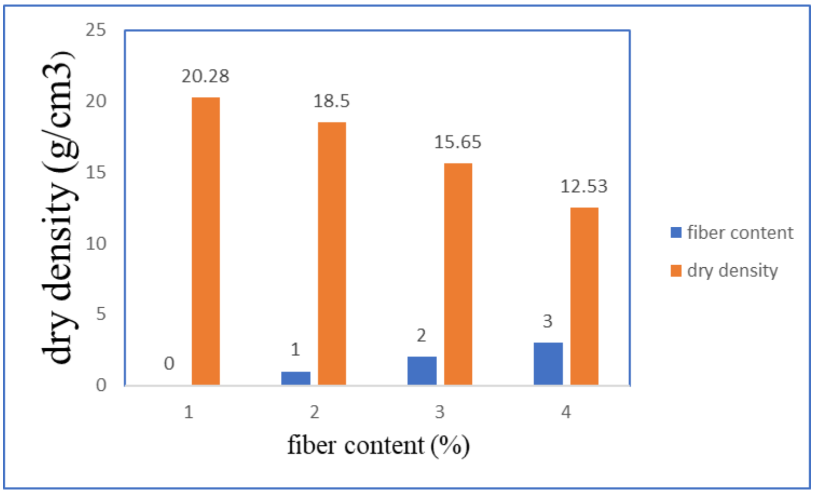

Figure 10 Maximum dry density and fiber content

3.6. Swelling potential

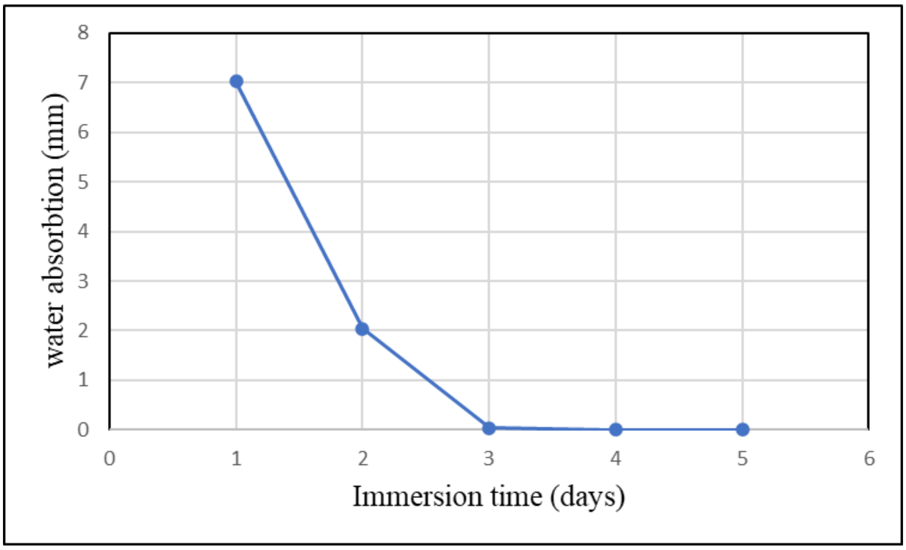

Figure 11 Water absorption of the compacted soil at 2% fiber content. As one can see the compacted sample with 2% fiber content when soaked in water absorbed water during the first two days and was saturated.

The expansion ratio of the compacted sample is carried out after 96 hours of soaking. It is calculated as follows:

Expansion ratio = $\frac{df-ds}{h} \times 100$ (7)

Where: df: final dial gauge reading in mm; ds: initial dial gauge reading in mm; h: initial height of specimen in mm. Expansion ratio = $\frac{9.08}{150} \times 100 = 6.05\%$

3.7. Effect of OPMF on California Bearing Ratio (CBR)

For Railway Formation purpose, the test was performed on remoulded specimens which were compacted dynamically. The methodology covers the laboratory method for the determination of C.B.R. of remoulded /compacted soil specimens in soaked state. Table 8 gives the loads recorded for different penetrations for the compacted, soaked specimen. The data allowed us to plot the CBR curve as seen on figure 12. The corrected CBR is drawn in red ink.

Table 8 Data sheet for CBR test

Soaking				
IS :2720 (Part 16) - Heavy compaction			Duration of immersion	4 days
Date of test	04 /04/2023	Water content after soaking		14.05%
Material description	Clay soil		Swelling (mm)	
Maximum dry density (g/cm³)	20.33		day 1	7.01
Optimum moisture content (%)	8		Day 2	2.04
CBR mould density (g/cm³)	3.49		day 3	0.03
			day 4	00

Table 9 Penetration test data

Penetration (mm)	0	0.5	1	1.5	2	2.5	4	5	7.5	10	12.5
Load (N)	2	14	28	60	91	144	284	337	440	510	562
Load from graph						210		360			

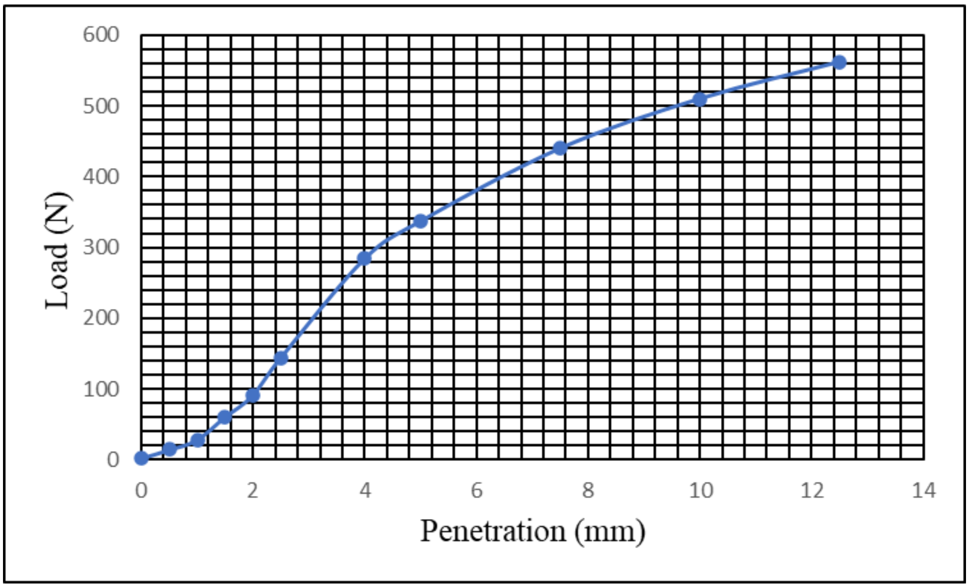

Figure 12 Load as a function of penetration for CBR test.

The C.B.R. of specimen at 2.5 mm penetration = $\frac{210}{1370\ x\ 9.81} \times\ 100 = 1.7$; while The C.B.R. of specimen at 5.0 mm penetration is CBR= $\frac{360}{2055\ x\ 9.81}\ \times\ 100 = 1.8$.

The minimum requirements for 48 hours soaking by the Federal ministry of works and housing (FMWH) specification for different layers of a road pavement are listed in table 3-13.

CBR = max (CBR at 2.5mm: CBR at 5mm)= `1.8%.

According to the Federal ministry of works and housing, the minimum value for CBR for subgrade in highway pavement is 5% .

Our CBR = 1.8% < 5%. Thus, the use of fiber as a reinforcement material for road subgrade is totally discouraged.

4. Conclusion

At the end of this research work, which the theme is, "effects of oil palm mesocarp fibers on the physical and mechanical properties of expansive soils". The analysis and interpretations of the results on the stabilization of expansive soils with OPMF, we have highlighted some observations, recommendations and perspectives on the different materials used. As part of this work, we have focused our thinking on the reinforcement of building materials (expansive soils) with OPMF, the objective was to study the influence of this fiber on California bearing ratio of expansive soil.

To achieve this, we first of all proceeded with the general introduction. Secondly, we talked about a literature review in order to give a general view of expansive soil, the description of natural fibers and the procedure to obtain the oil palm natural fibers from the palm tree. Expansive soils are weak soils, this is why recent studies tend to add fibers to it to make it more resistant and then we presented the various previous works on the use of natural fibers in the reinforcement of soft soil. Thirdly, we made analyses and interpretation of the results of the laboratory experiments. These experimental methods range from the treatment of materials, to the washing of the fibers, to the techniques of characterizing the soil grains size analyses, Atterberg's limits and specific gravity), to the compaction of the soil (modified proctor), and finally testing the compacted soil (swelling potential and penetration test). The penetration test enabled us to determine the bearing capacity of the soil (CBR). Furthermore, we did a general conclusion.

In the course of our study, the result of the water content shows that the natural water content of the soil is 21.6%. Also, the result of the sieve analysis proved that the soil is a poorly graded soil with up to 75% of finer ranging from 0.008-0.50mm in diameter and 20% range from 1.00-2.5mm grains. From the Atterberg's limit, we concluded that the soil is a medium plastic soil with liquid limit of 44%, plastic limit of 29,15% and plasticity index of 14.85%. Moreover, we studied the relative density of the soil which was 2.86 and this proved to us that the soil belongs to the clay and silty clay class of soil.

On the other hand, we carried out a compaction test on soil sample without fiber and samples mixed with the fiber. The result shows that the MDD was 20.28g/cm^3 for reference sample with 0% fibers and 18.5g/cm^3, 15.65g/cm^3, 12.53g/cm^3 for samples with inclusion of 1%, 2% and 3% respectively. Thus, the MDD reduces as the fiber content increases. In addition to that, the MDD is achieve at the OMC of 8%. Next on our study was the swelling potential and penetration test. The sample with 2% fiber content and OMC of 8% was tested for swelling and penetration. The result showed that the sample absorbed 6.05% of water within two days of soaking in water and became saturated. The penetration test was to enable us calculate the bearing capacity of the soil (CBR). From the result, the CBR is 1.8 after 4 days of soaking. According to the Federal ministry of works and housing, the minimum value for CBR for subgrade in highway pavement is 5%. (FMWH, 1997). Our CBR = 1.8% < 5%; therefore, the use of OPMF as a reinforcement of expansive soil for road subgrade is highly discourage.

It is recommended that application of OPMF as road material reinforcement should be confirmed after evaluation of its performance after chemical treatment. It can also be burnt to ash and be used as a pozzolanic stabilizing material.

Notwithstanding, the fiber soil has a better strength/density ratio and can be used for fiber cement mortar as studied by Bopda Fokam et al., 2021. Furthermore, it can be used as fiber earth blocks for nonloadbearing wall since it allows a lightening of the structure,

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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Appendix

Table 10 Particle size distribution of soil For 2000g of soil

Sieve sizes (mm)	Retained particles (g)	Cummulative retain		Cummulative % passin
		By weight	Percentage (%)	
2.5	0.25	0.25	0.0125	99.88
1.6	46.18	46.43	2.32	97.68
1.25	52.35	98.78	4.91	95.09
1	27.61	126.39	6.33	93.67
0.63	136.14	262.53	13.13	86.87
0.35	450.22	712.75	35.64	63.36
0.16	674.6	1387.35	69.37	30.63
0.1	533.3	1920.65	96.03	3.97
0.008	79.35	2000	100	0

Table 11 Modified proctor test at 0% fiber

NATURE	**Natural soil 0% fibe**		**Volume of mold: 2650.7cm3**		
No	symbol	1	2	3	4
% of water		5	10	15	20
mass of water added (g)		250	500	750	1000
Totala humid weight (g)	Pth	13780	14040	13950	13860
weight of mold (g)	Pth	9190	9190	9190	9190
weight of wet soil (g)	Ph= Pth-Pt	4590	4850	4760	4670
wet density (g/cm3)	ϒh=Ph/V	1.732	1.83	1.796	1.762
dry density (g/cm3)	ϒd = ϒh/1+w	20.33	26.28	16.9	14.5
Water content					
weight of can (g)	Pt	50.3	39.5	42	42
weight of can + wet soil (g)	Pth	241.2	262.3	277.5	273.7
weight of can + dry soil (g)	Pts	231.1	245.8	256.8	250.5
weight of water (g)	Pw=Pth-Pts	10.1	16.5	20.7	23.2
weight of dry soil (g)	Ps=Pts-Pt	180.8	206.3	214.8	208.5
water content (%)	w=Pw/Ps	5.59	8	9.64	11.13

Table 12 Modified proctor test at 1% fiber content

NATURE	**Natural soil 1% fibe**		**Volume of mold: 2650.7cm3**		
No	symbol	1	2	3	4
% of water		5	10	15	20
mass of water added (g)		22	44	66	88
Totala humid weight (g)	Pth	12.93	13.14	13.03	13.14
weight of mold (g)	Pt	9190	9190	9190	9190
weight of wet soil (g)	Ph= Pth-Pt	3.74	3.95	3.82	3.95
wet density (g/cm3)	Ɣh=Ph/V	1.41	1.49	1.44	1.49
dry density (g/cm3)	Ɣd = Ɣh/1+w	18.5	14.33	10.1	11.64
Water content					
weight of can (g)	Pt	30.99	32.53	29.49	32.53
weight of can + wet soil (g)	Pth	91.47	68.36	61.17	77.63
weight of can + dry soil (g)	Pts	86.74	65.27	57.46	72.67
weight of water (g)	Pw=Pth-Pts	4.73	3.09	3.71	4.96
weight of dry soil (g)	Ps=Pts-Pt	55.75	32.74	27.97	42.14
water content (%)	w=Pw/Ps	8	9.4	13.26	11.8

Table 13 Modified proctor test at 2% fiber content

NATURE	**Natural soil with 1% fiber content**		**Volume of mold: 2650.7cm3**		
No	symbol	1	2	3	4
% of water		5	10	15	20
mass of water added (g)		22	44	66	88
Totala humid weight (g)	Pth	12.93	13.14	13.03	13.14
weight of mold (g)	Pt	9190	9190	9190	9190
weight of wet soil (g)	Ph= Pth-Pt	3.74	3.95	3.82	3.95
wet density (g/cm3)	Ɣh=Ph/V	1.41	1.49	1.44	1.49
dry density (g/cm3)	Ɣd = Ɣh/1+w	18.5	14.33	10.1	11.64
Water content					
weight of can (g)	Pt	30.99	32.53	29.49	32.53
weight of can + wet soil (g)	Pth	91.47	68.36	61.17	77.63
weight of can + dry soil (g)	Pts	86.74	65.27	57.46	72.67
weight of water (g)	Pw=Pth-Pts	4.73	3.09	3.71	4.96
weight of dry soil (g)	Ps=Pts-Pt	55.75	32.74	27.97	42.14
water content (%)	w=Pw/Ps	8	9.4	13.26	11.8