FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 8 No. 6, December, 2024, pp 24 - 35
DOI: https://doi.org/10.33003/fjs-2024-0806-2679

STRENGTH PROPERTIES OF CEMENT STABILIZED CLAY SOIL WITH EPS FOOD PACK WASTE

*[1]Auwal Dauda and [2]Yunusa, G. H.

[1]Civil Engineering Department, Faculty of Engineering and Environmental Design, Usmanu Danfodio University, Sokoto, Nigeria.
[2]Civil Engineering Department, Faculty of Engineering, Bayero University Kano, Nigeria.

*Corresponding authors' email: auwal.dauda@udusok.edu.ng

ABSTRACT

The purpose of this study is to investigate the impact of EPS on geotechnical properties of soil through laboratory test and ANOVA analysis. These tests have been conducted on natural and stabilized soils in accordance with procedure outlined in BS1377 (1990). Four fibre contents (0.25%, 0.5%, 0.75%, and 1%) of the dry soil weight and three fibre size (random size, 20 mm x 2mm size and 20 mm x 5 mm) were used. The tests conducted included particle distribution, specific gravity, Atterberg limits, the standard compaction, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS). The laboratory result classifies the soil as A-7-6 (17) according to American Association of States Highway and Transport Officials (AASHTO) classification system and Clay soil of Low plasticity (CL) in accordance with the Unified Soil Classification System (USCS). The Specific gravity decreases from 2.7 to 2.1. MDD results also shows a decrease with increase of EPS waste fibre from 1.46Mg/m^3 to 1.32Mg/m^3 for British Light compaction and from 1.61Mg/m^3 to 1.47Mg/m^3 for British Heavy. The CBR result shows an improvement from 5.33% to a maximum value of 10.5% at 1% EPS waste fibre for unsoaked CBR and from 2.86% to a maximum of 7.73% at 0.5% EPS waste fibre for soaked CBR. The UCS result shows an improvement at 28 days from 2410 kN/m^2 of Natural soil to a maximum of 5593kN/m^2 at 0.5% EPS waste fibre. Based on the laboratory experimental result it was suggested that the EPS waste fibre of 0.5% dosage can be used as a reinforcing material for soil stabilization.
Keywords: Cement, expanded polystyrene food pack waste, clay soil, Califonia bearing ratio, unconfined compressive strength.

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INTRODUCTION

The industrial scale production of plastics since the 1940s has transformed our everyday life (Al-Salem et al., 2009). Given the versatile properties of plastics, such as it being inexpensive, lightweight, durable and strong, the production and usage of plastics has increased sharply ever since 1950 (Thompson et al., 2009).

For years, polystyrene has been used for many applications. Some common applications include using polystyrene to make containers, cups, dining utensils and toys among other things. Another common application is the use of expandable polystyrene to create loose-fill packing, also commonly known as Polystyrene peanuts to protect numerous items (Odian, 2004).

Disposal of waste materials continues to be a predominant issue for most countries in the world including Nigeria. The accumulation of these waste materials in huge quantities is causing both environment and financial problems. According to (Awuchi, 2019), the average plastic waste generation is estimated at 15.4 billion pieces per day. The most prevalent waste materials are plastic waste materials. However Plastics waste materials, are generating environmental and health problems considerably. One disadvantage is that plastic production relies heavily on the use of finite resources—fossil fuels. With the increasing demand of plastics around the world, huge amount of finite energy resources will be used up rapidly in current linear consumption of fossil fuels, "from oil to waste via plastics". Another crucial problem comes from the end-of–life phase of plastic materials. A wide accumulation of plastic wastes in the natural environment and in landfills affects the natural terrestrial, freshwater and marine habitats, with daily record of plastic debris on even some of the highest mountains (Thompson et al., 2009). Since the majority of plastics are not biodegradable and can sustain for many years, many countries are planning to decrease or prevent the effect of plastic materials through efficient recycling and reusing these materials in a wide range of fields. Many researchers have carried out studies to find effective methods to reduce the pollution caused by these materials including recycling and reusing these materials in civil engineering applications as a solution to preserve the environment from the pollution of plastic waste materials. An effective method to utilise these materials is to be used as a soil stabiliser for road construction (Tatone et al., 2018). Traditional soil stabilisers such as cement and lime are widely used for improving the geotechnical properties of weak soils ((Sherwood, 1993); (Yadav et al., 2018) and (Yadav & Tiwari, 2016). The effective-ness of these materials on improving the properties of soils is confirmed by various researchers ((Bell, 1996); (Little, 1995); (Rout et al., 2012); (J. Rasul et al., 2015); (J. Rasul et al., 2016); (Yadav & Tiwari, 2017); (J. M. Rasul et al., 2018). However, the high usage of these materials makes them non-cost-effective (Obo & Ytom, 2014). Therefore, many researchers attempt to find alternative cost-effective soil stabilisers such as plastic, tyre chips, and rice husk.

Using plastic wastes for soil stabilisation can improve the foundation layers of pavement (Khattab et al., 2011). Thus, this can solve the problem of wastes by reducing the quantities and recycling these materials for enhancing the properties of soils. One method of using plastic for soil stabilisation is to use the plastic in the form of discrete fibres (Yetimoglu & Salbas, 2003a), because when plastic materials are merged with soils, they behave similar to fibre-reinforced soil. Several researches have been conducted to investigate the effectiveness of plastic waste materials in the form of discrete fibres on properties of soils ((Ziegler et al., 1998); (Babu & Chouksey, 2011); (Mondal, 2012); (Ahmadinia et al., 2012); (Modarres & Hamedi, 2014); (Fauzi et al., 2015); (Changizi & Haddad, 2015); (Neopaney et al., 2012; Rawat & Kumar, 2016); (Peddaiah et al., 2018); (Salimi & Ghzavi, 2019). These researchers found that using plastic waste materials for soil stabilisation will improve the properties of weak soils such as an increase in Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), and Resilience Modulus and a decrease in the soil plasticity.

Most of those researches Uses a plastic waste from polyethylene, polypropylene, polyvinyl chloride, and polytetrafluoro-ethylene (PTFE) types of thermoplastics however not much has been done using polystyrene.

The plastic wastes emanating from poorly disposed Food Pack, a product of Expanded Polystyrene (EPS) which belongs to thermoplastic type of plastic, used in packaging food in Nigeria, are found as litters on streets, roads and highways in major cities of Nigeria due to the inability of EPS to biodegrade. This unfortunate situation is compounded by several factors including the poor attitude of the average Nigerian towards waste disposal. It is common place to find this waste are beaches, rivers, gutters and roadsides which are choked and filled with disposable food pack. The need for efficient solid waste management by alternative recycling and reusing regimes to curb this trend cannot be over-emphasized. Using plastic waste for soil stabilization have been researched and reported by different researchers. However not much have been done using expanded polystyrene disposable food pack.

The aim of this study is to investigate the effect of using disposable food pack made of expanded polystyrene as fibre-shaped material on Geotechnical properties of soils, through laboratory test, statistical analysis and numerical modelling.

MATERIALS AND METHODS

Materials

Natural Soil Sample

A disturbed clay soil sample was collected from a hand dug barrow pits located within the Usman Dan Fodio University, Main Campus, Sokoto State, Nigeria with latitude 13.1283700 and longitude 5.2108500. The sample was collected immediately after the top soil is being removed that is at a depth between 0.5m to 1.0m.

Expanded Polystyrene (EPS) recycled waste disposable food pack

The EPS recycled waste collected from dump sites was washed, dried and shredded using blinder, paper shredding machine and pair scissors to obtain the polystyrene fibres of random size (ranging from 2mm to 35mm), 20mm x 2mm and 20mm x 5mm sizes for the laboratory test. The EPS fibre was varied at 0%, 0.25%, 0.5%, 0.75% and 1.0% of the soil sample (recommended by (Igba et al., 2020) when he made Investigation on the Use of Expanded Polystyrene beads as a Partial Replacement of Fine Aggregate in Concrete) to study its behaviour in clay soil.

Cement

Portland Limestone Cement (PLC) CEM II/A.L 42.5N (BUA Sokoto Cement) used for the study was purchased from an Open market at Sokoto. Cement was added in a constant measure of 5% of the soil sample. This dosage was derived from the initial cement consumption test of clay proposed by (Minegishi et al. 2002).

Methods

Sample preparation

The samples were prepared by measuring the soil sample by weight and a substitution of the soil with 5% cement by weight of the soil and a varying percentage (0.25%, 0.50%, 0.75% and 1.00%) of random EPS fibre, 20mm x 2mm, and 20mm x 5mm EPS fibres by weight of the soil. The cement was added to the soil and mix thoroughly followed by the measured EPS fibre was then added and mix thoroughly.

Moisture Content

Water is present in most naturally occurring soils. The amount of water, expressed as a proportion by mass of the dry solid particles, known as the moisture content, has a profound effect on soil behaviour. In this context a soil is "dry" when no further water can be removed at a temperature not exceeding 110 °C. Moisture content is required as a guide to classification of natural soils and as a control criterion in recompacted soils and is measured on samples used for most field and laboratory tests. The oven-drying method is the definitive procedure used in standard laboratory practice therefore used also in this research. The (BS, 1990) Part 2;3.2 procedure was adopted. The following expression was used for moisture content computations.

$$w = \left(\frac{m_2 - m_3}{m_3 - m_1}\right) 100\% \qquad (1)$$

w = Moisture content (%)
m1 = weight of empty container (g)
m2 = weight of container+ wet soil (g)
m3 = weight of container dry soil (g)

Specific Gravity

The knowledge of particle density is important in analysis of particle distribution (sedimentation by Hydrometer) and calculation of soil properties like void ratio, degree of saturation. The procedures given in the BS1377: Part 2; 8.4 (Method of Large pycnometer) was used for the natural and the treated soil samples. To obtain a more accurate result two density bottles were used and their average taken.

The particle density was computed using equation 2.

$$G_S = \frac{m_2 + m_1}{(m_4 - m_1) - (m_3 - m_2)} \qquad (2)$$

Gs = Specific gravity
m1 = mass of empty density bottle (g)
m2 = mass of density bottle + dry soil (g)
m3 = mass of density bottle + soil + water (g)
m4 = mass of density bottle filled with water (g)

Particle size distribution

Combined sieving and sedimentation procedures were implemented to enable a continuous particle size distribution curve of a soil to be plotted from the size of the coarsest particles down to the clay size.

This method covers the quantitative determination of the particle size distribution in an essentially cohesionless soil, down to the fine sand size. The combined silt and clay fraction can be obtained by difference. The procedure given involves preparation of the sample by wet sieving to remove silt and clay-sized particles according to BS1377: Part 2; 9.2, followed by dry sieving of the remaining coarser material in accordance with BS1377: Part 2; 9.3. The soil does not contain particles retained on a 2 mm test sieve in significant quantity, the method specified in BS1377: part 2; 9.5 (sedimentation by Hydrometer) was used. This method covers the quantitative determination of the particle size distribution in a soil from the coarse sand size to the clay size. The analysis of data from the hydrometer tests requires that the particle density of the soil specimen is known, therefore the result from the specific gravity test of the natural soil sample was used.

Atterberg Limits

Atterberg limits tests include the determination of the liquid limit, plastic limit and the plasticity index for the natural soil. They were also conducted in accordance with BS 1377 (1990), Part 2;4,5,6.

Liquid Limits

The liquid limit is the empirically established moisture content at which a soil passes from the liquid state to the plastic state. It provides a means of classifying a soil, especially when the plastic limit is also known. Cone penetrometer method BS 1377 (1990), part 2; 4.3 was adopted. This method covers the determination of the liquid limit of a sample of soil from which material retained on a 425 µm test sieve has been removed. The cone penetrometer is preferred to that employing the Casagrande apparatus, as the test is both easier to carry out and is capable of giving more reproducible results. The cone penetrometer apparatus is easier to maintain in correct adjustment and the test procedure is less dependent on the judgement of the operator. The results obtained with the cone penetrometer may differ slightly from those with the Casagrande apparatus, but in most cases up to a liquid limit of 100 these differences will not be significant and will be less than the normal variations likely to be obtained using the Casagrande apparatus.

Plastic Limits

The plastic limit is the empirically established moisture content at which a soil becomes too dry to be plastic. It is used together with the liquid limit to determine the plasticity index which when plotted against the liquid limit on the plasticity chart provides a means of classifying cohesive soils. It is recognized that the results are subject to the judgement of the operator, and that some variability in results will occur. This method covers the determination of the plastic limit of a soil sample, i.e the lowest moisture content at which the soil is plastic. The sample shall be of soil in which material retained on a 425 µm test sieve has been removed.

Plasticity Index

This method covers the determination of the plasticity index and the liquidity index of a soil. The moisture content, wa, of the fraction passing a 425 µm test sieve of the sample of soil in its natural condition was determined by one of the procedures specified in clause 3 of the BS 1377 (1990), part 2. The liquid limit, wL, by one of the procedures specified in clause 4, and the plastic limit, wp, by the procedure specified in clause 5.3 of the BS 1377 (1990), part 2.

The plasticity of the soil is calculated using the following equations,

for the natural soil sample

$$PI = w_l - w_p \qquad (3)$$

Compaction Test

Compaction of soil is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the soil. The dry density which can be achieved depends on the degree of compaction applied and on the amount of water present in the soil. For a given degree of compaction of a given cohesive soil there is an optimum moisture content at which the dry density obtained reaches a maximum value.

The objective of the tests is to obtain relationships between compacted dry density and soil moisture content, using two magnitudes of manual compactive effort (the British Light compactive effort and the British Heavy compactive effort).

The samples were prepared using a starting moisture of 8% inclusive of the natural moisture within the soil sample after open drying and an increment of 2% moisture. The clay sample lumps are susceptible to crushing during compaction therefore the sample was prepared and compaction was carried out in accordance with clause 3.2.6 and 3.3.2 of the BS 1377 (1990), part 4 respectively.

The Moisture content was obtained using the equation 1. The bulk Densities and dry densities were obtained from the equation 4 and 5 respectively. The moisture content and the dry densities were plotted, their Optimum were determined as the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC).

$$Bulk\ density\ \rho = \frac{m_2 - m_1}{V}\ (in\ Mg/m^3\ ) \qquad (4)$$

$$dry\ density\ \rho_d = \frac{100\rho}{100 + w}\ (in\ Mg/m^3\ ) \qquad (5)$$

Where,

m1 is the mass of mould and baseplate (in g)

m2 is the mass of mould, baseplate and compacted soil (in g)

V is the internal volume of the mould (in cm3)

w is the moisture content (in %)

California Bearing Ratio (CBR) Test

This method covers the laboratory determination of the California Bearing Ration (CBR) of a compacted sample of soil and treated. The principle is to determine the relationship between force and penetration when a cylindrical plunger of a standard cross-sectional area is made to penetrate the soil at a given rate. At certain values of penetration, the ratio of the applied force to a standard force, expressed as a percentage, is defined as the California Bearing Ratio (CBR).

The samples were prepared using the maximum dry densities and optimum moisture content determined from the compaction test. The samples for unsoaked and soaked CBR were prepared according to clause 7.2 and 7.3 of the BS1377 (1990) part 4 respectively. The penetration was carried out in accordance with clause 7.4 while calculations and plotting in accordance with clause 7.5 of the BS1377 (1990) part 4.

Unconfined Compressive Strength (UCS) Test

In the unconfined compression test a cylindrical specimen of cohesive soil is subjected to a steadily increasing axial compression until failure occurs. The axial force is the only force applied to the specimen. The test is normally carried out on 38 mm diameter specimens. The test provides an immediate approximate value of the compressive strength of the soil in the undisturbed and the remoulded condition, it is carried out within a short enough time to ensure that no drainage of water is permitted into or out of the specimen. It is suitable only for saturated, non-fissured cohesive soils.

The natural sample and the treated soil sample were compacted with their corresponding OMC. The samples were extruded with sample extruder and trimmed to 76.1mm and cured for 7, 14, 28 days. The test was conducted for 0 day and elapsed curing days. The tests were conducted on tri axial load frame (tritest 50) at penetration speed of 0.2mm/min. The test was terminated when maximum compressive stress has been passed, or in the event of plastic failure which does not exhibit a maximum strength, until a strain of 20 % has been reached. The test was conducted in accordance with clause 7.2 of the BS1377 (1990) part 7.

Statistical Analysis

In this research two method of analysis adopted are

i. Graphical Method

ii. Two-way Analysis of variance (Anova) without replication

Graphical method

In this method graphs were used to show the relationship between two quantities. An independent variable usually plotted on the X - axis and a dependent variable on the Y-axis. The graphs were plotted using the Microsoft excel package.

Two-way Analysis of variance (Anova) without replication

In this method, the results of the test carried out on the natural and treated soil sample were tabulated and analysed based on the two - way analysis of variance (ANOVA) without replication. The aim of the analysis was to find out if there were any significant effects on the various soil – cement – EPS mixtures and also the size of the EPS waste particles.

RESULTS AND DISCUSSION

Index and Engineering Properties of the Soil

The result of index and engineering properties of the natural soil is tabulated in table 1

Table 1: Summary of index properties of Natural Soil sample

Property	Quantity
Natural moisture content, %	33.3
Specific gravity, %	2.72
Liquid limit, %	41.5
Plastic limit, %	20.5
Plasticity index, %	21
Linear shrinkage, %	14.5
% Passing sieve No. 200	82.3
AASHTO classification	A-7-6 (17)
USCS classification	CL
UCS, kN/m^2	230
California Bearing Ratio %	
Soaked	2.86
Unsoaked	5.33
Optimum moisture content, %	
BSL	13
BSH	15
Maximum dry density, Mg/m^3	
BSL	1.46
BSH	1.61
Colour	Greenish Gray
Dominant clay Mineral	Illite
General rating as Sub Grade	Poor

Effect of EPS Fibre on Cement Stabilized Clay

Compaction Test

Maximum Dry Density

The British Light MDD result of variation of EPS fibre with Soil-Cement mixture is represented graphically in figure 2, The maximum value of 1.46 of the MDD recorded for the natural soil sample and decreases with increase of the EPS fibre to a least value of 1.32 MDD. Also, there is a significant increase of MDD with increase of EPS fibre size.

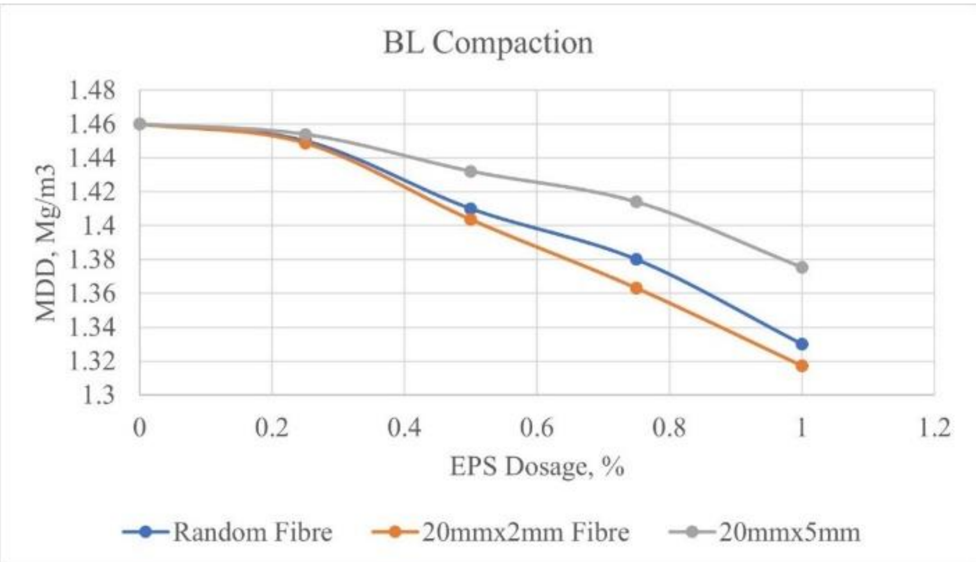

Figure 1: British Light MDD result of Variation of EPS fibre with soil – Cement mixture

The British Light MDD result of variation of soil - cement mixed with EPS fibre was analysed using the Analysis of variance (ANOVA) (see appendix table 2). The result of the analysis indicates that both the EPS fibre dosage and size are statistically significant (F=38.72078 > Fcrit=3.837853), (F=5.930419 > Fcrit=4.45897) respectively.

The British Heavy MDD result of variation of EPS fibre with Soil-Cement mixture is represented graphically in figure 2, The maximum value of 1.61 of the MDD recorded for the natural soil sample and decreases with increase of the EPS fibre to a least value of 1.47 MDD. Also, there is a significant increase of MDD with increase of EPS fibre size.

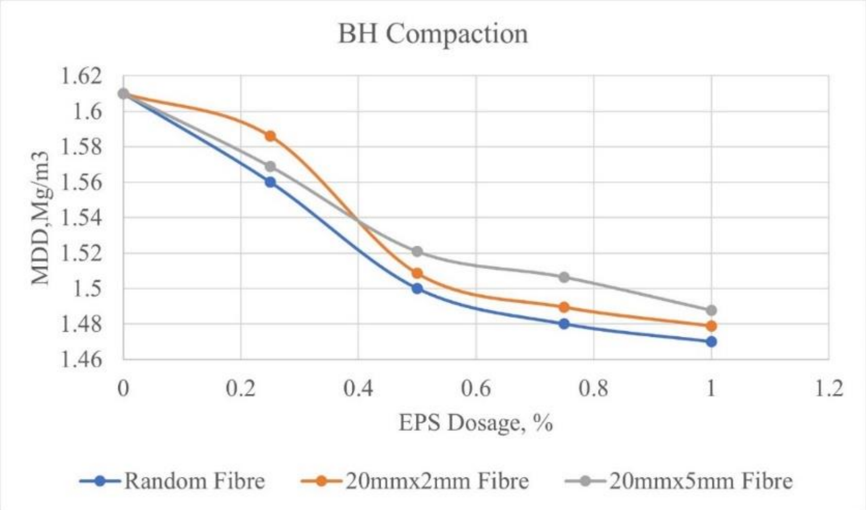

Figure 2: British Heavy MDD result of Variation of EPS fibre with soil – Cement mixture

The British heavy compaction results of variation of soil - cement mixed with EPS fibre was analysed using the Analysis of variance (ANOVA) (see appendix table 2). The result of the analysis indicates that both the EPS fibre dosage and size are statistically significant (F=149.7895 > Fcrit=3.837853), (F=4.567178 > Fcrit=4.45897) respectively. But the EPS fibre size is less statistically significant having a P-value very close to the alpha value of 0.05.

There is a general decrease of MDD for both compaction effort, The reduction is attributed to the EPS particles, of lower density, occupying the space that would have been occupied by the clay particles. Owing to the low volume mass ratio of EPS, the treated samples reduce in the MDD (Illuri & H.K, 2007) and (Mugera et al., 2019).

Decrease in dry density indicates that it needs low compative energy than the natural soil, to attain its maximum dry density as a result the cost of compaction will be economical (Muntohar & Hantoro, 2000). The decreased density of soil has an engineering application in light weight embankment construction (Kassa et al., 2020).

Optimum Moisture Content (OMC)

The British Light OMC result of variation of EPS fibre with Soil-Cement mixture is represented graphically in figure 3.

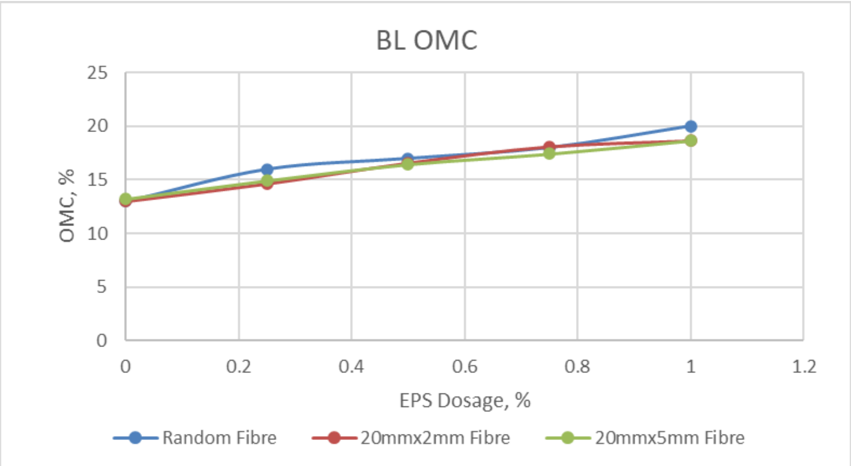

Figure 3: British Light OMC result of Variation of EPS fibre with soil – Cement mixture

The British Light OMC result of variation of soil - cement mixed with EPS fibre was analysed using the Analysis of variance (ANOVA) (see appendix table 4). The result of the analysis indicates that the EPS fibre dosage has statistically significant effect (F=96.44893 > Fcrit=3.837853), and EPS fibre size has no statistically significant effect (F=3.932809 < Fcrit=4.45897).

The British heavy OMC result of variation of EPS fibre with Soil-Cement mixture is represented graphically in figure 5, The maximum value of 15.08 % of the OMC recorded for the 0.5% dosage of 20mm x 2mm fibre - soil sample. Generally, there is no significant effect on OMC as the EPS dosage and Size increases. All the values recorded for the OMC using British heavy can be rounded to 15% in a whole number.

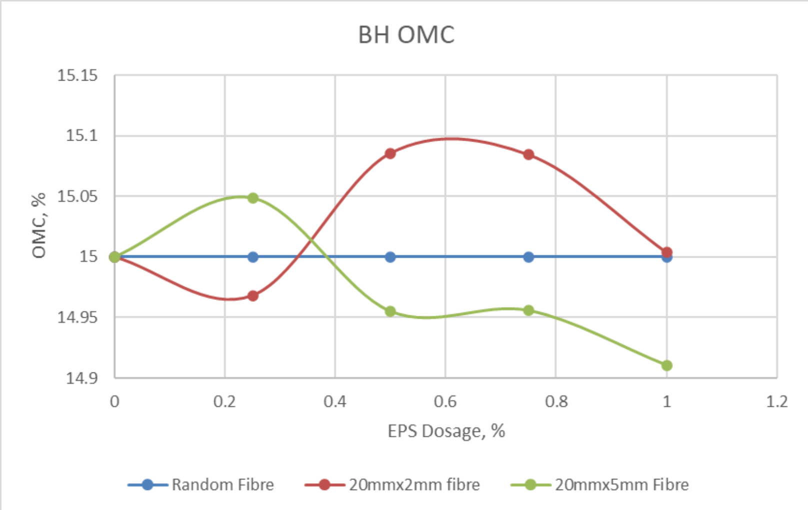

Figure 4: British Light OMC result of Variation of EPS fibre with soil – Cement mixture

The British Heavy OMC result of variation of soil - cement mixed with EPS fibre was analysed using the Analysis of variance (ANOVA) (see appendix table 5). The result of the analysis indicates that both the EPS fibre dosage and size has no statistically significant effect (F=0.385539 < Fcrit=3.837853), (F=1.562201 < Fcrit=4.45897) respectively. The minimum value of 13% of the OMC recorded for the natural soil sample and increases with increase of the EPS fibre to a value of 20% OMC using the British light compactive effort. This is due to the water absorbed in the air voids of the EPS. This indicates the need for British heavy compaction effort.

Generally, there is no significant effect on OMC using the British heavy compaction effort as the EPS dosage and Size increases. This might be due to increase in the compaction effort more water is expelled from the EPS voids. Similar result was observed by (Mugera et al., 2019).

California Bearing Ratio (CBR) Test

Unsoaked CBR

The unsoaked CBR result of variation of EPS fibre with Soil-Cement mixture is represented graphically in figure 5, The maximum value of 10.5% unsoaked CBR was recorded for the EPS dosage of 1%. The figure shows a general increase of CBR with increase of EPS dosage. This increase is in agreement with the findings of (Saravanan et al., 2020).

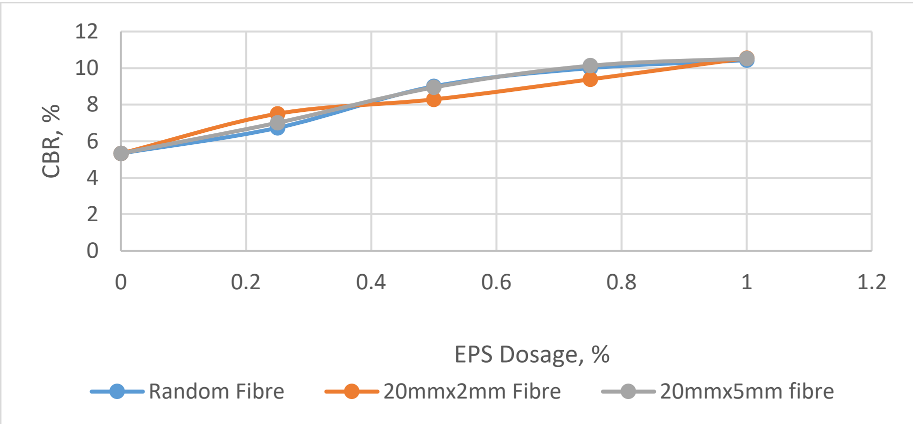

Figure 5: Unsoaked CBR result of Variation of EPS fibre with soil – Cement mixture

The Unsoaked CBR result of variation of soil - cement mixed with EPS fibre was analysed using the Analysis of variance (ANOVA) (see appendix table 6). The result of the analysis indicates that the EPS fibre dosage has statistically significant effect (F=122.7044 > Fcrit=3.837853), and EPS fibre size has no statistically significant effect (F=0.364118 < Fcrit=4.45897).

The increase in the CBR value with the inclusion of EPS fibre is generally due to the soil and fibre physical interactions as it provides resistance to the penetration plunger; and consequently, increases in the CBR value (Neopaney et al., 2012) and (Yetimoglu & Salbas, 2003) also confirmed through this behaviour when they stabilized the soil using polyvinyl plastic waste.

Soaked CBR

The soaked CBR result of variation of EPS fibre with Soil-Cement mixture is represented graphically in figure 6, The maximum value of 7.73% soaked CBR was recorded for the EPS dosage of 0.5% and a fibre dimension of 20mm x 5mm. The figure shows a general increase of CBR with increase of EPS fibre dosage up to 0.5% and decrease with further increase of EPS fibre. This behaviour was also recorded by (Harish & Ashwini, 2016).

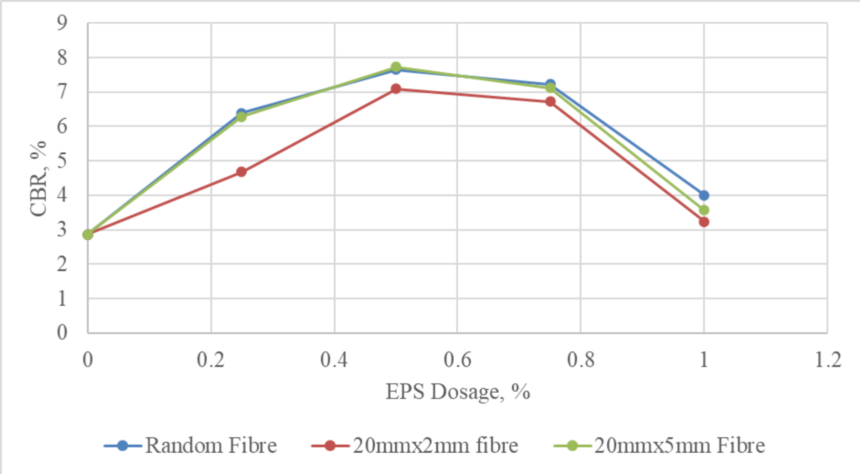

Figure 6: Soaked CBR result of Variation of EPS fibre with soil – Cement mixture

The Soaked CBR result of variation of soil - cement mixed with EPS fibre was analysed using the Analysis of variance (ANOVA) (see appendix table 7). The result of the analysis indicates that the EPS fibre dosage and size both has statistically significant effect (F=93.54289 > Fcrit=3.837853), and (F=5.380669 > Fcrit=4.45897) respectively.

However, CBR values were 7.65%, 7.09% and 7.73% for strip bands of Random fibre, 20mm × 2mm and 20mm ×5mm, respectively, with 0.5% fibre content. Therefore, the optimal value for the California bearing ratio (CBR) was 7.73%, and this was acquired with a fibre content of 0.5% of the strip size of 20mm × 5mm. Nonetheless, there was a sudden drop in the CBR of the soil with higher plastic fibre content greater than 0.5%; it might be because of the loose bonding between plastic strip and soil in submerged situation, and the development of the resistance force between plastic strip and soil might have a minor contribution.

However, the lowest CBR values for both soaked and unsoaked samples were recorded on the natural soil samples and this might be because the natural soil sample contains a higher percentage of fine particles (82.3% passing sieve no. 200).

This increase in CBR values of subgrade soils can have significant impact on required foundation thicknesses, especially for those pavement design methods such as Nigerian Highway Design Manual for Roads and Bridges, in which the thickness of the pavement foundation is depending on the CBR and modulus of elasticity of subgrades. The increase in subgrade CBR and modulus of elasticity reduces the required sub-base thickness considerably and results in the reduction in road pavement construction costs.

Unconfined Compressive Strength (UCS) Test

The UCS result of variation of EPS fibre dosage/sizes with Soil-Cement mixture is represented graphically in figure 7 to figure 10. The graphs of 0-day, 7 days (in figure 7 and figure 8 respectively) shows an increase of UCS with increase of EPS dosage while at 14 days (figure 9) curing, there is increase of UCS to a maximum at 0.75% EPS dosage from where it slightly reduces at 1% EPS dosage and at 28 days curing (figure 10) there is also an increase of UCS to a maximum at 0.5% EPS dosage and slightly reduces at 1% EPS dosage.

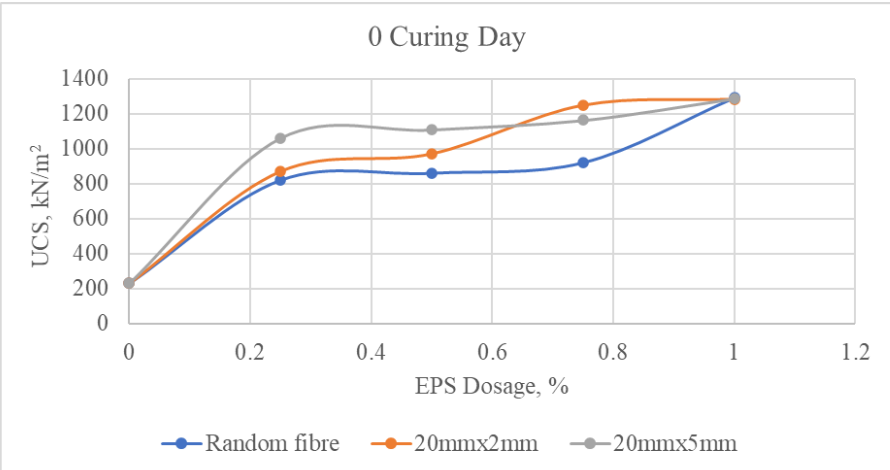

Figure 7: UCS result of variation of EPS fibre dosage with Soil-Cement mixture for 0 curing days

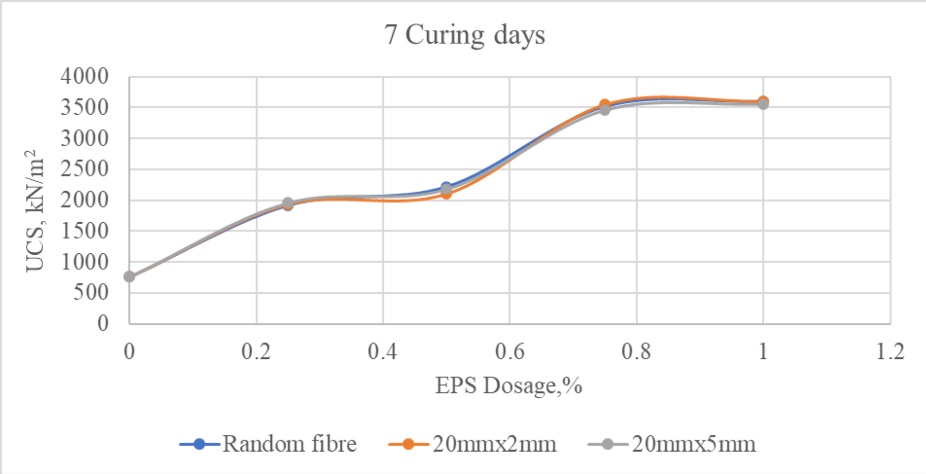

Figure 8: UCS result of variation of EPS fibre dosage with Soil-Cement mixture for 7 curing days

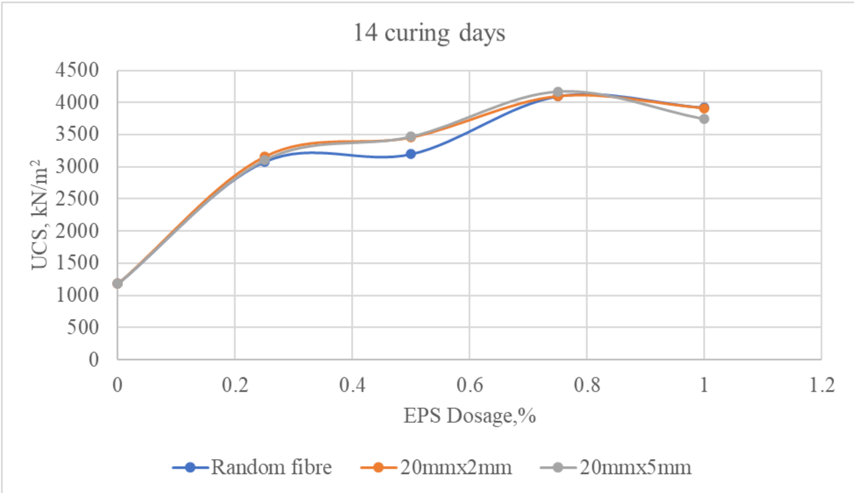

Figure 9: UCS result of variation of EPS fibre dosage with Soil-Cement mixture for 14 curing days

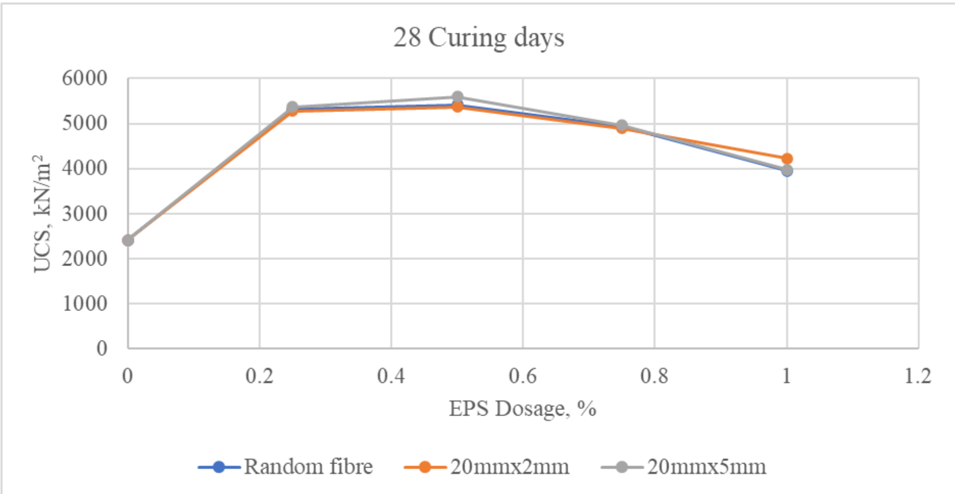

Figure 10: UCS result of variation of EPS fibre dosage with Soil-Cement mixture for 28 curing days

The UCS result of variation of soil - cement mixed with EPS fibre was analysed based on the fibre size using the Analysis of variance (ANOVA) (see appendix table 8). The result of the analysis generally indicates that the EPS fibre dosage has statistically significant effect from 0 to 28 days of curing, while the EPS fibre size has no statistically significant effect for the duration of curing.

The increase in the UCS values (or the gain in strength) was primarily due to the formation of cementitious compounds between the SiO_2 present in the soil and cement which form various compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) and micro fabric changes, which are responsible for strength development. The decrease in the values of the UCS was as a result of excess EPS fibre and OPC that occupied space within the soil to form weak bond between the soil, EPS fibre and cementitious compound formed by reaction which led to insufficient water to bring the pozzolanic reaction to completion (Osinubi, 1999).

The increase in shear strength parameters was as a result of the increase in the density of the EPS in the sample (Padade & Mandal, 2012). The decrease at 0.7 % EPS was as a result of the higher ratio of EPS to binder content at percentages greater than 0.5 % at 28 days curing. This reduces the binding effect hence the particles easily disintegrate under the action of the applied load (Mugera et al., 2019).

CONCLUSIONS

The natural soil is classified as A-7-6 (17) or CL according to AASHTO and USCS classification systems, respectively.

The effect of EPS on the behaviour of the soils

i. There is a general decrease of MDD for British light and British heavy compaction effort for all the fibre sizes. The reduction is attributed to the EPS particles, of lower density, occupying the space that would have been occupied by the clay particles.
ii. EPS food pack waste is effective in increasing the unsoaked CBR from 5.3% to a maximum 10.5% at 1% EPS dosage. Also, for the soaked CBR from 2.9% to a maximum of 8% at 0.5% random fiber EPS dosage. The Fibre size have statistical effect.
iii. The EPS food pack waste fiber inclusion increases the UCS value. For an optimum amount of 0.5% EPS fiber the UCS value of soil has increased from its original value of 230 kN/m^2 to 5590 kN/m^2. Further improvement was observed with curing period. An optimum curing period of 28 days, the UCS value increased in all the fiber sizes.
iv. The maximum recorded CBR, UCS and Stiffness Modulus of 8%, 5.59 Mpa, and 65Mpa respectively, were obtained at 0.5% EPS dosage with 28 days curing which attain the minimum requirement for effective subgrade classes in Road Notes 31 (8% CBR, 500-1500 kN/m^2 UCS and 50Mpa Stiffness Modulus).

RECOMMENDATIONS

i. 0.5% EPS dosage with 5% cement content can be adopted for improvement of embankment soil/ subgrade to achieve CBR, UCS and Modulus of 8%, 5590 kN/m2 and 65Mpa Modulus.
ii. It is also recommended that further research on the use of EPS waste material in soil stabilization to be conducted.
iii. There is a need to find effective utilization of EPS waste materials for cleaner environment.

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APPENDIX
Analysis of variance tables

Table A1: Two - way analysis of variance for specific gravity result of soil – cement mixed with EPS fibre

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Remark*
EPS fibre Dosage	0.568403	4	0.142101	24.42562	0.000154	3.837853	$F > F_{Crit}$ Significant effect
EPS fibre Sizes	0.008496	2	0.004248	0.730175	0.511365	4.45897	$F < F_{Crit}$ No Significant effect

Table A2: Two - way analysis of variance for British Light MDD result of soil – cement mixed with EPS fibre

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*	*Remark*
EPS fibre Dosage	0.028664	4	0.007166	38.72078	2.8E-05	3.837853	$F > F_{Crit}$ Significant effect
EPS fibre Sizes	0.002195	2	0.001098	5.930419	0.026325	4.45897	$F > F_{Crit}$ Significant effect

Table A3: Two - way analysis of variance for British Heavy MDD result of soil – cement mixed with EPS fibre

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Remark*
EPS fibre Dosage	0.037703	4	0.009426	149.7895	1.49E-07	3.837853	$F > F_{Crit}$ Significant effect
EPS fibre Sizes	0.000579	2	0.000289	4.597178	0.046862	4.45897	$F > F_{Crit}$ Significant effect

Table A4: Two - way analysis of variance for British Light OMC result of soil – cement mixed with EPS fibre

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Remark*
EPS fibre Dosage	65.83399	4	16.4585	96.44893	8.38E-07	3.837853	$F > F_{Crit}$ Significant effect
EPS fibre Sizes	1.342226	2	0.671113	3.932809	0.064645	4.45897	$F < F_{Crit}$ No Significant effect

Table A5: Two - way analysis of variance for British Heavy OMC result of soil – cement mixed with EPS fibre

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Remark*
EPS fibre Dosage	0.003628	4	0.000907	0.385539	0.813439	3.837853	$F < F_{Crit}$ No Significant effect
EPS fibre Sizes	0.007351	2	0.003675	1.562201	0.267457	4.45897	$F < F_{Crit}$ No Significant effect

Table A6: Two - way analysis of variance for Unsoaked CBR result of soil – cement mixed with EPS fibre

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Remark*
EPS fibre Dosage	53.13568	4	13.28392	122.7044	3.27E-07	3.837853	$F > F_{Crit}$ Significant effect
EPS fibre Sizes	0.078839	2	0.039419	0.364118	0.705755	4.45897	$F < F_{Crit}$ No Significant effect

Table A7: Two - way analysis of variance for Soaked CBR result of soil – cement mixed with EPS fibre

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Remark*
EPS fibre Dosage	50.55477	4	12.63869	93.54289	9.44E-07	3.837853	$F > F_{Crit}$ Significant effect
EPS fibre Sizes	1.453977	2	0.726989	5.380669	0.03306	4.45897	$F > F_{Crit}$ Significant effect

Table A8: Two - way analysis of variance for UCS result of soil – cement mixed with EPS fibre dosage/Size

Days	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Remark*
0 days	EPS Dosage	1.942501907	4	0.485625477	58.73692328	5.7238E-06	3.837853355	$F > F_{Crit}$ Significant effect
	EPS fibre Size	0.054304851	2	0.027152425	3.28411504	0.090935358	4.458970108	$F < F_{Crit}$ No Significant effect
7 days	EPS Dosage	16.7551112	4	4.188777799	2749.063632	1.39584E-12	3.837853355	$F > F_{Crit}$ Significant effect
	EPS fibre Size	0.001506314	2	0.000753157	0.49429125	0.627473101	4.458970108	$F < F_{Crit}$ No Significant effect
14 days	EPS Dosage	16.10829174	4	4.027072935	516.1304298	1.1066E-09	3.837853355	$F > F_{Crit}$ Significant effect
	EPS fibre Size	0.009938335	2	0.004969168	0.636874135	0.553781873	4.458970108	$F < F_{Crit}$ No Significant effect
28 days	EPS Dosage	19.00242556	4	4.750606391	519.7331375	1.07637E-09	3.837853355	$F > F_{Crit}$ Significant effect
	EPS fibre Size	0.007746246	2	0.003873123	0.423733347	0.66847351	4.458970108	$F < F_{Crit}$ No Significant effect