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The Effect of Coir Fiber on the Geotechnical Properties of Clayey Soil, in Wudil, Northwest, Nigeria

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INFORMATION

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ABSTRACT

Various Geotechnical soil test which includes particle size distribution, Atterberg's limit test, specific gravity test, compaction test, California Bearing Ratio (CBR) test and shear box test were carried out to investigate the effect of coir fiber on the geotechnical properties of clayey soil, with specific emphasis on its bearing capacity in Wudil, Northwest, Nigeria. The particle size distribution test result indicated that the soil sample from Wudil contains 14% clay. Additionally, the Atterberg's limit test showed that the inclusion of coir fiber significantly impacted the soil's properties. Specifically, the liquid limit, plastic limit, and plasticity index of the clayey soil showed notable improvement with the addition of coir fiber compared to the untreated soil. The specific gravity of the soil saw no increase but fluctuated at different coir fiber treatment as the value before the mix which was 2.48 was more than those of the fiber mixtures. During the CBR test, the application of 3cm average length of coir fiber at different percentage of 0.5%, 1%, 1.5%, 2%, 2.5% and 3% to the soil shows a significant improvement as the CBR values are found to be 7.25, 7.79, 11.3, 12.35, 14.89 and 14.68% respectively, which is more than 6.71% of the soil without mix. At different treatment of 0.5%, 1%, 1.5%, 2%, 2.5% and 3% coir fiber, shear box test shows an increase in cohesion and the frictional angle of the soil, as well as significant increase in the shear strength. This implies that coir fiber is an effective reinforcement material, which is capable of strengthening the soil structure and enhancing the bearing properties of clayey soil.

1. Introduction

Coir fiber, a cost-effective plant fiber derived from Cocos nucifera, is obtained from the fruit of the coconut palm. The exploration of coir fiber as a reinforcement material for clayey soil has the potential to revolutionize geotechnical engineering practices. By harnessing the inherent properties of coir fiber, we can enhance the bearing capacity of soil, leading to more robust and cost-effective construction projects.

In construction projects, maintaining adequate bearing capacity is essential to ensure the stability and longevity of structures (Babu and Vasudevan, 2007). One innovative approach that has gained attention in recent years is the utilization of natural fibers to enhance the engineering properties of soil. Among this natural fiber, coir fiber, derived from the husk of coconut, has emerged as a promising material with numerous advantages. Coir fiber is the thickest and most resistant of all commercial natural fibers, it is divided into two types, the brown color coir fiber and the white color coir fiber. Brown color coir fiber, which is harvested from fully ripened coconuts is thick, strong and has high abrasion resistance. Matured brown coir fibers are typically 10 to 30 cm long have high lignin content and less cellulose content, which contributes to their strength and durability. White color coir fibers are harvested from coconuts before they are ripe and are white or light brown in color, they are smoother and finer, but also weaker.

Coir fiber is a renewable resource, abundantly available, biodegradable, and possesses desirable mechanical properties (Hubballi and Rahman, 2021). Coir fiber is known for its exceptionally high tensile strength, low density, higher elongation at break, and low modulus of elasticity. Furthermore, coir fiber generally exists 1.1 to 1.5 g/cm^3 density, 105 to 593 MPa tensile strength, and 2 to 8 GPa Youngs modulus. It has a higher tensile strength compared to other natural fibers like cotton or jute, which makes it suitable for applications where strength is essential. Coir fibers are also natural insulators, providing excellent thermal insulation properties. When incorporated into soil, coir fiber acts as a reinforcing agent, imparting strength and stability to the soil mass (Gbenga and Peter, 2016).

According to Subramani and Udaykumar (2016), the potential benefits of utilizing coir fiber in soil stabilization and reinforcement are multifaceted. Firstly, the addition of coir fibers can enhance the shear strength and internal friction angle of the soil, resulting in improved load-carrying capacity. Secondly, the fibers act as a reinforcement network, distributing the applied load and reducing differential settlements. Moreover, coir fibers can enhance the cohesion and drainage properties of the soil, leading to better overall stability. By incorporating coir fiber into soil, it is possible to enhance its load-bearing characteristics, reduce settlement, and mitigate issues associated with weak or problematic soils (Banerjee, 2002). This is achieved by carrying out index and strength test on natural and treated soil and determining the compaction characteristics of the natural and treated soil.

The primary objective of this study is to investigate the effects of coir fiber reinforcement on the geotechnical properties of soil, with specific emphasis on its bearing capacity. Several experimental techniques will be employed to evaluate the performance of coir fiber-reinforced soil samples under different loading conditions. These techniques include geotechnical laboratory tests such as particle size distribution, Atterberg's limit test, specific gravity test, direct shear tests, and CBR test. All tests would be carried out in accordance to procedures outlined in British Standard code (BS 1377, 1990).

2. The Location of Study Area

Wudil (latitude 11° 47' N and longitude 8° 50' E), one of the 44 local government areas in Kano State, Northwest Nigeria has an estimated land area of 362 km² with a population of over 185,189 (Dambatta et al., 2021) (Fig. 1). The town is located on the outskirts of the Kano metropolis and is among the most populous local governments of the state's 44 local government councils according to 2006 census (Muhammad, 2011). The region's topography features a mix of flat plains and gently undulating terrain. The area is part of the Sudan Savannah, characterized by grasslands and scattered trees.

The predominant soil types in Wudil are sandy and clay soils, which is highly fertile and well-drained, making it suitable for various agricultural activities.

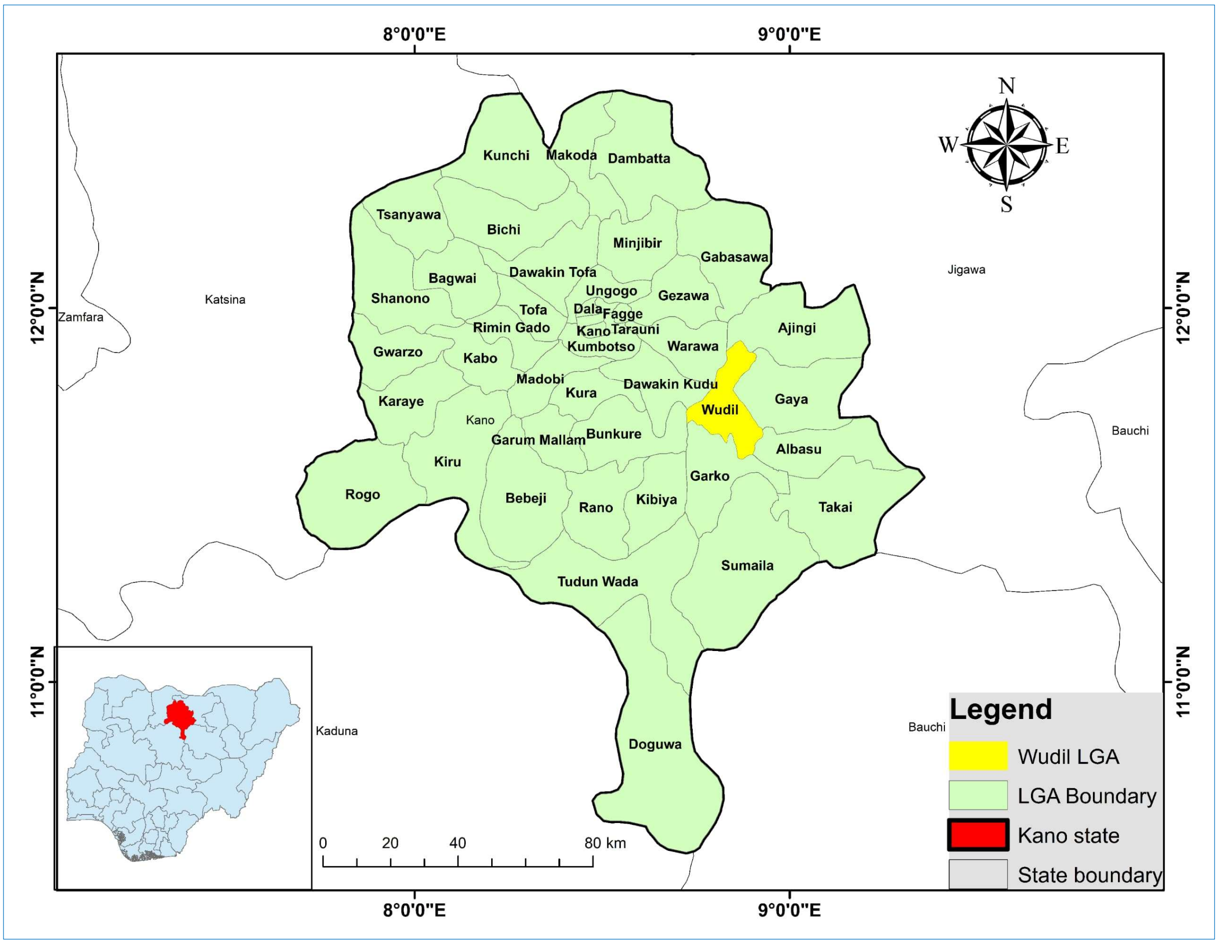

Fig. 1. Location map of Wudil, in Kano State, Northwest, Nigeria

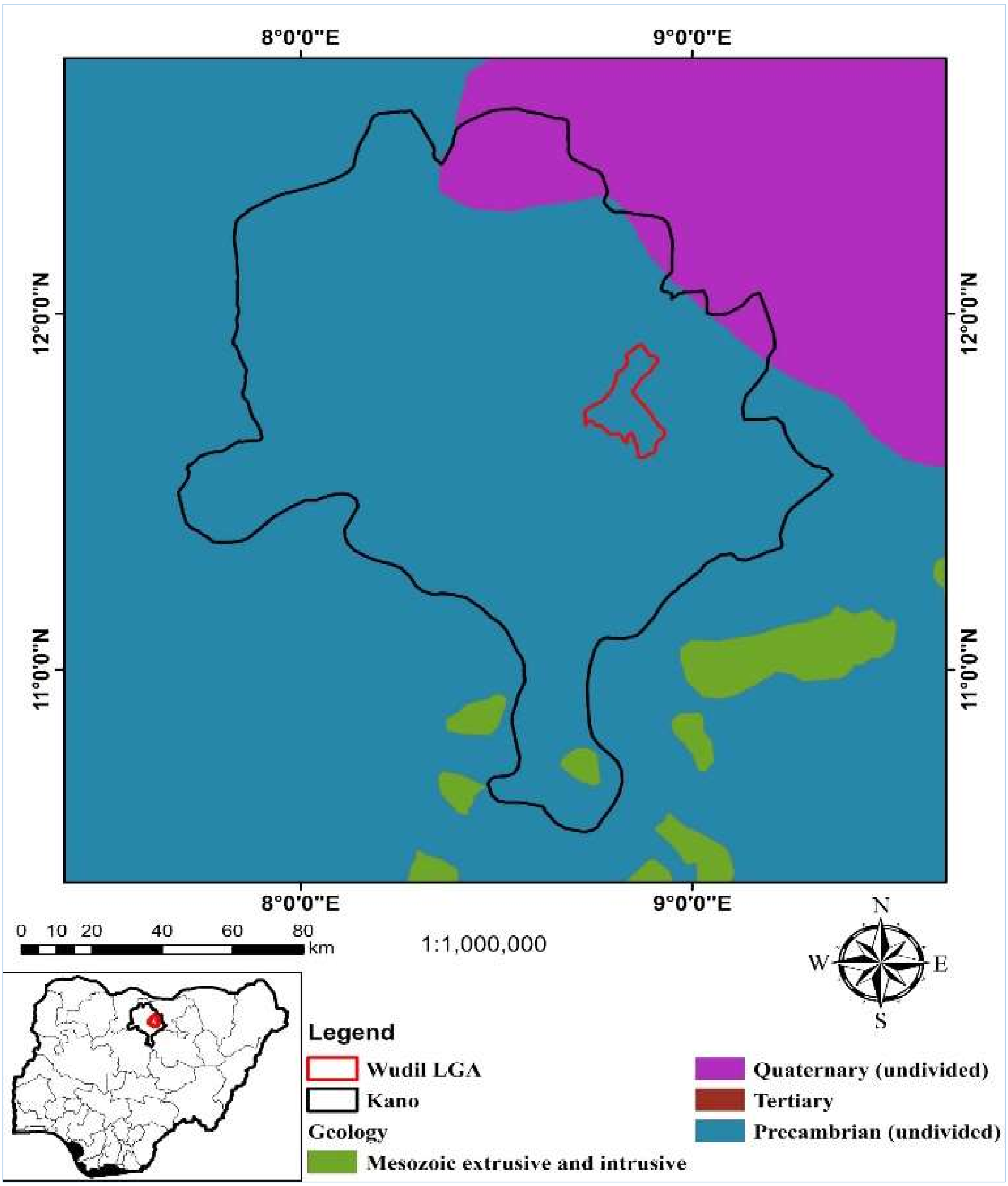

Fig. 2. Geological map of Wudil in Kano State, Northwest, Nigeria

3. The Geological Setting of Wudil, in Kano State, Northwest, Nigeria

Wudil is predominantly underlain by Precambrian basement complex rocks, which form the foundation of the region's geology (Fig. 2). These rocks are primarily composed of granites, gneisses, and migmatites, indicative of high-grade metamorphic processes. Just little deposit of Quaternary, Mesozoic extrusive and intrusive rocks are found around Wudil. Kano Agricultural and Rural Development Authority (KNARDA, 1989) identifies the individual members of the Older Granite suite, but rocks of the Younger Metasediments and those of the migmatite-gneiss complex were simply grouped as the migmatite gneiss complex in some places. The study area covers Wudil which is located in Kano state, Northwest, Nigeria. Kano State exhibits a diverse and complex geological setting as depicted by the geological and mineral resources map created by the Nigeria Geological Survey Agency (NGSA, 2009) shown in Fig. 3.

The granitoids in this area are typically coarse-grained, and their exposure is often marked by rugged terrain and inselbergs, which are prominent features in the landscape. In addition to its Basement Complex, there are significant occurrences of younger sedimentary formations, particularly in the southwestern part of Kano State. These sedimentary rocks belong to the Cretaceous Chad Basin, which extends into parts of the state. The sedimentary sequence in this basin includes sandstones, siltstones, and clays, which were deposited in a fluvial to lacustrine environment. These deposits are relatively softer and less resistant to erosion compared to the surrounding basement rocks, often forming low-lying plains and valleys. Kano State also features a variety of mineral resources associated with its geological setting. Notable minerals include tin, columbite, and gold, which are often found within the alluvial deposits and quartz veins that cut across the Basement Complex rocks.

Additionally, the presence of industrial minerals such as kaolin, limestone, and gypsum are significant, particularly in the sedimentary regions.

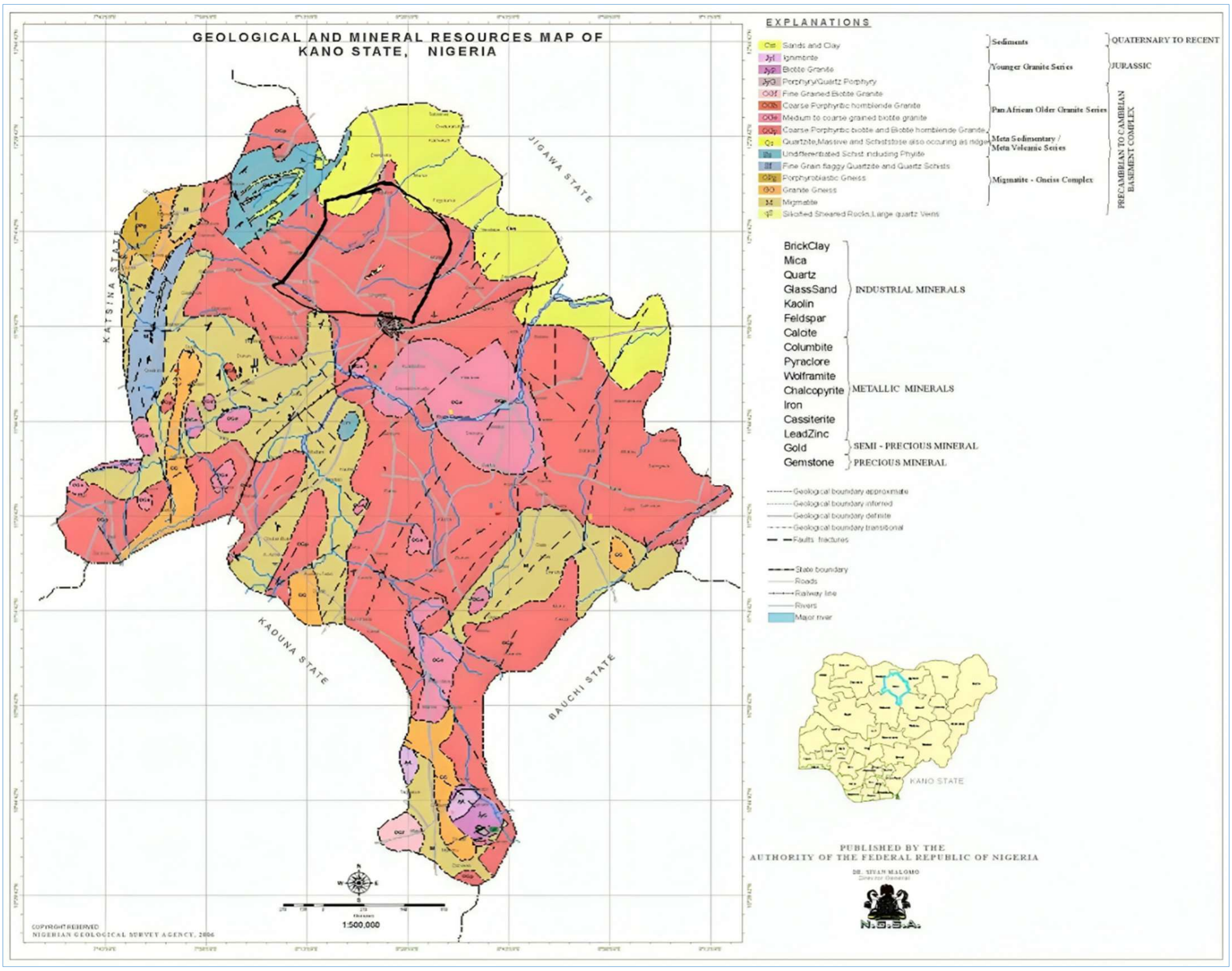

Fig. 3. Geological Map of Kano State, Northwest, Nigeria (Adapted from Nigeria Geological Survey Agency, 2009)

These resources have been extensively explored and exploited, contributing to the local economy and industrial activities. This geological diversity not only shapes the physical landscape of the region but also underpins its mineral wealth and potential for further geological exploration and development.

4. Materials and Methods

To conduct this investigation, two major materials were used: the clayey soil obtained from Wudil in Kano State, Northwest, Nigeria, and the coir fiber. Soil samples having 14% clay content (classified as clayey soil according to Aleksandar et al. (2020) were sourced from an abandoned grassless field adjacent to Wudil Football Stadium along Wudil Police Station Road (Fig. 4). The disturbed soil was taken from a depth of 1m below the top surface. The samples were stored in cement bags and then transferred to Shinga Lab in Kano State, Nigeria. The coir fiber, which is a natural fiber extracted from the husk of coconuts, was procured from a local market in Osun State and transported to Kano State.This was due to the limited availability of coir fiber in Kano State and its high procurement cost. The average length of the fiber used was 3cm, and it was mixed at 0, 0.5, 1, 1.5, 2, 2.5, and 3% by weight of the soil. The following geotechnical laboratory test were conducted to investigate the effects of coir fiber on the geotechnical properties of clayey soil, with specific emphasis on its bearing capacity in Wudil, Northwest, Nigeria. All test was carried out in accordance with procedures outlined in British Standard (BS 1377: 1990).

- Particle size distribution (Cone and Quartering method)
- Atterberg's Limit Test (Cone Method)
- Compaction Test
- Shear box test
- CBR test
- Specific gravity

Fig.4. Soil sample collection using hand auger

4.1. Particle Size Distribution

Sieves of different sizes (ranging from 0.02 mm to 100 mm), a bottom pan and a cover, a mechanical sieve shaker, a balance sensitive up to 0.1 g, and an oven are materials used for this Geotechnical Laboratory test. The method of wet sieving was used, where a 1000 g soil sample was collected, washed thoroughly, and its weight measured to be 380 g. The sample was then oven-dried, and 150 g of the dried sample was taken. The sieves are stacked in order, with the largest aperture size at the top and the smallest at the bottom. A receiver was placed underneath to collect samples. The sample was poured into the top sieve, covered with a lid, and the stack was placed in a sieve shaker with the clamps fixed. The timer was set between 10 and 15 minutes, and the shaker was switched on. After shaking, the mass of each sieve and the retained material was measured (Table 1). The sample retained on each sieve was weighed, and the results were then analyzed and recorded. The composition of the soil is shown in Table 2.

4.2. Atterberg's Limit Test

There are three main Atterberg's limits, namely Liquid Limit (LL), Plastic Limit (PL), and Shrinkage Limit (SL). The apparatus and materials used included a cone penetrometer, aluminium containers (moisture cans), a spatula, a 425-micron sieve, evaporating dishes, a mortar and pestle, a digital scale (sensitive up to 0.01g), and an oven. 500g of prepared sample was taken, and the sample was ground and sieved with a 425-micron sieve. 150g of the sample that passed through the sieve was taken.

A uniform paste of the sample was made by adding distilled water. The prepared paste was transferred to the cylindrical cup of the cone penetrometer apparatus (air was let out during the process). The cone was levelled with the cup and placed on the base of the cone penetrometer apparatus, adjusted so that the cone point just touched the surface of the soil paste. The initial reading was taken, the vertical clamp was released, allowing the cone to penetrate the soil paste under its own weight for 5 seconds, and the test was repeated 4 times. For the Liquid Limit, weights of different cans were taken, wet samples were added at varying weights, containers were oven-dried, and the differences in weight before and after drying were recorded. The empty cans' weight was recorded as W1, the weight of the can plus wet soil was taken as W2, and the weight of the can plus dry soil was taken as W3. The equation for calculating the Plasticity Index (PI) is presented in *Equation 2*. For the Plastic Limit, clean cans were prepared, ellipsoidal-shaped soil masses were formed and rolled into threads until they crumbled. The crumbled threads were collected, filled into cans, covered, and oven-dried. The weights W1, W2, and W3 were recorded similarly, and the Plasticity Index (PI) was calculated from the obtained values. For the Shrinkage Limit, the same steps as the plastic limit test were followed, with the initial length of the crumbled threads (L_o) and the length after oven drying (L) measured, and the difference in length (ΔL) noted. Hence, the equation for calculating the Shrinkage Limit (SL) is presented in *Equation 3*.

$$MC = \frac{W2-W3}{W3-W1} X\ 100 \quad (1)$$

$$PI = LL - PL \quad (2)$$

$$SL = \left(1 - \frac{\Delta L}{L_o}\right) X\ 100 \quad (3)$$

4.3. Specific Gravity

Volumetric flask (500 ml), thermometer graduated in 0.5^{0}C division scale, balance sensitive up to 0.01 g, distilled water, pycnometer, evaporation dishes, spatula, plastic squeeze bottle, and drying oven are the materials that were used for this test. The mass of a flask was determined, and water was filled to the 500 ml mark (Wi). A thermometer was inserted to measure the water temperature. Approximately 100 grams of air-dry soil was placed in an evaporating dish, mixed with de-aired distilled water to form a smooth paste, and soaked for half to one hour (optional for non-cohesive soils). The soil (granular) or soil paste (cohesive) was transferred to the volumetric flask, and distilled water was added to fill it two-thirds full. Air was expelled from the soil-water mixture by gently boiling for 15 to 20 minutes with agitation or applying a vacuum until all air was expelled. The mixture was brought to room temperature, poured into an evaporating dish, and the flask was rinsed to ensure no soil remained. The evaporating dish was dried in an oven to a constant weight, and the mass of the dry soil (W) was determined.

4.4. Standard Proctor Compaction Test

The material used includes a compaction mould, No. 4 U.S. sieve, standard Proctor rammer (2.5 kg), large flat pan, jack, steel straight edge, moisture cans, drying oven, plastic squeeze bottle with water, and pallet knives.

4.5 kg of air-dry soil was used for the compaction test; all soil lumps were broken and sieved through a No. 4 U.S. sieve, and all of the material was collected in a large pan. Water was added and mixed thoroughly to achieve the desired moisture content required for the test. The weight of the Proctor mould with the base plate (excluding the extension) was determined, and the extension was attached to the mould. The moist soil was poured into the mould in three equal layers, each compacted uniformly with 25 blows from a standard Proctor rammer. The top attachment was carefully removed, and the excess soil was trimmed with a straight edge to level it with the mould's top. The weight of the mould with the base plate and compacted moist soil (W2) was recorded. The base plate was removed, and the compacted soil cylinder was extruded using a jack. The mass of a moisture can (W3) was determined, and a moisture sample from the extruded soil was collected in the can, recording the mass of the can plus moist soil (W4). The moisture can with the moist soil was placed in an oven to dry to a constant weight. The rest of the compacted soil was broken down to No. 4 sieve size and then mixed with the leftover moist soil in the pan. More water was added to raise the moisture content by about 2%.

4.5. CBR Test

The materials and apparatus used included a CBR machine, a cylindrical (corrosion-resistant) metal mould, a base plate, a 5.0 kg rammer, lubricating oil, screw plugs, a water bottle, coarse filter paper, a flat tray, and pallet knives. Six kilograms of dried clay soil were collected in a tray and mixed with water according to the optimum moisture content percentage from the previous compaction test. The sample was divided into five portions and poured into a lubricated mould with a filter paper and spacer disc at the bottom. Each layer received at least 50 blows from a 5 kg rammer. The top attachment was carefully removed, and the excess soil was trimmed with a straight edge to level the compacted soil with the mould's top. The mould with the test specimen was placed on the lower plate of a penetration testing machine, and the penetration piston was placed on the center of the specimen with the smallest possible load, but in no case in excess of 4 kg, to ensure full contact with the sample.

The load and deformation gauges were set to read zero. The load was applied on the piston so that the penetration rate was about 1.25 mm/min. The load readings were recorded at penetrations of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, and 7.0 mm. The plunger was raised, and the mould was detached from the loading equipment. The readings at 2.5 mm and 5.0 mm penetration were taken, and the CBR value was calculated at different coir fiber applications of 0%, 0.5%, 1%, 1.5%, 2.0%, 2.5%, and 3.0% of the dried soil, with the average length of the fibre being 3 cm.

4.6. Shear Box Test

The materials and apparatus used for this test includes a shear box, a shear box container, a base plate with cross grooves on its top, porous stones (2 Nos), plain grid plates (2 Nos), perforated grid plates, a loading pad with a steel ball, a digital weighing machine, a loading frame with a loading yoke, a proving ring, dial gauges, weights, a tamping rod, a spatula, a rammer, and a sampler. A 600g sample was measured, and a cake was prepared for 10kg, 20kg, and 30kg. The ring base plate and the hitting edge of the tamping rod were lubricated with engine oil. The first layer of the sample was placed in the cake cone and given 27 blows, then trimmed and compacted with spatula knives. This process was repeated for three layers. The box was placed in a container and mounted on the loading frame. The proving ring was arranged to contact the upper half of the shear box, and the loading yoke was placed on the steel ball of the loading pad. Two dial gauges were fitted: one for measuring shear displacement and the other for vertical displacement. The locking pins were removed from the shear box, and spacing screws were positioned to raise the upper half slightly. Normal stress of 25 kN/m² and shear load were applied at a constant rate of strain. Load reactions were recorded every 30 seconds from the proving ring and dial gauges. When the proving ring reached maximum and suddenly dropped, it indicated that the specimen failed. The maximum value, which is the failure stress, was recorded. The procedure was repeated with fiber applications of 0%, 0.5%, 1%, 1.5%, 2.0%, 2.5%, and 3.0% of the dried sample.

5. Presentation and Discussion of Results

All the results obtained from the tests performed are tabulated (Tables 1-4) and provided in the graph (Figs. 4-12).

5.1. Particle Size Distribution Test Result

The result of the sieve analysis carried out on the soil sample are presented in Table 1 and Fig. 5. Only 14.13% of the sample passed through the 63-microns sieve which weighs 21.2 g. The total weight of sample used was 150 g. The classification percentage of soil sample is shown in Table 2.

5.2. Atterberg Limits Test Results

Atterberg's limits (liquid limit, plastic limit and plasticity index) test was performed on the soil sample. The values obtained for liquid limit (LL), plastic limit (PL) and plasticity index (PI) at 0% fiber mix are 38%, 27% and 11% respectively. At 0.5% fiber mix, the values of LL, PL and PI were 39%, 27.8% and 11.2%. There was a little increase in all the parameters at 0.5% mix of the fiber compared to the values before the mix. At 1% fiber, the values of LL, PL and

PI increased significantly to 42%, 29.92% and 12 % respectively. At 1.5% fiber, both LL and PI saw an increase in value to 43.44%% and 17.44 respectively except for PL which decreased to 26%. LL, PL and PI were 43.9%, 30% and 13.91% at 2% fiber addition.

Table 1. Particle Size Distribution as obtained from the Geotechnical testing laboratory

Diameter of sieve (mm)	Weight (gm)	Retained (%) (Initial weight = 150g)	Passing (%)
10	0	0.00	100.00
5.0	15.2	10.13	89.87
2.5	17.1	11.40	78.47
1.2	17.9	11.90	66.57
0.6	19.0	12.67	53.90
0.3	22.0	14.67	39.23
0.212	12.3	8.20	31.03
0.15	10.0	6.67	24.36
0.063	13.3	8.87	15.49
Sample passed through 63-microns sieve	21.2	14.13	1.36

Table 2. Classification percentage of soil sample obtained from Wudil

Material	Ratio
Gravel	0.00%
Coarse Sand	22.87%
Medium Sand	46.13%
Fine Sand	15.53%
Clay	14.14%

Table 3. Summary of Geotechnical laboratory result of soil sample obtained from Wudil (1)

Diameter of sieve (mm)	Percentage of soil sample passed through sieve (%)
10	100.00
5.0	89.87
2.5	78.47
1.2	66.57
0.6	53.90
0.3	39.23
0.212	31.03
0.15	24.36
0.063	15.49

Table 4. Summary of Geotechnical laboratory result of soil sample obtained from Wudil (2)

Coir Fiber Mix (%)	Atterberg Limit			Specific Gravity	Standard Proctor Compaction Test		CBR	Shear Box Test	
	LL (%)	PL (%)	PI (%)		MDD (g/cm³)	OMC (%)		Cohesion (Kpa)	Frictional Angle (⁰)
0.0	38.00	27.00	11.00	2.20	1.81	23.60	6.71	3.50	30.00
0.5	39.00	27.80	11.20	2.15	1.80	23.69	7.25	10.20	31.50
1.0	42.00	29.92	12.00	2.11	1.79	23.92	7.79	17.50	34.00
1.5	43.44	17.44	26.00	2.19	1.75	24.10	11.30	21.10	38.00
2.0	43.90	30.00	13.91	2.28	1.75	24.67	12.35	28.00	39.10
2.5	47.00	35.10	11.90	2.39	1.70	24.82	14.89	40.00	39.90
3.0	44.10	35.00	9.10	2.33	1.69	25.11	14.68	40.00	41.00

At 2.5% fiber addition saw the values to be 47%, 35.1% and 11.9% respectively. Lastly, at 3% fiber, the values of LL, PL and PI were 44.11%, 35% and 9.1% respectively and there wasn't any improvement in values at this point. The highest values of LL and PL were obtained at 2.5% fiber except for PL. The results showed that the maximum plasticity index (PI) was attained at 1.5% fiber mix.

When the before and after mix results of fibers were compared, we concluded that the introduction of fiber will help improve the Atterberg's limits of the soil (Swetha and Kumar, 2017). Fig. 6 shows the graphical representation of Atterberg's limit test results of soil sample.

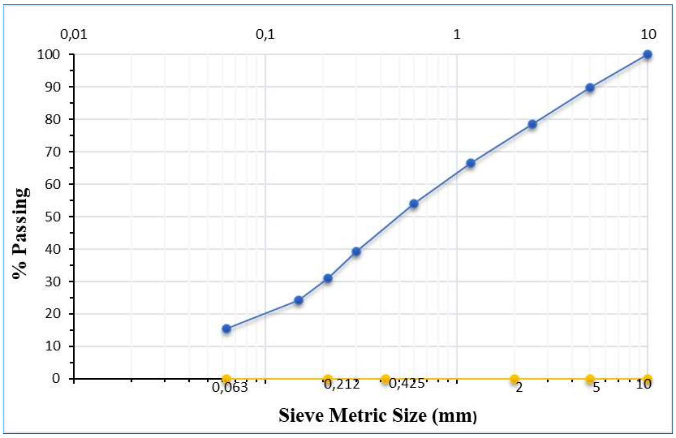

Fig. 5. Graphical representation of particle size distribution showing percentage of soil sample passed through the sieve against sieve metric size

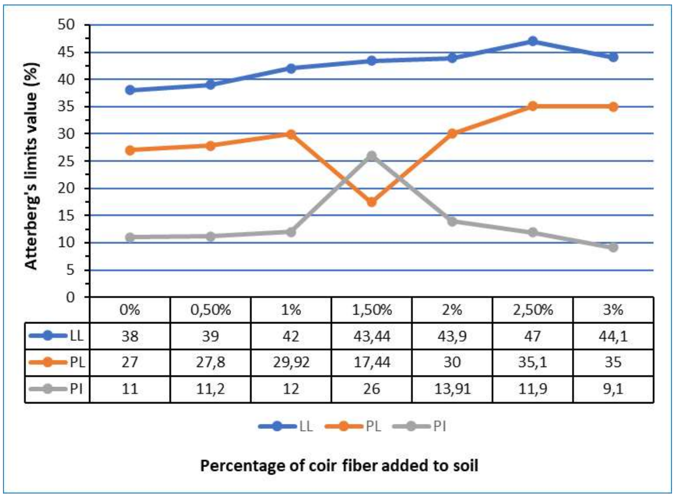

Fig. 6. Graphical representation of Atterberg's limit test results of soil sample

5.3. Specific Gravity Test Results

Fig. 7 presents the result of the specific gravity of soil at different level of fiber applications. The value of the specific gravity of untreated soil (0% fiber mix) was found to be 2.48. The value of the specific gravity when treated with 0% fiber mix was found to be 2.20 which showed a drop in the specific gravity. The value further dropped to 2.15 at 0.5% and 2.11 at 1% fiber mix. It showed significant increase at fiber mix of 1.5%, 2% and 2.5% which had a specific gravity of 2.19, 2.28

and 2.39 respectively. At 3% mix, the value was found at 2.33, this indicate that the specific gravity is found highest at 0% fiber mix. According to Nafiul Islam et al. (2021), sometimes the value of the specific gravity can be found highest for the untreated soil.

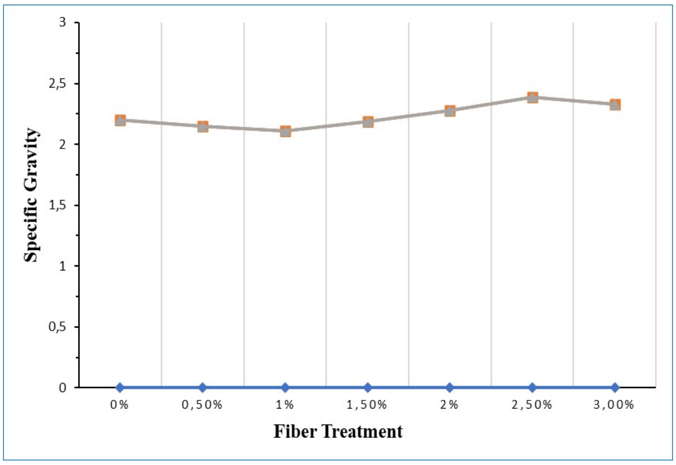

Fig. 7. Graphical presentation of specific gravity test

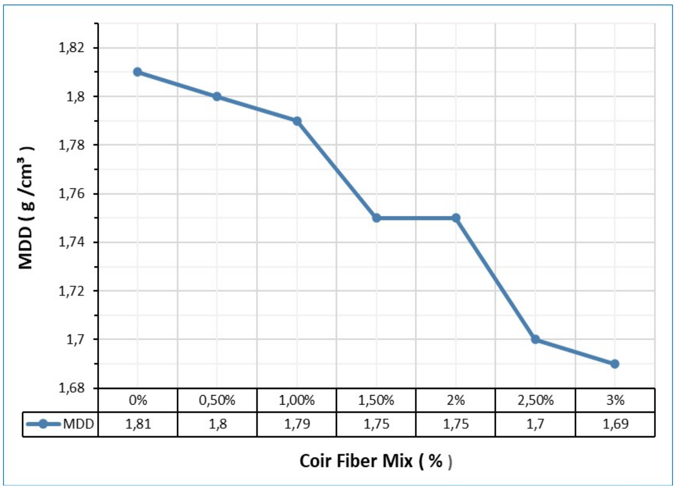

Fig. 8. Graphical representation of MDD against coir fiber mix

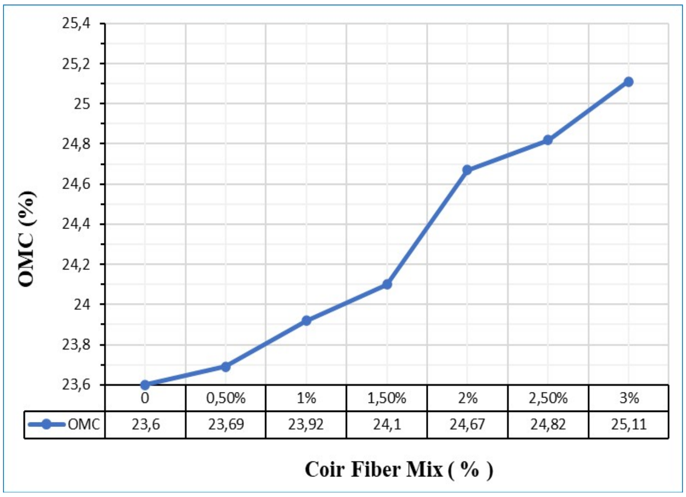

Fig. 9. Graphical representation of OMC against coir fiber mix

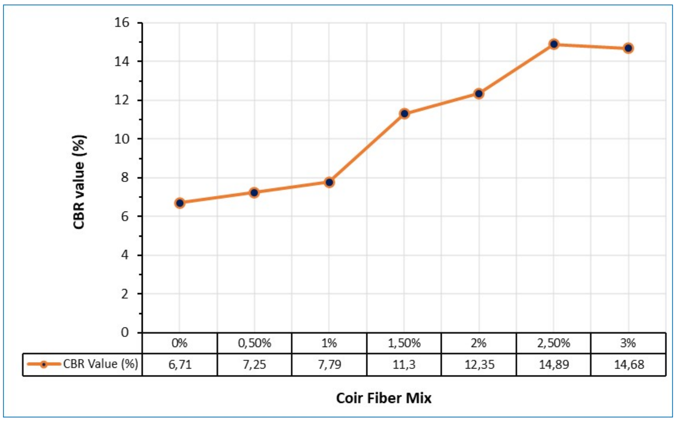

Fig. 10. Graphical representation of CBR value against coir fiber mix

5.4. Standard Proctor Compaction Test

The compaction results showed the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD) of the soil sample to be 23.6% and 1.81g/cm³ at 0% fiber mix, just as described by Soundara et al. (2015) and Hubballi et al. (2021), the values of MDD at subsequent addition of the coir fiber saw decrease. The reason for this decreasing trend may be because of how light coir fiber is compared to the soil particles, hence their inclusion in the soil replaces heavyweight clay particles imparting less overall weight to the soil sample (Soundara et al., 2015).

The OMC values saw increase at different addition of coir fiber, this may be due to the fact that coir fibre has a more water-absorbing tendency than clayey soil. Hence the presence of coir fiber requires more water to achieve MDD for the same compaction energy (Hubballi et al., 2021). Fig. 8 and Fig. 9 show the graphical representation of MDD and OMC against fiber mix.

5.5. CBR

The CBR test conducted showed that the addition of mixture variations in coir fiber percentage to clay soil help improved the CBR value of the parent soil as the value of the CBR after the mixture was found out to be more than the value when the soil was at 0% coir fiber mix.

The CBR value of the natural soil at 0% fiber mix was 6.71 %. At 0.5% fiber mix, the value of the CBR increased to 7.25%, showing that the addition of fiber improves the CBR value of the soil. The value of the CBR saw subsequent increase with different increase in the addition of fiber as the CBR value at 1%, 1.5%, 2%, 2.5% and 3% fiber mix were 7.79%, 11.3%, 12.35%, 14.89% and 14.68% respectively. It was observed that the CBR value decreased at 3% fiber addition. The result is similar to those conducted by Singh and Mittal (2014), Lekha, et al. (2015) and Shukla et al. (2015). Fig. 10. below shows the graphical representation of CBR value against coir fiber mix.

5.6. Shear Box Test

The shear box test was performed and the cohesion (c) of the soil was compared before and after the introduction of fiber. It was found out that the cohesion of the soil increased with every introduction of coir fiber, as well as the frictional angle and the shear strength of the soil. The percentage of coir fiber added to the soil was 0.5%, 1%, 1.5%, 2%, 2.5% and 3%, each coil fiber added had an average length of 2-3cm. At 0% mixture, the cohesion and frictional angle were 3.5kPa and 30^0 respectively. The various addition of the fiber saw an increase in the value of cohesion and frictional angle. At 2.5% fiber, the value of cohesion stopped increasing which indicated that the optimal fiber content was reached. The same cohesion value was seen at 3% fiber mix. This result is similar to the report made by Bhatt Himanshu et al. (2017). Figs. 11 and Fig. 12 show the graphical representation of cohesion and frictional angle against fiber mix.

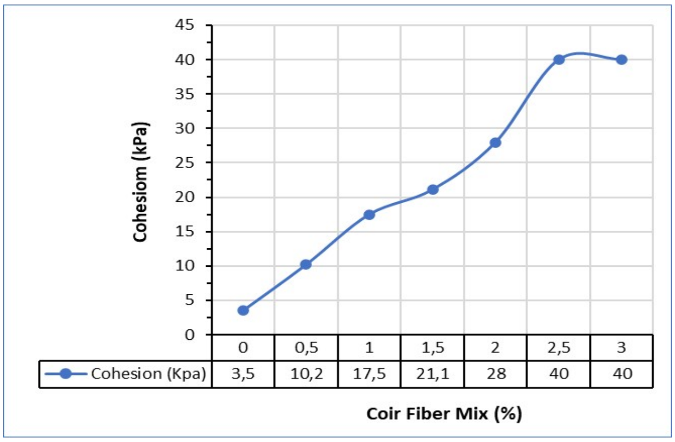

Fig. 11. Graphical representation of cohesion against coir fiber mix

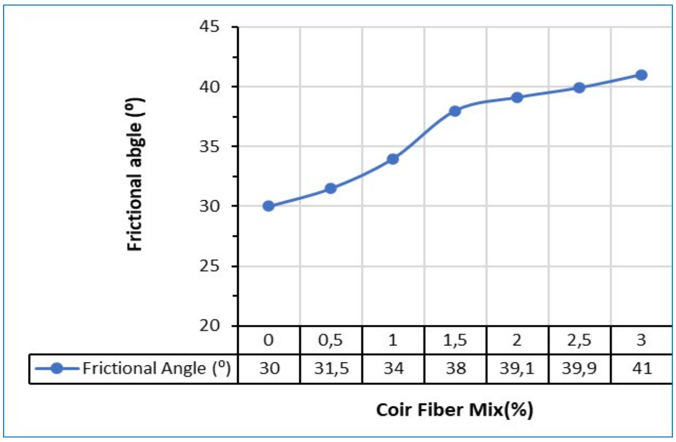

Fig. 12. Graphical representation of friction angle against coir fiber mix

6. Conclusion

The result of the maximum dry density obtained after the introduction of various fiber to the soil saw a reduction in the value of the MDD, and on the other side saw increase in the OMC. This goes in line with the previous findings about the use of coir fiber in enhancing the properties of soil. The MDD and OMC values are 1.81 and 25.11 respectively. Summary of Geotechnical laboratory results are as follows.

- Optimum fiber content was observed at 2.5% of fiber mixture.
- Cohesion value also increases up to the optimal fiber content but the value of angle of internal friction increases with the increase in the fiber content.
- The Atterberg's limit results showed that the application of fiber has an impact in the LL, PL and PI soil as the soil improves more than before the addition of fiber.
- The CBR value increases with every increase in fiber level and the optimal fiber content was observed at 2.5% fiber mix with CBR value of 14.89%.

This study has shed light on the promising potential of coir fiber in enhancing soil bearing capacity. The findings indicate that coir fiber acts as an effective reinforcement material, strengthening the soil's structure and enhancing the bearing properties of the soil. Moreover, it offers an eco-friendly and sustainable solution. However, it is important to note that the effectiveness of coir fiber may vary depending on factors such as fiber type and soil composition which ranges from one location to another. Further research and field testing are recommended to optimize its application in various soil types and engineering projects.

7. Recommendations for Future Works

Further Research and Testing: To provide comprehensive understanding of coir fiber's effectiveness, it is advisable to conduct additional research and testing. This should encompass a wider range of soil types and environmental conditions to assess the versatility and reliability of coir fiber as a soil improvement material.

Standardization: Collaborate with relevant regulatory bodies and organizations to establish standardized guidelines and specifications for the use of coir fiber in soil improvement. Standardization can promote consistency and ensure safe and effective application.

Environmental Impact Assessment: Given the eco-friendly nature of coir fiber, it is important to conduct a comprehensive environmental impact assessment. This assessment should evaluate the sustainability and ecological benefits of incorporating coir fiber into soil stabilization practices.

Awareness and Education: Promote awareness and education within the construction and engineering industries regarding the benefits of coir fiber. Training programs and workshops can help engineers, contractors, and stakeholders understand how to best utilize this sustainable material.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Ojefia, F.E., & Ajiboye, S.T. both carried out the Geotechnical laboratory tests and wrote the manuscript while Eberemu, A. O, supervised the processes and provided professional guidance.

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