



## Investigating Coconut Coir Fiber as a Soil Reinforcement to Enhance the Geotechnical Properties of Lateritic Soil

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### ABSTRACT

*This study investigates coconut coir fiber (CF) as a sustainable reinforcement to enhance the geotechnical properties of lateritic soil treated with CF at 0%, 2%, 4%, 6%, and 8% by weight, the soil exhibited notable improvements. Specific gravity increased from 2.61 (untreated) to 2.75 with 6% CF, while maximum dry density rose from 1.66 Mg/m<sup>3</sup> to 1.76 Mg/m<sup>3</sup> at 4% CF. Shear strength parameters, including cohesion and internal friction angle, improved significantly, indicating enhanced mechanical stability. The optimal moisture content and plastic limit were also influenced, suggesting better compaction behavior and workability. Microstructural analyses (SEM) revealed fiber-soil interactions that modified the soil fabric and elemental composition, reinforcing the matrix. The results demonstrate that coir fibers, particularly at 4–6% inclusion, strengthen lateritic soil by improving its density, shear strength, and structural integrity. As a low-cost, renewable material, coconut coir offers an eco-friendly alternative to conventional stabilizers, promoting sustainable practices in soil engineering. Its ability to enhance soil properties makes it viable for construction and infrastructure applications where stabilized soil is required, aligning with environmentally conscious engineering solutions.*

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### INTRODUCTION

Laterite soils are widely used as fill materials for various construction works in most tropical countries. These soils are weathered under conditions of high temperatures and humidity with well-defined alternating wet and dry seasons resulting in poor engineering properties such as high plasticity, poor workability, low strength, high permeability, tendency to retain moisture and high natural moisture content (Maigien, 1966; Gidigas, 1976; Charman, 1988). The effective use of these soils is therefore often hindered by difficulty in handling particularly under moist and wet conditions typical of tropical regions and can only be utilized after modification / stabilization. Laterite soils that present such problems during construction processes are termed problematic laterites (Osula, 1991; Oyediran, 2021). According to recent studies, the

modification/stabilization of engineering properties of soils is recognized by engineers as an important process of improving the performance of problematic soils (Edeh et al., 2022).

The application of chemicals such as cement, lime, fly ash etc. or combination of these often results in the transformation of soil index properties which may involve the cementation of the particles. Lateritic soils have been used successfully for the construction of roads, highways, airfield runways, embankments and earth dams in various parts of the tropical regions. The degree of success in the use of these soils as a construction material is said to depend on their characteristics and the specific purpose for which they are being used (Nwaiwu et al., 2021). A number of geotechnical studies on both stabilized and un-stabilized lateritic soils which are for

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specific applications to road construction have been conducted (Osinubi, 1998; Osinubu and Katte, 1997).

Its usage has led to development of its potentials as reliable and durable construction materials that is readily available. Some lateritic soils require improvement on their engineering properties before they are used in construction work. The improvement normally brings the soil within acceptable limits in terms of good quality for variety of engineering work such as pavement construction, manufacture of soil crete blocks and satisfactory foundation materials etc. Today, with increasing urbanization and industrialization, the use of soil stabilization techniques is inevitable; hence a systematic study for optimization of the Technique is necessary with that under consideration, the current study is based on the optimization of fiber reinforced lateritic soil stabilization.

Of all the available natural fibers, coir fibers are preferred because it is a natural and eco-friendly material. Coir fibers are extracted from the husk of coconut. This biodegradable and environment friendly material is virtually irreplaceable by any of the modern synthetic substitutes. Studies conducted have indicated that coir is better preferred, as compared to jute or other natural material owing to certain characteristics like durability, strength etc. (Akinwumi et al., 2022). Places in Southern Eastern Nigeria, such as Abia, Anambra, Ebonyi, Enugu, and Imo states, are experiencing challenges with laterite soils, including gully erosion and landslides. This study aims to determine the effect of coir fibre serving as soil reinforcement on engineering properties of lateritic soil.

## MATERIALS AND METHODS

### Materials

#### Lateritic soil

The laterite soil used for this study was collected by method of disturbed sampling from a lateritic soil formation located in Shika is located in the Giwa Local Government Area of Kaduna State, Nigeria.

#### Coir fiber

Coir fiber was obtained from the outer husk of coconut, harvested from a coconut tree grown locally in the northern part of Kaduna, Kaduna state.

#### Methods

##### Index Properties:

Laboratory tests were conducted to determine the index properties of the natural soil and lateritic soil reinforced with coir fibre in accordance with British Standards BS 1377 (1990) and BS 1924 (1990) respectively. A summary of the soil index properties is presented in Table 1.

##### Compaction

The compactive effort used are the British Standard Light, West African Standard and British standard heavy

##### British standard light (BSL) test

About 3 kg of air-dried and pulverized for natural and stabilized soil with different CF content were taken separately, thoroughly mixed with small quantity of water and were covered and allowed to mature for at least 5 minutes. About 300 ml of water were added to each of the samples. The collar was fixed to the mould (105 mm internal diameter, and 116 mm internal effective height and a volume of 1000 cm<sup>3</sup>) on the base plate and the thoroughly remixed matured soil were compacted into the mould in three layers in the compaction mould (which was weighed and recorded as W<sub>1</sub>) which was made to sit on a uniform rigid floor. Each layer was given 27 uniformly distributed blows of 2.5 kg rammer falling from a full drop over the soil. The last compacted layer was made to project about 10 mm into the collar. The collar was removed and the excess projection drained off to the level of the mould. The mould and the fully compacted soil were weighed and recorded as W<sub>2</sub>. The mould was emptied after the representative sample was taken from the top and bottom of the compacted specimen for moisture content determination.

The soil removed from the mould were broken up with hand, remixed with the remainder

of the original sample and about 100 g of water was added again. The sample was allowed to mature again and compacted in three layers again, levelled and the weight of the compacted sample and the mould was taken again. The steps above were repeated again and again until a decrease in the weight of the compacted sample and mould was observed. The bulk density and the corresponding dry density for the compacted soil can be obtained from equations (1) and (2).

$$\text{Bulk density } \rho = \frac{W_2 - W_1}{V} \quad (\text{g/cm}^3) \quad (1)$$

$$\text{Dry density } \rho_d = \frac{\text{bulk density}}{1 + w} \quad (\text{g/cm}^3) \quad (2)$$

Where;

$W_2 - W_1$  = mass of wet compacted soil  $w$  = moisture content  $v$  = volume of mould

#### **West African standard (WAS) test**

About 3 kg of air-dried and pulverized for natural and stabilized soil with different CF content were taken separately, thoroughly mixed with small quantity of water and were covered and allowed to mature for at least 5 minutes. About 300 g of water were added to each of the samples. The collar was fixed to the mould (150 mm internal diameter, and 125 mm internal effective height and a volume of 2210 cm<sup>3</sup>) on the base plate and the thoroughly remixed matured soil were compacted into the mould in five layers in the compaction mould (which was weighed and recorded as  $W_1$ ) which was made to sit on a uniform rigid floor. Each layer was given 10 uniformly distributed blows of 4.5 kg rammer falling from a full drop over the soil. The last compacted layer was made to project about 10 mm into the collar. The collar was removed and the excess projection drained off to the level of the mould. The mould and the fully compacted soil were weighed and recorded as  $W_2$ . The mould was emptied after the representative sample was taken from the top and bottom of the compacted specimen for moisture content determination.

The soil removed from the mould were broken up with hand, remixed with the remainder of the original sample and about 100 g of water was added again. The sample was allowed to

mature again and compacted in three layers again, levelled and the weight of the compacted sample and the mould was taken again. The steps above were repeated again and again until a decrease in the weight of the compacted sample and mould was observed. The bulk density and the corresponding dry density for the compacted soil was obtained.

#### **British standard Heavy (BSH) test**

About 3 kg of air-dried and pulverized for natural and stabilized soil with different CF content were taken separately, thoroughly mixed with small quantity of water and were covered and allowed to mature for at least 5 minutes. About 300 g of water were added to each of the samples. The collar was fixed to the mould (105 mm internal diameter, and 116 mm internal effective height and a volume of 1000 cm<sup>3</sup>) on the base plate and the thoroughly remixed matured soil were compacted into the mould in five layers in the compaction mould (which was weighed and recorded as  $W_1$ ) which was made to sit on a uniform rigid floor. Each layer was given 27 uniformly distributed blows of 4.5 kg rammer falling from a full drop over the soil. The last compacted layer was made to project about 10 mm into the collar. The collar was removed and the excess projection drained off to the level of the mould. The mould and the fully compacted soil were weighed and recorded as  $W_2$ . The mould was emptied after the representative sample was taken from the top and bottom of the compacted specimen for moisture content determination.

The soil removed from the mould were broken up with hand, remixed with the remainder of the original sample and about 100 g of water was added again. The sample was allowed to mature again and compacted in three layers again, levelled and the weight of the compacted sample and the mould was taken again. The steps above were repeated again and again until a decrease in the weight of the compacted sample and mould was observed.

#### **Shear Box Test**

The direct shear test is widely used in laboratory test in geotechnical engineering to

determine the shear strength of soils. The test involves applying a normal load and a shear load to a soil sample and measuring the resulting shear displacement and shear stress. the test is typically conducted on undisturbed soil samples, and the result are used to determine the peak shear strength, residual shear strength, and friction angle of the soil. To conduct a shear box test, the following equipment is required: a shear box apparatus, a soil sample, a loading frame, a proving ring or load cell, and a displacement transducer.

The test procedure begins with preparing the soil sample by trimming it to fit the shear box and ensuring it is saturated. Next, the shear box apparatus is assembled, including the soil sample, loading frame, proving ring or load cell, and displacement transducer. A normal load is then applied to the soil sample through the loading frame, followed by a shear load applied at a constant rate. The displacement of the soil sample is measured using the displacement transducer. The peak shear stress and corresponding displacement are recorded, and the shear strength parameters are calculated using the following equations (3) and (4):

$$\text{Shear Stress} = \frac{P_r \times RCF}{A} \quad (3)$$

where

$P_r$  = Proving ring reading

RCF = Ring Calibration factor

A = Area of sample

Shear stress unit is (kN/m<sup>2</sup>)

$$\text{Normal Stress} = \frac{\text{Normal load} \times \text{Gravitational Force}}{\text{Area of sample}} \quad (4)$$

The graph of shear stress ( $\tau$ ) kN/m<sup>2</sup> against normal stress ( $\sigma$ ) is then plotted to determine the value of angle of internal friction ( $\phi$ ) and cohesion (c).

## RESULTS AND DICUSSION

### Index Properties

Results of tests carried out on the natural and treated soil are summarized in Table 1. The soil is classified under the A – 7 – 6 subgroups of the AASHTO classification system. Liquid limit and plasticity index values of 67.5 % and 44.7 %, respectively, suggest that the soil is highly plastic. Thus, from the results obtained, the soil falls below the standard recommended for most geotechnical works.

**Table 1:** Engineering Properties of Lateritic Soil Reinforced with Coir Fibre

Engineering Properties	Coir Fibre (%)				
	0	2	4	6	8
Liquid Limit, %	44.23	42.78	43.9	44.85	43.58
Plastic Limit, %	18.9	17.81	17.99	16.55	17.63
Plasticity Index, %	25.33	24.9	25.91	28.3	25.95
Linear Shrinkage, %	-	-	-	-	-
Percentage Passing BS No. 200 Sieve.	43.05	41.65	39.95	35.0	32.7
AASHTO Classification	A-7-6	A-7-6	A-7-6	A-7-6	A-7-6
USCS Classification	CL	CL	CL	CL	CL
Specific Gravity	2.61	2.69	2.70	2.75	2.61
OMC%	1.75	1.74	1.76	1.73	1.73
MDD%	13.14	13.55	13.33	13.65	13.65

### Maximum Dry Density

Compaction test was conducted to attain the result of the maximum dry density of the

soil samples using both BSL, WAS and BSH Compactive effort. The compaction test results for Soil mixed with CF at various percentages (0%,

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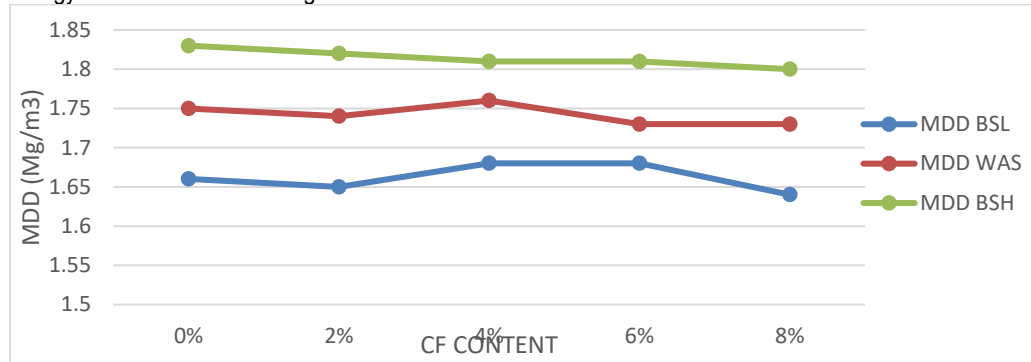
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2%, 4%, 6% and 8%) showed an increase in maximum dry density (MDD) from 1.66Mg/m<sup>3</sup> with higher CF content to 1.68Mg/m<sup>3</sup> for 4% and 6% for BSL. And later decreases at 8% with 1.64 Mg/m<sup>3</sup> while using WAS compactive effort it increases only at 4% with 1.76Mg/m<sup>3</sup> and reduces all through using BSH effort. There was a general increase in maximum dry density for the two energy levels as shown in Figure 1. This could

probably be as a result of the higher specific gravity value of 2.75 (Osinubi and Ijimdiya, 2008) which enhances the compressive strength of the soil material. A greater maximum density gives good compressive strength to the soil material (Moses, 2019). These trends are similar to those reported by Nwachukwu, 2020; Suleiman, 2020; & Salimnezhad, 2021.

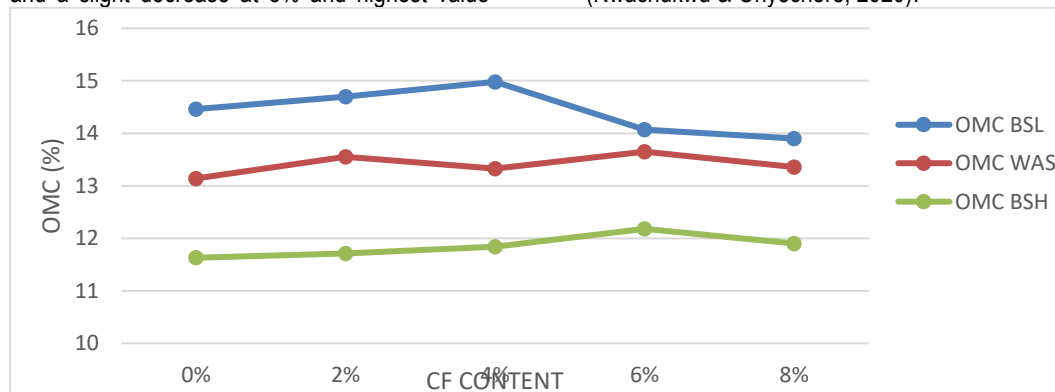


**Figure 1:** Variation of Maximum Dry Density With CF

### Optimum Moisture Content

The optimal moisture content (OMC) of Soil (BCS) mixed with CF at various percentages (0%, 2%, 4%, 6% and 8%) is shown in Figure 2. The results indicate a general increase in OMC with increasing CF content for both BSL at 2% and 4% CF with 14.7 and 14.98% and later decreases at 6% and 8% CF while at WAS the OMC shows a slight increase at 2% and 6% with 13.55 and 13.65% from 13.14%. For BSH compactive efforts there was an increase at treatment from 2% to 6% and a slight decrease at 8% and highest value

obtained at 6% with 12.18%. This anomaly may be attributed to the increased coir fiber content, which requires more water for hydration and reaction due to its larger surface area, leading to higher water demand. The lower OMC can be seen to be due to the increasing effort which increases the thickness of the adsorbed water and relatively decreases the particle to particle contact of the soil grains, the addition of water ensures the lubrication of the particles and closer packing of the soil grains. This trend was also observed by (Nwachukwu & Onyechere, 2020).



**Figure 2:** Variation of Optimum Moisture Content With CF

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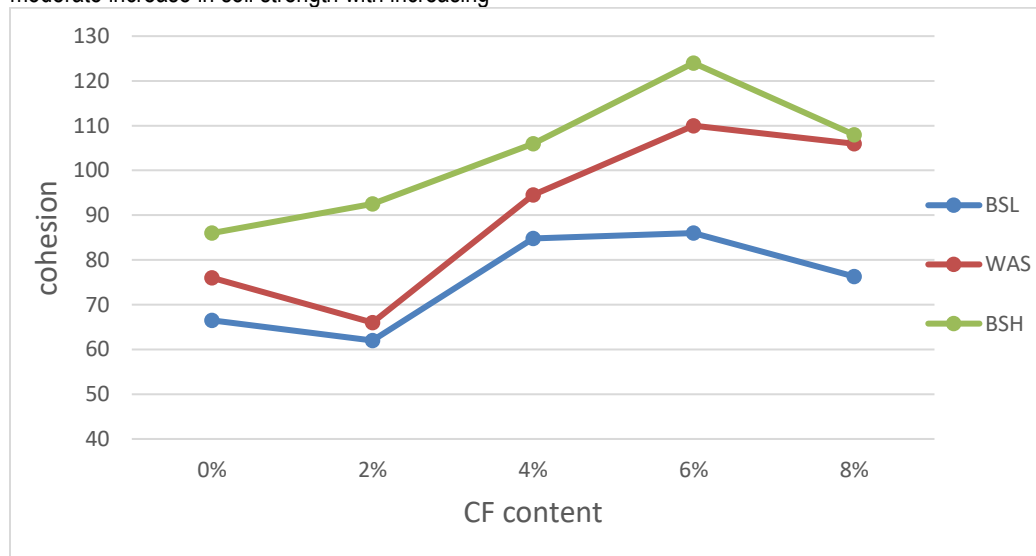
### Shear Strength

Two main factors are used to quantify shear strength of the soil; cohesion and angle of internal friction. cohesion represents the shear strength contributed by the bonding forces between soil particles, while the angle of internal friction relates to the resistance offered by the soil particles frictional interactions.

### Cohesion

The result of cohesion for the varying percentage of CF at different compactive effort is shown in figure 3. The values indicating that the compactive effort affects the soil strength. WAS and BSH have higher cohesion value than BSL. The cohesion values for BSL range from 62 kN/m<sup>2</sup> to 84.8 kN/m<sup>2</sup>, and higher at 4% CF, indicating a moderate increase in soil strength with increasing

CF. For WAS and BSH the highest value is at 6% CF, and for WAS the cohesion values range from 66 kN/m<sup>2</sup> to 94.5 kN/m<sup>2</sup>. indicating a significant increase in soil strength with increasing CF. The cohesion value for BSH range from 86 kN/m<sup>2</sup> to 124 kN/m<sup>2</sup>, indicating a significant increase in soil strength. This behavior has implications for the management of soil with coir fiber showing higher cohesion values may require more addition of cementitious material to reduces the pore spaces while soils with lower cohesion values may be more susceptible to erosion and other transport. The cohesion values for all three standards are higher than those reported by (lee, 2019) which may be due to differences in moisture content or soil composition.



**Figure 3:** Variation of Cohesion with CF content at different compactive efforts

### Angle of Internal Friction

The result of cohesion for the varying concentration at different compactive efforts is shown in Figure 4. The value shows that the angle of internal friction for BSL varies with the content of CF, with a peak value of 13 at 2% CF, the value then decreases and increases again, forming a slight curve. The value for WAS shows a fluctuating pattern with CF content. The highest value occurs at 2% CF of 15, indicating peak shear

resistance. The lowest value occurs at 0% CF with 10 as value, suggesting reduced shear strength. And for BSH, the values are low compared to WAS, only high at 8% CF, having 16. Lower values may indicate a higher moisture content or a more uniform soil texture, which can reduce the soil's resistance to shear stress; higher values may indicate a lower moisture content or a more varied soil texture, which can increase the soil's resistance to shear stress.

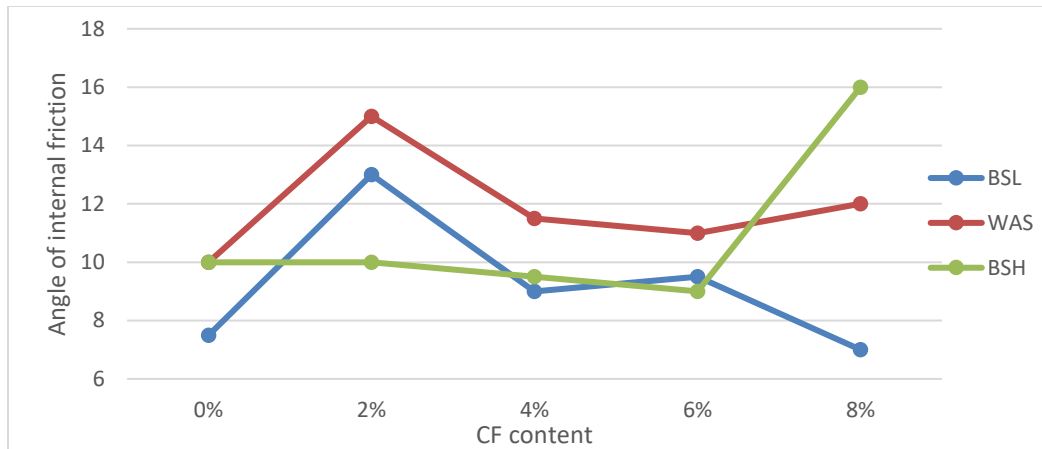
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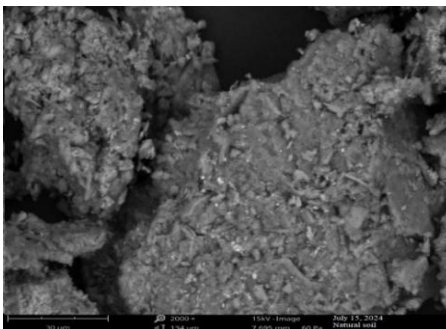




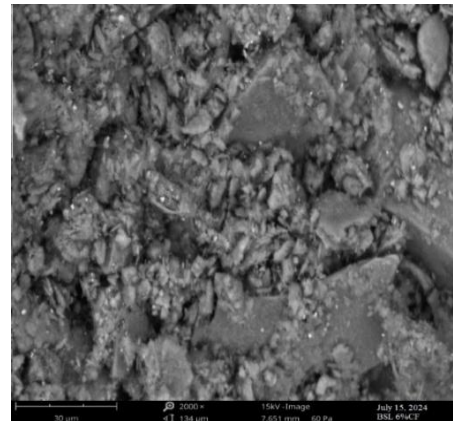
**Figure 4:** Variation of the angle of internal friction with CF content at different compactive efforts

### Scanning Electron Microscopy Analysis

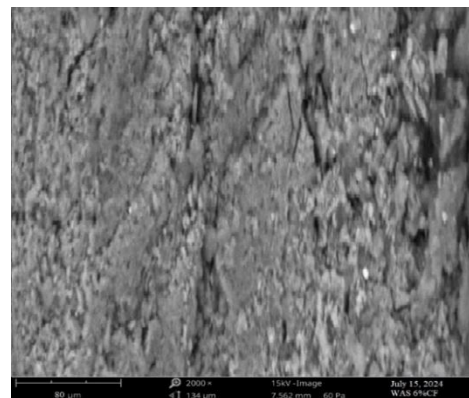
The SEM analysis for the natural soil and soil treated with CF of BSL, WAS and BSH is shown in Figure 5 – 8. Overall, the SEM result provide valuable insights into the effect CF mix on soil microstructure and cohesion, highlighting the potential benefits of using CF in soil stabilization applications, as seen in figures 5 – 7, the CF likely facilitated the formation of stronger bonds between soil. The BSL compacted soil exhibited irregularly shaped particles with a rough surface and a strip of tread like form, indicating a high degree of heterogeneity. The WAS compacted soil displayed continuous joint particles with increased aggregation and a smoother surface, suggesting a more stable structure. The BSH compacted soil showed a mix of smaller irregular and rough stretched particles, aggregated, and a rough surface indicating a more stable structure.



**Figure 5:** SEM analysis of natural soil



**Figure 6:** SEM analysis of 6% CF at BSL compaction



**Figure 7:** SEM analysis of 6% CF at WAS compaction

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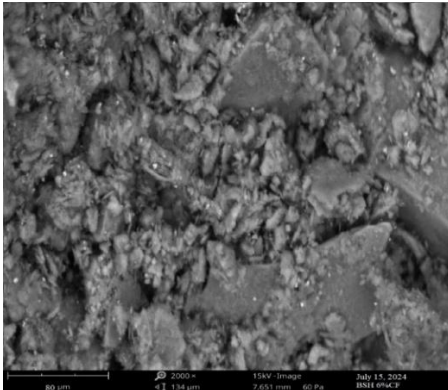


Figure 8: SEM analysis of 6% CF at BSH compaction

## CONCLUSIONS

In conclusion, the research on the reinforcement of lateritic soil with coir fibre for slope stabilization has provided valuable insights into the potential of coir fibre as a natural reinforcement material for enhancing the stability of lateritic soil. The following conclusions are drawn:

1. Based on index properties result, the soil belongs to A-7-6 AASHTO Soil Classification System.
2. Treatment of the lateritic soil with CF showed a general increase in the OMC and decrease in MDD with increased CF. There was an increase in maximum dry density at 4% and 6% for all the energy levels.
3. Cohesion values increase with increasing CF content, with peak values at 4% CF for BSL and 6% CF for WAS and BSH. Angle of internal friction varies with CF content, with peak values at 2% CF for BSL and WAS. Higher cohesion values may require addition of cementitious material to reduce pore spaces.
4. The SEM analysis for the natural soil and soil stabilized soil with CF at BSL, WAS, and BSH showed high cohesion values at 6% CF content, indicating a more stable and cohesive soil matrix.

5. The utilization of 6% coir fiber (CF) with a higher energy level is recommended for stabilizing lateritic soil, as it has shown promising results in improving the soil's geotechnical properties.

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