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Suitability of Enset Fiber with Coffee Husk Ash as Soil Stabilizer

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Abstract: Expansive soil is a problematic soil due to swelling and shrinkage behavior during moisture variation. Damage to shallow foundations like pavement and footings of residential houses occurred due to these soils. Different scholars deal with stabilizing expansive soils using different mechanisms. This study also evaluated the suitability of Enset fiber with coffee husk ash materials to improve the expansive property of soils found in Jimma town. Different geotechnical parameters were determined for virgin soil and coffee husk ash with virgin soil. After treating the natural soil with varying percentages of coffee husk ash (5%, 10%, 15%, and 20%), the optimum levels of coffee husk ash were determined. Different laboratory tests such as CBR value, compaction test, and Atterberg limits were determined using the optimum coffee husk ash with varying percentages of enset fiber (0.3%, 0.6%, 0.9%, and 1.2%). The study reveals that the addition of coffee husk ash to enset fiber significantly increases the shear strength of expansive soils. With the addition of 15% of coffee husk ash and 0.9% of enset fiber, all tested geotechnical parameters improved the expansive soils to be used as subgrade materials. The soil changed from highly swelled material to poorly swelled material. Therefore, it can be concluded that the reuse of agricultural waste of coffee husk ash with enset fiber is applicable for expansive soil stabilization since it can improve the engineering strength of expansive soils and it is an economic and environmentally friendly material.

Keywords: Coffee Husk Ash, Enset Fiber, Expansive Soils, Stabilizer

1. Introduction

Expansive soils are well known around the world for their volume change behavior caused by changes in water content [1-5]. The presence of montmorillonite clay minerals, which enables the soil to absorb water during the monsoon season, plays a significant role in the swelling shrinkage behaviour of expansive soils [6, 7]. This soil is regarded as a problematic soil and is unsuitable for use in road construction as a subgrade material or for shallow foundations [8-10] Different infrastructures like pavement distress, building cracks around the corner, pipe line cracks, and power line collapses have occurred due to these soils [11-13]. The applied pressure should be greater than the swelling pressure from the soil [14, 15]. Therefore, the swelling pressure is greater for shallow foundations and causes a lot of damage during the rainy season. In semi-arid and arid regions, expansive soils can seriously harm infrastructure [1, 10, 16 17]. They lose their strength when they get moisture, while they are strong when they dry out [16, 18-20]. Large areas of eastern Africa, including Sudan, Kenya, Ethiopia, and Uganda, are covered in expansive soils.

To control the issues associated with this soil, it must be treated prior to being used as subgrade materials for pavements or foundation supporting materials [13, 21-23] As stated by previous researchers [3-12] mechanical stabilization and chemical stabilization as the most common methods of expansive soil stabilization. Dynamic compaction, reinforce ment, prewetting, treating with solid wastes are among the mechanical stabilization mechanisms, while using traditional and nontraditional agents in soil is among chemical stabilization methods [2, 3, 10, 17, 19]. Nowadays, replacing traditionally known chemical stabilizers like cement and lime with industrial and agricultural by-products is practiced [5, 7, 12, 23, 24]. Agricultural by-products are the most suitable materials for soil stabilization because they are easily available and cheap to purchase [2, 3, 25]. Using those materials is also applicable for environmental protection from solid waste.

Coffee husk and enset fiber is the agricultural byproduct available in large quantity in Ethiopia. Coffee husk is obtained from coffee processing [2, 6, 21]. Ethiopia is the leading producer and consumer of coffee in the area [16, 27]. Tefera et al. [24] stated that with suitable growth conditions, Ethiopia's coffee production is estimated to reach 7.62 million bags (457,200 MT) in 2021–2022, grown steadily over the previous three years. Ethiopia consumes domestically 50–55 percent of its output. 3.55 million Bags will reportedly be consumed locally in MY 2020/21 [24]. About 30 to 50 percent of the weight of the entire coffee produced is waste as coffee husk during the coffee-processing process [6]. This amount of waste is severe environmental pollution if not used as reusable materials. Previous researchers [2, 9, 21] investigate the effect of coffee husk on the engineering properties of expansive soil and revealed that coffee husk ash is a suitable material for expansive soil stabilizer. Enset fiber is also another agricultural byproduct which available in abundant in Ethiopia [28-30]. This fibers may have a good tensile strength and less susceptible to decompose [28]. The effect of this enset fiber to stabilize expansive soil is not studied yet, and this study can investigate the effect of coffee husk ash and enset fiber to stabilize the expansive soil found in Jimma town.

This study aimed to examine the suitability of enset fiber with coffee husk ash on the strength properties of expansive clay soil through experimental investigation. The effectiveness of utilizing enset fiber and coffee husk ash to stabilize an expansive soil is proven by the results of CBR, compaction, and swelling tests.

2. Materials and Methods

2.1. Materials

2.1.1. Expansive Soils

About 40% of the total surface area is covered by expansive soils in Ethiopia, and Jimma town is dominated by these soils. Therefore, soil samples were collected from Jimma City for this study. Different geotechnical properties performed on soil samples before being treated with selected materials reveal that the soil is classified as highly plastic clay soil. Based on the laboratory tests, the soil in the study area is highly expansive soil. The values obtained from laboratory test were tabulated in Table 1 shown below. Whereas the XRD result also shown in Figure 1 shown below.

Table 1. *Engineering Properties of Soils.*

Soil Parameter	Value	Unit	Standard Specification
Natural Moisture Content	48.7	%	ASTM D 2216
Percentage of Course	6.4	%	ASTM D422-63
Percentage of Fine	93.5	%	
Liquid Limit	98.4	%	ASTM D 4318
Plastic Limit	43.5	%	
Free swell	104.8	%	ASTM D 4546
Optimum Moisture Content	23.6	%	ASTM D 1557
Maximum Dry Density	1.47	g/cm^3	
Unconfined Compression Strength	107	Kpa	ASTM D 2166
California Bearing Ratio	1.2	%	

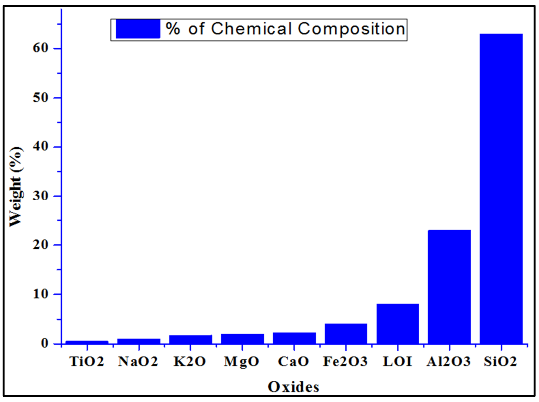

Figure 1. *Chemical Composition of natural clay soils.*

2.1.2. Coffee Husk Ash

Ethiopia is among the top countries producing coffee in abundance. In the same manner, the amount of coffee husk produced during coffee processing was large, and the utilization of this waste material was poor [13]. The CHA used for this study was shown in Figure 2 given below.

Figure 2. *CHA used in this study.*

Little research was done to determine the suitability of coffee husk for soil stabilization in expansive soils. According to some authors [2, 16, 21, 26] investigated the effect of coffee husk on the engineering properties of expansive soils and revealed that this material is suitable for soil stabilization.

The chemical composition of coffee husk ash was determined by XRD and the result was presented in Figure 3 given below. Potassium oxide (K_2O), Loss onignition (LOI), Calcium Oxide (CaO) are the dominant elements in the chemical composition of CHA.

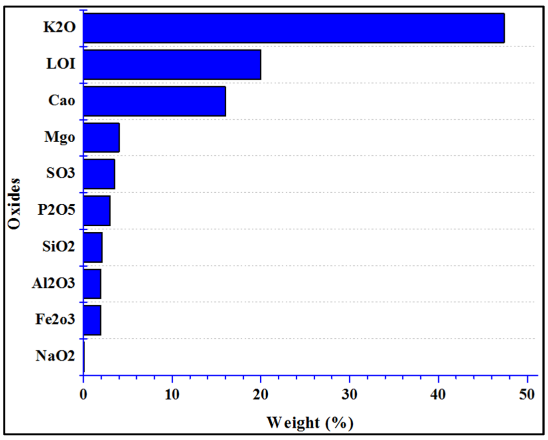

Figure 3. *Chemical Composition of Coffee husk ash.*

The tendency of chemical reaction of coffee husk ash with water may influence the cementation properties of additive material with clap particles. Montmorrillonite is the dominant clay mineralogical exists in expansive soils. This mineralogical is bonded together by alumina and silica sheets. Therefore, the potassium ions found in coffee husk ash react with silica and alumina found in clay particles with water to form cementing agents; which have a significant effect to reduce the plasticity of soil and improve its geotechnical characteristics.

Plasticity of soil is highly affected due to cation exchange existing between clay particles and additive agents. Clay particles have negatively charged particles in nature. But different oxides found in coffee husk ash as shown in Figure 3 above such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), sodium (Na^{+}) hydrogen (H^{+}), aluminum (Al^{3+}), iron (Fe^{2+}), manganese (Mn^{2+}) are positively charged particles [29]. Hence, cation exchange is performed between negatively charged clay soils and positively charged ions found in additive agents. During the process of cation exchange, the thickness of double layer thickness reduced and the clay soils with additive agents increase the flocculations that results in increasing engineering properties of soil. The flocculation agglomoration process occurs when cation exchange take place between clay particles and additive agents. During this process, the pore water pressure present between clay particles reduced and the interparticle friction between clay soils rise, which significantly increased the engineering properties of expansive soils.

2.1.3. Enset Fiber

Enset Fiber is an agricultural waste and available in abundant in Ethiopia. The locally referred to "kacha" (enset fiber) is obtained when the leaf sheath and leaf bases around the pseudo stem are scarped [27]. The structure of this fiber is comparable to that of hair. The inside of the pseudo stem is basically wasted. These leftovers have the potential to provide cellulose fiber and are a significant renewable resource. The test conducted to determine the organic content of enset fiber indicates that enset fiber contains 62% cellulose, hemicellulose 19%, and lignin [26, 25]. Variations in elastic modulus along and across the stem were negligible. Enset fiber has a rupture stress of 360.11 + 181.86 MPa, an elastic modulus of 12.80 + 6.85 GPa, and a strain result of 0.04 + 0.02 mm/mm, respectively [28, 29]. The EF used for this study was shown in Figure 4 shown below.

Figure 4. *Enset fiber used for the study.*

2.2. Methods

The dry soil sample and coffee husk ash are mixed in different proportions. The coffee husk were collected from Jimma town and burned to form ash in a furnace at a controlled temperature. The burning process is free from smoke and environmentally friendly. During mixing, the soil is prepared according to the test standards and the test requirements. The mixes were prepared with different percentages (5%, 10%, 15%, and 20%) of CHA by weight as shown in Figure 5 shown below. After all optimum is taken out of the CHA-soil mix, and for Enset fiber, 0.3%, 0.6%, 0.9%, and 1.2% with the optimum mix of CHA were tested. In order to mix the enset fiber with natural soil and coffee husk ash, it was chopped in to 1-1.5cm.

Figure 5. *Soil-CHA and Enset fiber mix preparation.*

3. Results and Discussion

The suitability of agricultural enset fiber mixed with coffee husk ash as a soil stabilizer was evaluated by conducting different laboratory tests. The tests on treated soil reveal that the enset fiber with coffee husk ash has significantly improved the strength of expansive soils. Some geotechnical tests like Atterberg limits, free swell, California Bearing Ratio (CBR), and compaction tests were used to evaluate the suitability of enset fiber mixed with coffee husk ash to stabilize the expansive soils.

3.1. Optimum CHA Content

The optimum CHA was determined by mixing different percentages of CHA with natural soil and the result was tabulated in Table 2. The addition of CHA in a percentage from 5% to 20% increases MDD from 1.41 g/cm^3 to 1.57 g/cm^3 at an addition of 15% CHA, while it slightly decreases for an addition of 20% CHA. An addition of 15% CHA increases the MDD by 11.35%. In the same manner, the OMC also decreased from 28.6 to 22.5 with the addition of a different percentage of CHA to natural soil. CBR value also increased from 1.4 to 7.6 by 442.86%. The free swell values also decreased from 91.8% to 32.1% for an addition of various percentages of CHA.

Therefore, based on the results obtained with different parameters listed in Table 2 given below, the addition of 15% of CHA to natural soil (NS) improves the strength behaviour of expansive soils in all parameters. Hence, 15% CHA were obtained as the optimum CHA used to treat the expansive soil in this study.

Table 2. *Effect of various percentage of CHA on soil properties.*

Sample	Parameter						
	LL	PL	PI	FS	MDD (g/cm^3)	OMC	CBR
NS +0%CHA	98.4	43.5	54.9	91.8	1.41	28.6	1.4
NS +5%CHA	93.8	45.2	48.6	80.9	1.46	27.4	2.8
NS +10%CHA	82.1	42.7	39.4	68.3	1.51	25.9	4.3
NS +15%CHA	75.5	38.4	37.1	40.6	1.57	24.2	6.5
NS +20%CHA	71.5	36.3	35.2	32.1	1.54	22.5	7.6

3.2. Atterberg Limits Results

3.2.1. Atterberg Limit Results for Treated NS with Varying Percentage of CHA

The Atterberg Limit result for various percentages of CHA was shown in Figure 6 given below. The potential usage of expansive soils can easily determined from Atterberg limits. The higher values of LL and Pl indicate that the soil is highly expansive soil and have a great tendency to swell and shrink for moisture variations [30]. The Liquid Limit decreased from 98.4 to 71.5, the Plastic Limit decreased from 43.5 to 36.3, and the PI decreased from 54.9 to 35.2. At optimum CHA (15% CHA), the plasticity index decreased by 35.34%.

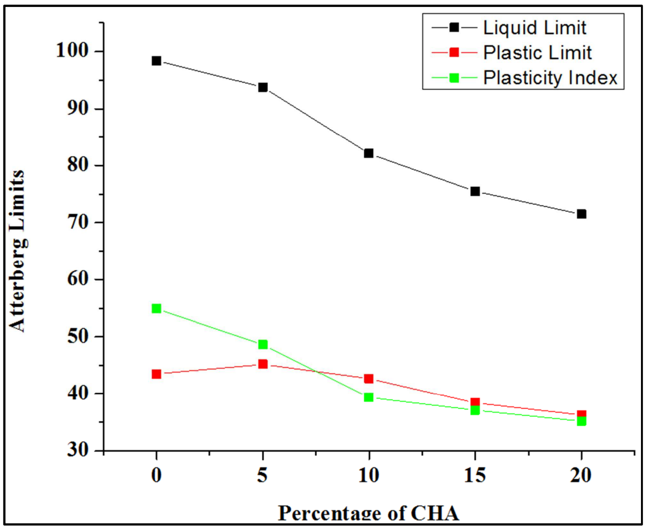

Figure 6. *Effect of CHA on Atterberg Limits.*

According to Munirwan et al. [21] a decrease in LL indicates the reduction of swelling potential of expansive soils. The degree of expansion of natural soil is very high prior to treatment with CHA, but it is changed to a low degree of expansion after treatment with CHA.

3.2.2. Atterberg Limit Results for Treated NS with Optimum CHA and Varying Percentage of EF

The strength of expansive soil can be evaluated from the plasticity index values obtained during the Atterberg limitation experiment. The effect of an addition of CHA and enset fiber on the expansive soil was shown in Figure 7 given below. The addition of optimum 15% of CHA with various percentages of enset fiber from 0.3% to 1.2%, a decrease in liquid limit, and an increase in plastic limit, which can decrease the plasticity index of the soil. As a result, the strength of the soil increased since the plasticity index of the soil decreased.

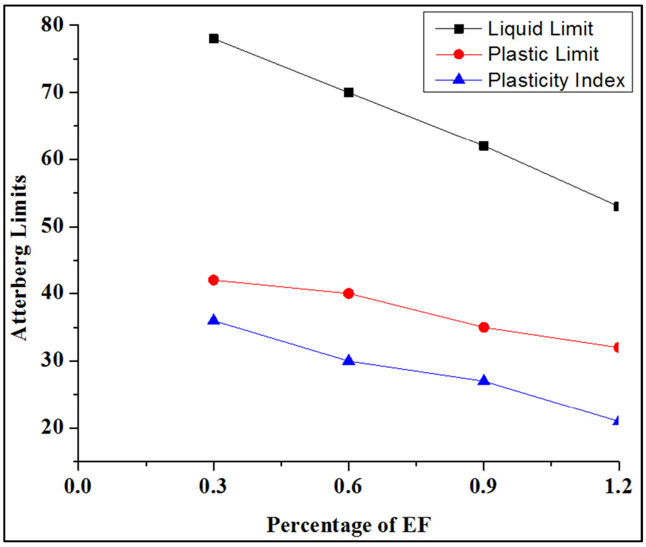

Figure 7. *Effect of EF with optimum CHA on Atterberg Limits.*

The addition of CHA and EF to expansive soil decreases the plasticity of the soil since the addition of pozzolanic materials like CHA and EF reduces the diffuse double layer thickness and enables the flocculation of clay particles to fill the voids in the soil. The reduction in double layer thickness significantly reduces the repulsive force occurring in clay particles, which blocks the density of clay particles. As a result, the clay particles can move freely from one to another and form good agglomeration and flocculation. This result agrees with the findings of [2, 21, 24]. They studied the effect of CHA on expansive soils and state that the addition of CHA decreased the plasticity properties of the soil due to the reaction of pozzolanic materials and clay particles. The flocculation and agglomeration properties of soils with materials reduce the plasticity of expansive soils and increase soil shear strength.

3.3. Free Swell Results for Treated NS with Varying Percentage of CHA

As shown in Table 2 above, the free swell result of natural soil is categorized under highly expansive soils. The FS was decreased from 91.8% to 32.1% for the additional various percentages of CHA from 5% to 20%, which gives an improvement of 65.03%. The effect of various percentages of

CHA on the FS of the soil is shown in Figure 8, given below.

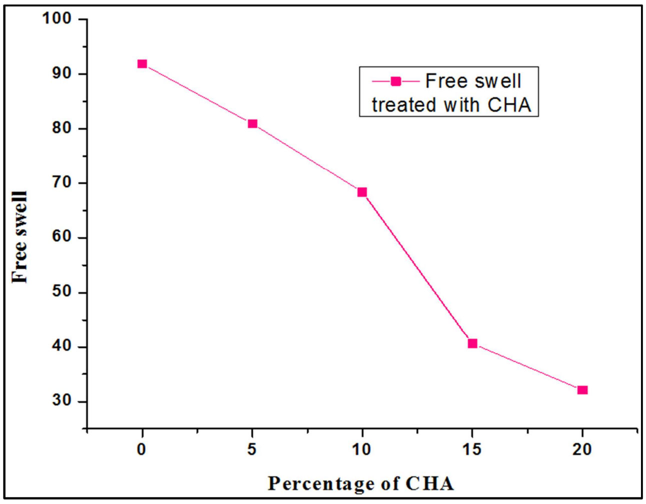

Figure 8. *Effect of CHA on Free swell test.*

3.4. Compaction Test

3.4.1. Compaction Test Results for Treated NS with Varying Percentage of CHA

The effect of the addition of various percentages of CHA on compaction was shown in Figure 9 given below. From Figure 9, we can understand that the addition of CHA with various percentages increases the MDD and decreases the OMC. With an addition of 15%CHA, the MDD increased from 1.41 g/cm^3 to 1.57 g/cm^3, which shows an 11.35% improvement. The addition of CHA increased the dry density of expansive soil since it is used as a filler to fill the voids and the chemical composition of CHA interferes with the adsorbed capacity of expansive soil. The OMC decreased from 28.6% to 22.5%, which implies an improvement of 21.33%.

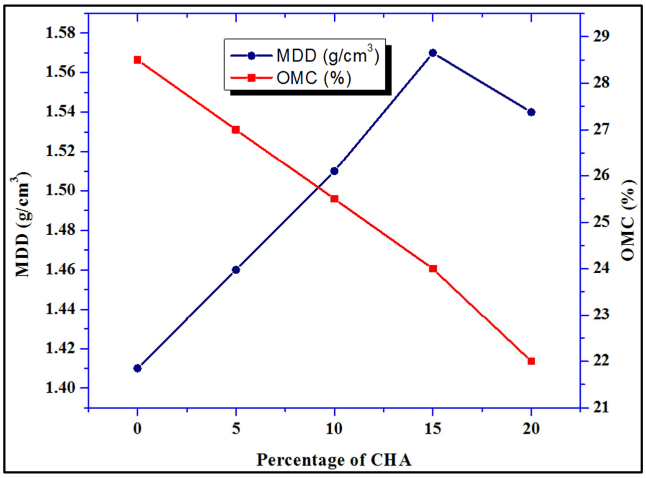

Figure 9. *Effect of CHA on Compaction test.*

3.4.2. Compaction Test Results for Treated NS with Optimum CHA and Varying Percentage of EF

The addition of EF to constant optimum CHA further increases the MDD and decreases the OMC in the compaction test. As shown from Figure 10 given below, the MDD increased from 1.54 g/cm^3 to 1.67 g/cm^3 for an addition of EF with optimum CHA. The increase in MDD also increases the shear strength of the soil. As Munirwan *et al.*, (2022) state the addition of agricultural and industrial ash increases the MDD and decreases the OMC during compaction tests and results in replacing nonusable expansive soil with the most suitable construction material. The same author also stated that some researchers reported different trends for compaction tests using fly ash as a stabilizing agent. The more the soil has MDD, the greater the shear strength of the soil. This increment of MDD basically comes from the filling property of EF materials in the void spaces of the soil. The chemical nature of stabilizing agents provides a reasonable insight into how effective they are at stabilizing soil, and the reaction of calcium hydroxide with silica and alumina in the soil can result in cementation products [10, 16].

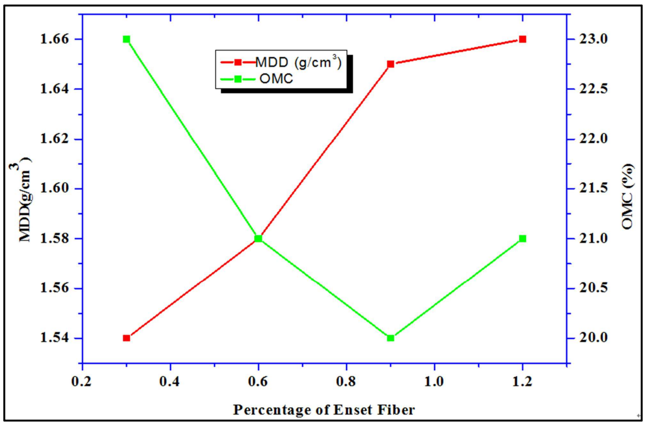

Figure 10. *Effect of EF with optimum CHA on Compaction test.*

The reduction in repulsive force in clay particles due to the minimization of diffuse double layer thickness enables the expansive soil to compact with small water content and results in an increasing density of soil as well as the shear strength of the expansive soil. The agglomeration and flocculation of clay particles results in quick cation exchange between soil and stabilizing materials, which significantly increases the MDD of expansive soils [3]. The water solubility of soil is decreased after treating the soil with the additive agents, which results in a decrease in OMC. This result strongly agrees with previous researchers. Previous researchers studied the effect of CHA on MDD and OMC, and they stated that an addition of CHA increased the MDD while decreasing the OMC of expansive soils [9, 26].

3.5. California Bearing Ratio (CBR) and CBR Swell Test

3.5.1. CBR and CBR Swell Test Results for Treated NS with Varying Percentage of CHA

The CBR value is used to evaluate the suitability of subgrade materials for pavement construction. Soaked CBR is used in this study since soaked CBR is considered the worst condition of expansive soil in high moisture [21]. According to ERA, [31] a CBR value of less than 5 is considered a poor subgrade material and not suitable for road construction. The subgrade soil, which has a poor CBR value, can cause large destruction on other pavement layers before the road serving pavement design period. The cost used during the maintenance of the road also causes economic losses. Poor subgrade material has a direct impact on pavement or economic losses. The CBR values of natural soils treated with CHA are shown in Figure 11, given below.

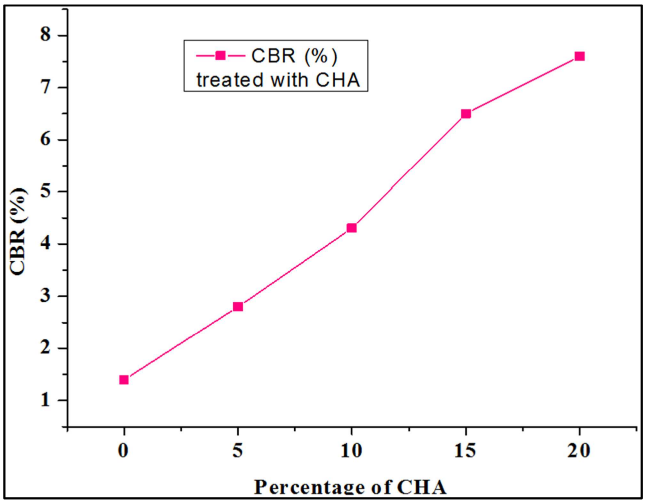

Figure 11. *Effect of CHA on CBR value test.*

As shown in Figure 11 shown above, the CBR value increased as the amount of CHA increased, while the CBR Swell test decreased. The natural soil has a CBR value of 1.4, which is a poor subgrade material. However, the addition of CHA by 5%, 10%, 15%, and 20% increases the CBR value by 100%, 207.1%, 364.29%, and 442.86%, respectively. The CBR swell values also decreased from 10% to 8.1%, 6.3%, 4.0%, and 2.6% for an addition of 5%, 10%, 15%, and 20% of CHA with natural soils. The swell potential of natural soil was reduced by 60% at the optimum CHA content. The reduction of CBR swell is due to the addition of nonswelling CHA material to natural soils. During the mix of CHA with natural soils, they form good agglomeration and reduce the change in volume of expansive soils. This result highly agrees with previous studies on the effect of CHA on expansive soils. Sabat Ak., (2012) stated that the addition of CHA decreases the CBR swell in addition to increasing the CBR value [2, 9] Atahu et al. [17] also mentioned that the addition of CHA decreases the CBR swell and, according to his findings, the addition of CHA with weight varying from 5% to 25% reduces the CBR swell by 9.41% to 82.77%.

3.5.2. CBR and CBR Swell Test Results for Treated NS with Optimum CHA and Varying Percentage of EF.

The soaked CBR value was significantly increased by treating expansive soils with optimum CHA and varying the EF content. The CBR value increased from 4.5% to 15.8% for an addition of EF with optimum CHA. The CBR value increased by 200% at an addition of 0.9% of EF with optimum CHA. The effect of optimum CHA with a varying percentage of EF on CBR value is shown in Figure 12.

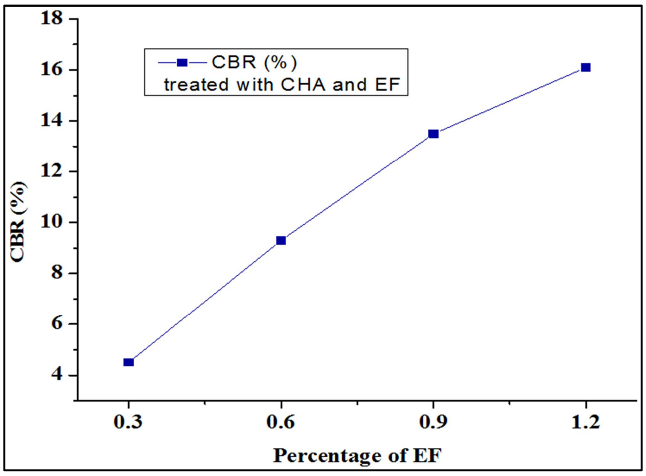

Figure 12. *Effect of EF with optimum CHA on CBR value test.*

The addition of enset fiber with optimum coffee husk ash enables the soil to have good tensile properties and it acts as a frictional inhabitant component. The toughness of the soil also becomes greater than the virgin soil due to the addition of CHA and EF, which significantly increase the CBR values of the soil. Because of the interlocking of the soils with additive agents, the CBR value increased significantly. The enset fiber increases the tensile property of the soil-mixture sample and increases the deformation resistance of soil. The CBR swell was also significantly decreased due to the addition of EF with optimum CHA. The CBR swell decreased from 3.1% to 1.2% with an addition of EF with optimum CHA.

4. Conclusion

This study aims to evaluate the suitability of enset fiber mixed with coffee husk ash as a soil stabilizer. To achieve the objectives of this study, natural soil is mixed with different percentages of coffee husk ash (5%, 10%, 15%, and 20%) and the optimum CHA is obtained as 15% CHA. After determination of optimum CHA, natural soil was mixed with optimum CHA and a varying percentage of EF (0.3%, 0.6%, 0.9%, and 1.2%) and different geotechnical parameters were evaluated. In general, 15% of CHA and 0.9% of EF were taken as optimum additives according to the result of this study. Based on the findings, the following conclusions can be drawn from this study:

1) The agricultural wastes used in this study are suitable to stabilize the expansive soil for use as subgrade materials.
2) The use of agricultural waste in the construction industry, such as soil stabilization, is critical because it can help with waste management, environmental protection, and increasing the use of environmentally friendly materials.
3) The addition of CHA and EF to expansive soil increases PL and decreases the LL and PI. The decrease in PI significantly increases the shear strength of the soil.
4) When CHA and EF were combined, the free swell value

decreased. After treatment with CHA and EF, the virgin soils were transformed from highly expansive clay soils to low expansive soil.

5) For an increase in both CHA and EF, the MDD increased while the OMC slightly decreased.
6) Both CBR and swell improved in this study. The CBR value increased from 4.5% to 15.8% for an addition of EF with optimum CHA. The CBR value increased by 200% at an addition of 0.9% of EF with optimum CHA.
7) On the basis of the results, it is concluded that at 15% of CHA and 0.9% of EF, the expansive soil is stabilized and more suitable for subgrade material.
8) This study examine the suitability of coffee husk ash with enset fiber for expansive soil stabilization, so it is concluded that using both waste materials is cost effective and environmental friendly materials for stabilization of expansive soils.

Data Availability

All information provided in the conclusion is presented in the full document.

Conflict of Interest

The author declares that they have no conflicts of interest.

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