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Research Article

Effects of Corn Cob Ash as Partial Replacement of Cement for Stabilization of an Expansive Clay

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Expansive soil is a serious problem because it damages civil engineering projects and has an impact on Ethiopia's road development expansion. In this study, an attempt has been made to assess the effects of corn cob ash (CCA) as a partial replacement of cement for the stabilization of an expansive clay to be used as road subgrade material. Corn cob is a waste agricultural product obtained during the production of corn. After it has been converted to ash, tests are carried out on the pozzolanic property and elemental composition of corn cob ash (CCA). Preliminary tests were performed on the natural soil sample for purposes of classification and identification of some required properties of the sample. Following the required preliminary laboratory analysis, the clay was stabilized with cement and CCA in varying proportions of 2, 4, 6, and 8%, separately. The maximum stabilization effect occurs at 8 and 4% of cement and CCA, respectively. With this percentage, the CBR of the sample increased from 2.62% at 0% to 10.47% and 3.31% at 8 and 4% of cement and CCA, respectively. As a result, 8% of cement was taken as the total amount for different cement and corn cob ash (C: CCA) ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4 in the blending stabilization. The optimum blending effect on the strength of stabilized subgrade occurs at a 1 : 2 ratio, containing 2.7% cement and 5.3% CCA. With this ratio, the CBR of the sample increased from 2.62% at 0% to 6.72%. As a result, 5.3% of the cement was substituted with CCA, which had a comparable effect on subgrade strength due to the ideal percentage of cement stabilized. Hence, it can be concluded that CCA can serve as a good complement for the partial replacement of cement in subgrade stabilization.

1. Introduction

Engineers and geologists are now more aware of a wide range of features due to studies on the engineering properties of these materials. One of the key elements that directly affects the investment cost of road projects across the globe is the accessibility of natural construction materials within an acceptable travel distance. However, in some areas, natural building materials are either unavailable or fall short of the standards for materials used to build roads. A scenario that typically necessitates the use of resources imported from other regions, resulting in increased expenses, does not provide economic road building [1]. One of these materials that are readily available in Ethiopia is clayey.

Fertile, agriculturally suitable, and forest-covered lands in Ethiopia are dominated by expansive soils [2]. Under changing environmental conditions, these soils exhibit very strong swelling and shrinkage properties [3, 4]. Volumetric changes hinder the subgrade by causing cracking, which causes damage to the structures above. In areas where resources are scarce, it is common to use appropriate stabilization methodologies by mechanical or chemical means to create an enhanced soil material with the desired engineering properties [5–7].

Soil stabilization is the mechanical or chemical modification of one or more soil properties in order to produce an improved soil material with the preferred engineering properties [6]. Through cation exchange, flocculation, agglomeration, and pozzolanic reactions, those procedures are utilized to stabilize soils and change their characteristics. Commercial soil improvement agents, such as cement [8], lime [9, 10], and bitumen [9], are used. Although they are popular additives, the fact that they are produced industrially keeps the cost high. Large amounts of domestic and agricultural wastes [11], fly ash [12], sugarcane bagasse, and husk ash, on the other hand, have been used as alternate solutions and cost-effective raw materials for soil stabilization [13–15]. Stabilization improves soil strength while decreasing plasticity and decreasing or sometimes rising permeability, leading to higher soil strength, lower volume changes due to moisture variations, and improved soil workability [16]. According to the Index, properties limit value, and gradation test, clay soil can be classified as having low, medium, high, or very high expansion potential. Soils designated as CH by USCS, in general, [17] According to AASHTO categorization systems, A-7-5 and A-7-5 may be termed expansive soils [18, 19]. Clay soil is chemically stabilized by the stabilizer's pozzolanic activity or cationic interchange. Pozzolana, a chemical component, combines chemically with calcium hydroxide, which is produced when Portland cement hydrates at ordinary room temperature, to produce compounds with cementitious properties when finely divided and in the presence of moisture [20, 21]. Pozzolanic materials are made up of alumina (Al_2O_3), silica (SiO_2), and ferrite (Fe_2O_3) oxides in amounts equal to or greater than 70% by weight [22, 23]. Pozzolanas are added, which reduces porosity and pore diameters and increases strength. Pozzolanic reactions are silica reactions that result in the formation of calcium silicate hydrates when calcium hydroxide and water are present (C-S-H) [24]. The cost of constructing stabilized roads has remained expensive because of an excessive reliance on soil-improving additives produced industrially, such as cement, lime, and others [25]. The expense of building highways in developing countries has soared since most of them are inaccessible to rural people, who make up a substantial proportion of their population. The potential use of agricultural wastes such as corn cob ash (CCA) will significantly reduce construction costs.

Corn is one of the major production crops in Ethiopia. Next to Nigeria, Ethiopia produces the second most corn in sub-Saharan Africa. Ethiopia's corn production in 2020 was 8600 thousand tonnes [26] and it fulfilled the minimum requirements for pozzolanic properties stated by ASTM. However, the crop's by-products (corn cob) are still thrown off without any use. Therefore, this study aims to use this abundant agricultural waste product as a stabilizing agent in the hope of reducing the amount of CO_2 released into the atmosphere during the production of commercial stabilizing agents. And reducing the extraction of substantial amounts of nonrenewable natural resources for construction projects also creates significant damaging impacts on the local environment and its inhabitants. And, it also creates a source of income for corn producers (farmers).

2. Materials and Methods

The purpose of the study was to determine the applicability of cement, corn cob ash, and their combination to stabilize expansive clayey soil.

2.1. Materials

2.1.1. Corn Cob Ash. After the harvest season, corn cobs from Gojjam, Amhara Regional State, Ethiopia, were acquired for this investigation.

The gathered corn cobs were dried by the sun before being openly burned on a metal sheet until they were reduced to ash, keeping the ash separate from the dust. When the burned corn cob had cooled, it was crushed, and the ashes were sieved through a 425 μm (see Figure1).

2.1.2. Cement. A local market was used to obtain commercially available type I ordinary Portland cement (OPC). This cement has a specific gravity of 3.15, a grade of 42.5R, and a good capacity for sulphate resistance [9]. It is also easily accessible in Ethiopia Table 1.

2.1.3. Expansive Clay. The clayey sample was obtained around Hamusit, Amhara Regional State, Ethiopia, at the location of 11°47′N and 37°28′E. The depth of any specimen hole should not be less than 1.5 m, unless rocks or other material difficult to extract by hand are encountered, according to ERA. To avoid the presence of organic matter, the disturbed sample soil was collected along the soil profile at a depth of 1.5 m. According to preliminary examinations, the soil was greyish black in colour, extremely fractured, and flexible in character.

2.2. Methods. Grain size distribution, free swell, specific gravity, and Atterberg limits were among the tests used to determine the classification of the soil. To determine if the soil is expansive or not, these are suggestive tests that are frequently employed. Analyses of hydrometers, wet sieves, and the relationship between moisture density and CBR were all part of the experiments that were run.

2.2.1. Standard Tasting Procedures. Standards and specifications for this study were adapted from AASHTO, ASTM, and IS. Those are tabulated in Table 2.

2.2.2. Chemical Property of Corn Cob Ash. According to ASTM C 618, the chemical make-up of CCA was evaluated. Table 3 lists the CCA's chemical attributes that were employed in this study. X-ray fluorescence apparatus was used to evaluate the chemical composition of corn cob ash (Spectro X-lab). The utility of natural pozzolanas in enhancing the material's sulphate resistance is assessed using this apparatus.

2.2.3. Sample Preparation. The soil samples were ground up after being air dried, and a dry mixture of the soil and the addition was used to create the mixed sample. A range of 2 to 8% of the weight of the soil used for each test was used to blend the expanding clay with the cement-stabilized sample, with 2% intervals between the two percentages. In a similar manner, the expanding clay was mixed with the ash

Figure 1: Pieces of corn cob.

Table 1: Oxide content of ordinary portland cement.

Oxides	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_2	MgO	Na_2O	K_2O
Ranges (%)	60–70	17–25	3–8	0.5–6	1–3	0.1–4	0.5–1.3	0.5–1.3

Table 2: Summary of standards and specifications.

Tests conducted	Test methods		
	AASHTO	Astem	IS
X-ray fluorescence equipment (spectro X-lab)		C618-03	
Moisture content	T265		
Grain size analysis		D422-63	
Atterberg limits	T89 & 90		
Soil classification		D2487-98	
Specific gravity		D854-83	
Standard proctor compaction	T99-94	D698-98	
CBR	T193-93	D1883	
Free swell index			2720 (part 40)

Table 3: The oxide content of corn cob ash (CCA).

Oxide composition	Test result in (%)	ASTM (C618) requirement in (%)	Remark
SiO_2	63.53	35 min	Satisfied
Al_2O_3	5.45		
Fe_2O_3	2.91		
CaO	1.71		
MgO	0.63	5 max	Satisfied
$SiO_2 + Al_2O_3 + Fe_2O_3$	71.89	70 min	Satisfied

stabilized sample at intervals of 2% to 8% of the weight of soil used for each test. The cumulative percentage for the blending of cement and CCA with various cement and corn cob ash (C: CCA) (1 : 1, 1 : 2, 1 : 3, and 1 : 4) ratios is taken into consideration for blending stabilization.

2.2.4. Grain Size Analysis. This experiment is carried out to determine the percentage of various grain sizes that are present in a certain soil. To ascertain the particle distribution, sieve analysis and the hydrometer method are both employed. According to ASTM D422-63, wet sieve analysis and hydrometer analysis were both completed. Mechanical (sieve) analysis or sedimentation analysis are also possible methods for determining particle size. For the investigation of fine-grained soil (silt and clay) whose particle size is less than No. 200, sedimentation analysis is utilized (0.075 mm). Hydrometer analysis was used to accomplish the sedimentation analysis [22].

2.2.5. Specific Gravity. A soil sample that had been put through a 2 mm sieve and had been oven dried at 110°C was used to estimate the specific gravity, which is a measurement of how heavy the soil particles are. The mass of a unit volume of soil at a given temperature divided by the mass of a unit volume of gas-free distilled water at that same temperature is known as specific gravity. The samples' specific gravities were calculated utilizing ASTM D 854-83.

2.2.6. Atterberg Limit Test. The purpose of this test was to identify the soil's plastic and liquid limits. The water content, expressed as a percentage, is the arbitrary definition of the liquid limit (LL). The existence of clay minerals has a significant impact on a soil's liquid limit. In compliance with AASHTO T 89 test methods, the liquid limit test was completed. When a soil reaches its plastic limit (PL), it can no longer be deformed without disintegrating into 3.2 mm (1/8 in.) diameter threads. The mixed CCA and cement content is applied using the same manner to the treated soil. The traditional plastic limit test is conducted in accordance with AASHTO T 90s instructions. Table 4 illustrates the outcomes of the Atterberg limit test computed for the samples that were collected.

2.2.7. Linear Shrinkage. The reduction in a soil mass's one dimension, expressed as a percentage of the mass's initial dimension, is known as linear shrinkage (LS). It describes the length change brought about by drying a cylindrical soil sample that was initially at its liquid limit. LS is the length of the sample at which the liquid limit for standard mould is approximately reached.

2.2.8. Compaction. For each sample of cement, CCA, and blended (C: CCA) stabilized, a compaction test was performed to ascertain the ideal moisture content (OMC) and maximum dray density (MDD). The process was repeated with different water contents until the sample's OMC and MDD were determined with standard compaction in accordance with ASTM D698 and AASHTO T99-94. Each compacted soil sample's density and moisture content were measured after which the correlations between dry density and moisture content were determined.

2.2.9. California Bearing Ratio (CBR). As per ASTM D1883 and AASHTO T193 standards, the California Bearing Ratio (CBR) was calculated using air-dried samples of natural soil with cement, CCA, and blending additives of the recommended percent compacted with their respective densities and optimal moisture contents. Take 5 kg of natural soil and a mixture of soil with varied percentages of additions, both at their optimal moisture level, then compact them with 56 blows for three layers for each sample. For 96 hours, the compacted samples of the CBR moulds were submerged in water to replicate the worst-case scenario that might occur in the field. A soil's resistance to shear under-regulated moisture and density conditions is measured by the CBR test. This number is calculated by dividing the load required to achieve the same depth of penetration on a standard sample of crushed stone (2.45 mm and 5.08 mm) by the load necessary to compact the soil at the specified OMC and MDD.

2.2.10. CBR Swell of the Soil. The CBR swell of the soil is obtained by immersing the compacted soil samples of the CBR mould in water for 96 hours. The initial dial reading of the soil is obtained immediately after the sample has been soaked in the CBR mould. The dial indicator's final reading is obtained after 96 hours have passed.

3. Results and Discussion

The following tests were run as part of the study to evaluate the natural and stabilized soil samples independently. In order to achieve the necessary chemical interaction between the constituents, a 24-hour-soaked sample was used to evaluate gradation, specific gravity, and Atterberg limits. A 4-day-soaked sample was used to assess CBR and CBR swell.

3.1. Chemical Properties of Corn Cob Ash (CCA). Pozzolana's fundamental properties, including density, surface area, and chemical composition, affect how quickly the pozzolanic reaction occurs. The rate can also be influenced by outside variables such mix ratios, water content, reaction temperature, curing conditions, and time [20].

SiO_2, Al_2O_3, and Fe_2O_3 made up 71.89% primary oxide composition, above the minimum of 70% required by ASTM (C618) for a satisfactory pozzolan. Table 3 presents the outcomes of the chemical composition test performed on corn cob ash.

3.2. Untreated Expansive Soil. The findings of the tests performed to identify and/or ascertain the characteristics of the natural soil before adding cement and corn cob ash are shown in Table 4.

3.2.1. Grain Size Distribution. For material that is retained on No. 200 sieves, the gradation analysis must be carried out using mechanical sieves, and for material that passes through No. 200 sieves, it must be done using a hydrometer. According to the laboratory results from the mechanical sieve and hydrometer tests, as shown in Figure 2, the sample subgrade soil contains 6% of sand, 42% of silt particles, and 52% of clay particles.

3.2.2. Soil Classification. The expansive clay soil's liquid limit, plastic limit, and plasticity index were calculated and are shown in Table 5. According to the findings of the laboratory tests performed on the untreated soil sample used in this study, the percentage of fines passing the No. 200 sieve is 92.09%, the percentage of liquid is 96.5%, and the percentage of plasticity index is 57.11%. This suggests that the sample was classified as CH under the Unified Soil Classification System (USCS) in accordance with ASTM D2487 and A-7-5 under the AASHTO M145 classification system as illustrated in Figures 3 and 4, respectively. When it comes to this class of soils' engineering performance, expansive soils with significant volume change and variable moisture content are what is meant [27]. The expansive nature of the soil was also demonstrated by the free swell index of 83%, which is higher than 50%.

3.2.3. CBR and CBR Swell of Untreated Soil. After soaking samples for 96 hours, CBR and CBR swell were determined. Table 4 illustrates that the samples exhibited CBR and CBR swell of 2.62% and 4.11%, respectively.

Table 4: Summary of geotechnical properties of the untreated soil sample.

Parameter		Laboratory result	
Percentage of passing through No. 200		92.9%	
Liquid limit		96.5%	
Plastic limit		39.39%	
Plasticity index		57.11%	
Linear shrinkage		26%	
Soil classification	USCS		CH
	AASHTO		A-7-5
Specific gravity of soil		2.71	
Natural moisture content		45.48%	
Free swell		83%	
Compaction test result	MDD		1.385 g/cm^3
	OMC		36.5%
California bearing ratio (CBR)		2.62%	
CBR swell		4.11%	

Table 5: CBR and CBR swell data for cement-treated sample.

% of cement	% CBR swelling	Penetration (mm)	CBR (%)	Max CBR (%)	ERA requirement	Remark
0	4.11	2.54	2.62	2.62		Poor
		5.08	2.45			
2	3.52	2.54	5.04	5.04		Satisfied
		5.08	4.58			
4	3.37	2.54	4.94	6.16	>3%	Satisfied
		5.08	6.16			
6	2.94	2.54	6.23	7.11		Satisfied
		5.08	7.11			
8	2.64	2.54	10.30	12.25		Satisfied
		5.08	12.25			

Liquid limits of less than 35% generally indicate poor plasticity, limits of 35 to 50% suggest intermediate plasticity, limits of 50 to 70% indicate high plasticity, and limits of 70 to 90% indicate extremely high plasticity [9]. These results show that the soil sample has a very high plastic clay content. As a result, the subgrade is easily affected by changes in temperature and does not withstand the external or internal load. The building will finally start to crumble and can be easily destroyed. Stabilization with various chemicals ought to be necessary to protector against this failure.

In addition, the soils' CBR and percent swell of 2.62% and 4.11%, respectively, show that they have a low load-bearing capacity and a high swelling potential when compared to the ERA's specifications of CBR >3% and percent swell of less than 2%, rendering them unsuitable for construction in the absence of an appropriate treatment measure. But based on the comparisons made above between the ERA design guideline and the soil test findings, it can be concluded that the soil sample does not meet the criteria for use as a subgrade and is therefore inappropriate for use as a subgrade in road construction. Consequently, before to usage, the subgrade soil should be improved using the right techniques.

3.3. Laboratory Test Results of Stabilized Expansive Soil

3.3.1. Test Results of Cement-Stabilized Soil. The laboratory test findings for the Atterberg limit reveal that as the proportion of cement increases, the plasticity index drops. The cement proportion ranges from 2 to 8%, with 2% intervals in between. As demonstrated in Figure 5, the plastic index drops from 57.39% to 10.47%, and the linear shrinkage drops from 26% to 8.29%. This is because the calcium ion content in cement was significant enough to decrease the space in the clay by displacing the sodium ions [23].

The ASTM D698 technique C is used to estimate the moisture density relations. Various cement addition rates to the sample soil (2%, 4%, 6%, and 8%) were tested. Figure 6 plots the moisture content against a dry density graph to determine MDD and OMC; this suggests that as cement is applied to the soil, the dry density rises from 1.385 g/cm^3 to 1.460 g/cm^3 and the OMC falls from 36.5% to 30.5%. The explanation is cement's high water absorption capacity, which results in a decrease in OMC and an increase in MDD. With different amounts of cement, the fluctuation in the ideal moisture content and dry density was plotted as shown in Figure7.

According to the findings of the CBR laboratory tests, adding different types of cement to the soil enhances the soil's capacity to swell as well as its overall strength. CBR values vary from 2.62 to 12.25 and CBR swellings drop from 4.11 to 2.64 when the cement percentage rises from 0 to 8%, as illustrated in Table 5 and Figure 8.

3.3.2. Soil Stabilized by Corn Cob Ash Test Results. The Atterberg limit was detected in the laboratory test. CCA was added to the sample soil with the specified percentage of

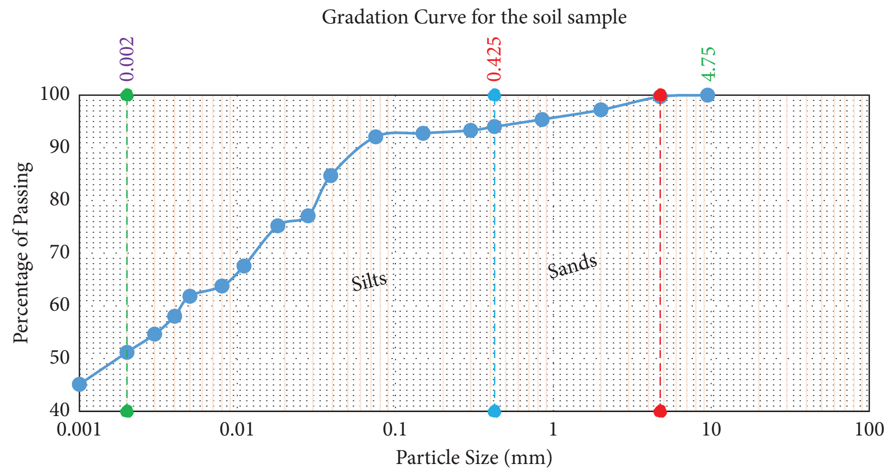

Figure 2: Grain size distribution curve for sample soil.

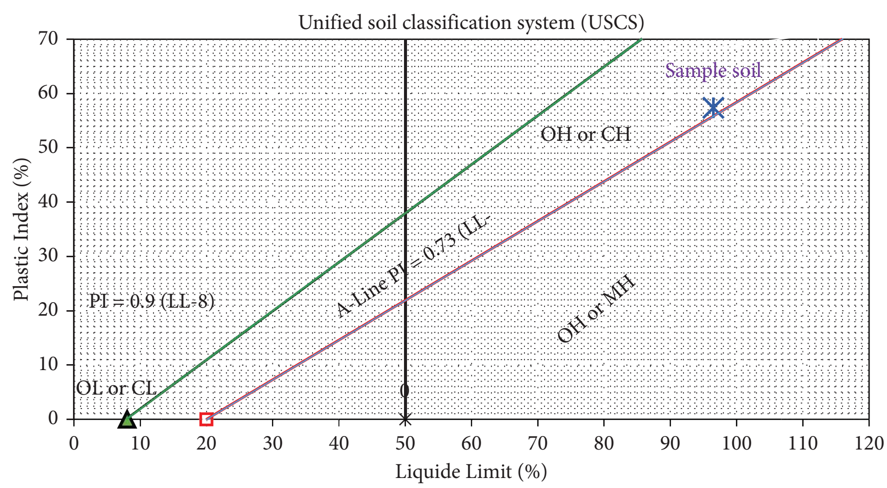

Figure 3: USCS classification of natural soil.

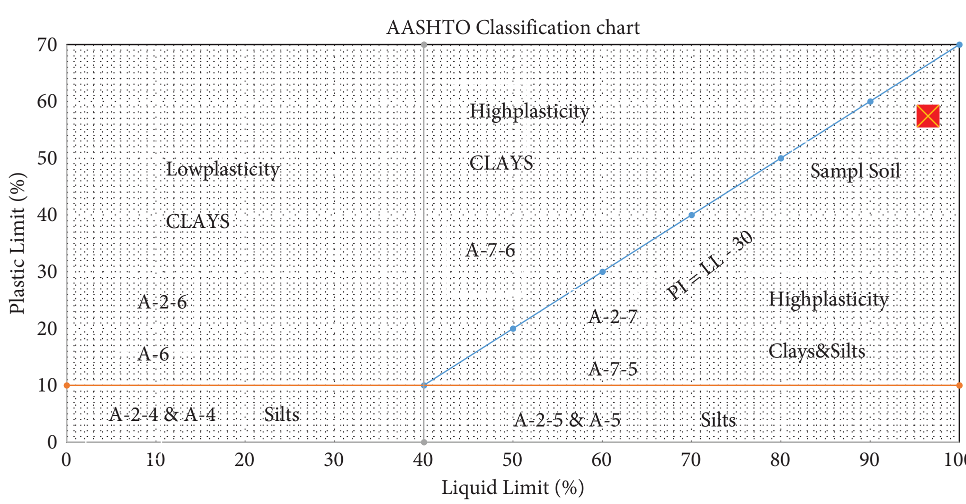

Figure 4: AASHTO Classification of natural soil.

2–8% with a 2% interval as a stabilizer. By adding CCA, the soil's proportion of CCA grew by 2, 4, 6, and 8%. The linear shrinkage also changes, as seen in Figures 9 and 10, and the plasticity index varies by 34.26, 33.73, 36.96, and 41.74%, as shown in Figure 5. The plasticity index typically declines until it reaches its maximum value as the amount of CCA

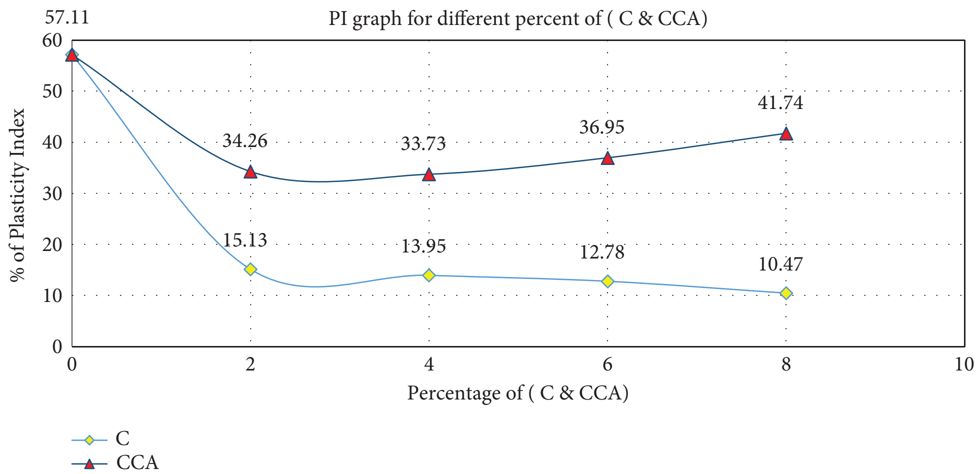

Figure 5: Effect of cement and CCA on plasticity index of sample soil.

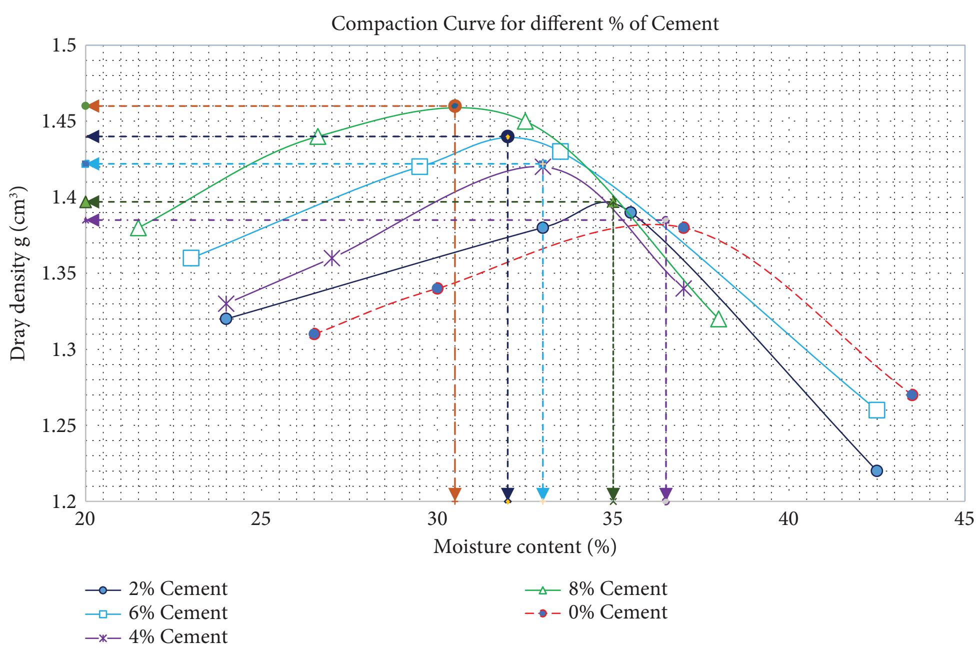

Figure 6: Compaction curve for cement-treated soil sample.

added to the soil increases in comparison to natural soil. As more CCA is applied to the soil, the linear shrinkage reduces. [7].

To determine the impact of adding various CCA concentrations to the subgrade soil on the relationships between moisture and density, compaction tests were carried out for this investigation. The results of this test showed how the maximum dry density and its related ideal moisture content were influenced by the recommended proportion of CCA stabilizer based on the compaction curve in Figure 10. Until the soil reaches its optimum dosage of CCA, the amount of CCA added improves maximum dry density as compared to untreated soil, but as soon as the dosage of CCA is exceeding the optimum dosage, the MDD starts to decrease. In comparison to natural subgrade soil, the ideal moisture level likewise dropped, proving the CCA's water-absorbing characteristics. Figure 7 illustrates the difference in optimal moisture content and dry density with varied cement percentages.

The CBR value has increased somewhat as compared to untreated soil, and the CBR swell decreased until it received the ideal dose from CCA, after which the dosage increased above the optimum replacement dosage, as indicated in Table 6 and Figure 8. Except for 2% of CCA, which is the minimal criterion as per ERA subgrade specification, all samples' test results for the CBR value were greater than 3%. The investigation demonstrates that the least CBR swell was reached at 4% CCA, the greatest CBR, and comparatively untreated sample. Therefore, in both situations, a low dose of the additive was preferred.

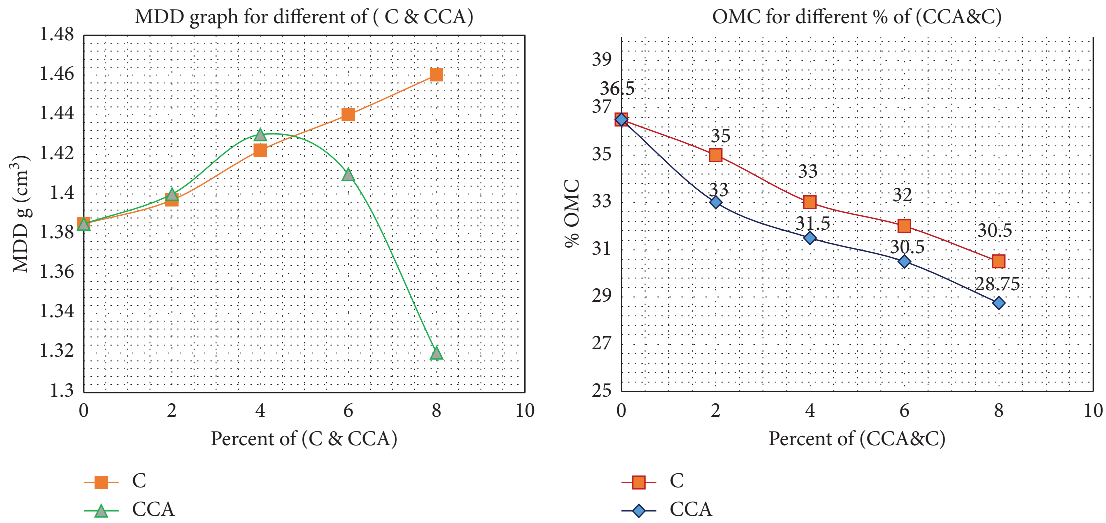

Figure 7: Variation of OMC and MDD for different % of cement and CCA.

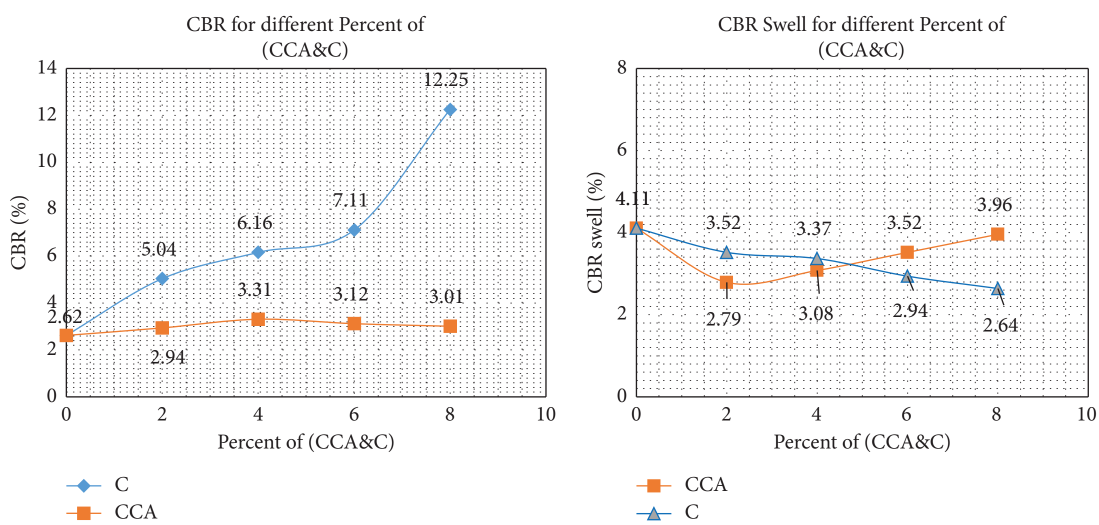

Figure 8: Effect of different % of cement and CCA on CBR and CBR swell.

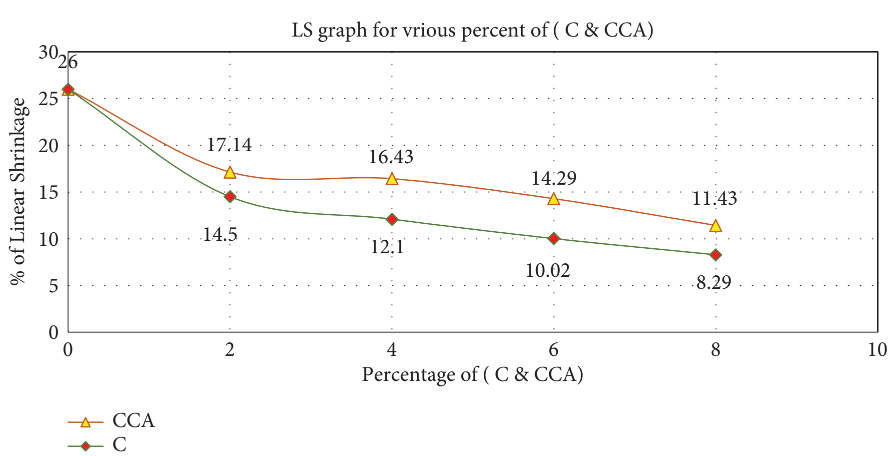

Figure 9: Effect of cement and CCA on linear shrinkage limit.

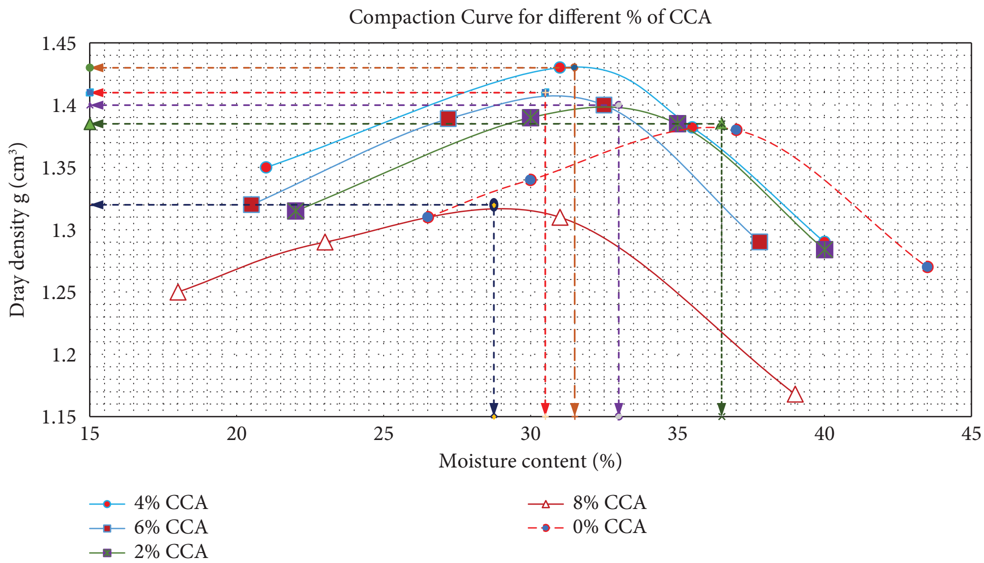

Figure 10: Compaction curve for CCA-treated soil sample.

Table 6: CBR and CBR swell data for CCA-treated sample.

% of CCA	% CBR swelling	Penetration (mm)	CBR (%)	Max CBR (%)	ERA requirement	Remark
0	4.11	2.54 5.08	2.62 2.45	2.62		Poor
2	2.79	2.54 5.08	2.87 2.94	2.94		Poor
4	3.08	2.54 5.08	3.31 2.99	3.31	>3%	Satisfied
6	3.52	2.54 5.08	3.12 2.91	3.12		Satisfied
8	3.96	2.54 5.08	2.80 3.01	3.01		Satisfied

Table 7: Percentage of proposed stabilizer.

Percentage of stabilizer				
Cement stabilization	Blending stabilization			CCA stabilization
		Commutative value optimum 8% of C		
% of C	C: CCA ratio	% of C	% of CCA	% of CCA
2	1 : 1	4	4	2
4	1 : 2	2.7	5.3	4
6	1 : 3	2	6	6
8	1 : 4	1.6	6.4	8

3.3.3. Results of Soil Stabilized by Cement Blend with Corn Cob Ash. The main objective of this study was to assess the impact of corn cob ash on index characteristics, linear shrinkage, moisture density relation, CBR, and CBR swell for partial replacement of cement. The cumulative value of cement and corn cob ash was taken to be the maximum strength of 8% of cement for all laboratory tests. According to Table 7, the highest strength occurs at 8% cement stabilized for the suggested 2 to 8% with a 2% interval. Therefore, this percent is used as the cumulative amount for blending stabilization (C + CCA = 8%) with various C: CCA ratios (1 : 1, 1 : 2, 1 : 3, and 1 : 4).

To investigate the blending effects of cement and corn cob ash added to the natural soil in various ratios of 1 : 1, 1 : 2, 1 : 3, and 1 : 4, linear shrinkage tests and Atterberg limit lab results such as liquid limit, plastic limit, and plastic index were carried out. The findings of the laboratory test demonstrate that the plasticity index of the treated soil samples

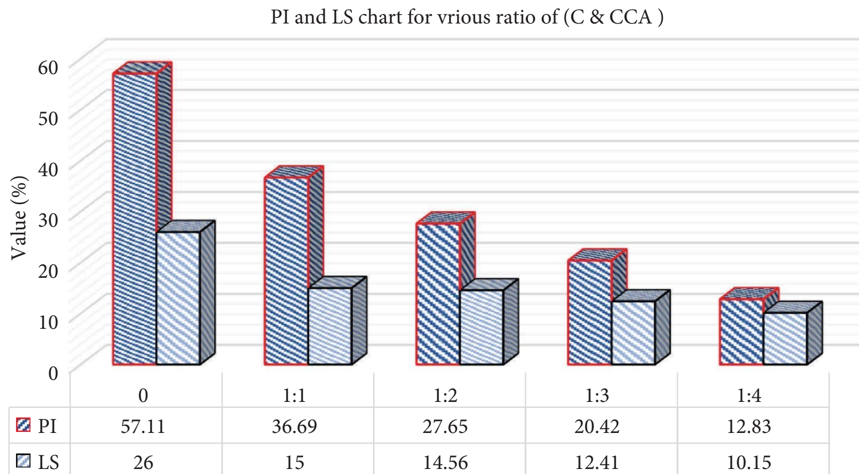

Figure 11: PI and LS chart for different ratios of (C: CCA).

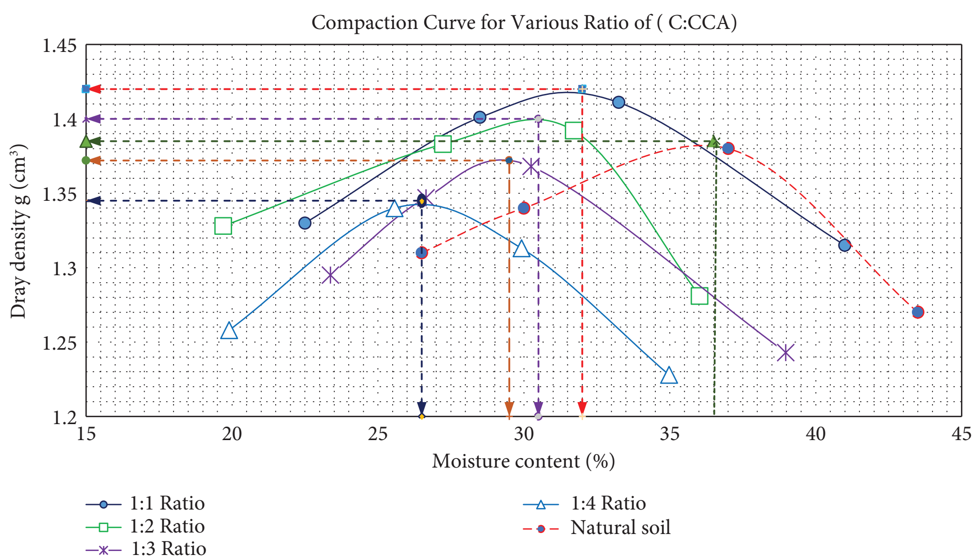

Figure 12: Compaction curves for different ratios of (C: CCA).

dramatically fell as the percentage of cement grew, whereas it increased when the percentage of CCA increased. In addition, linear shrinkage somewhat decreased, as shown in Figure 11. This is the cause, as a result of the amount of calcium ions in CCA is insufficient to completely replace the sodium ions in soil particles. So in order to replace the sodium ion in a soil particle, it is necessary to move a specific amount of calcium ion from cement.

Figure 12 depicts the influence of varying blending ratios of the suggested stabilizer on maximum dry density and its related optimal moisture content from the compaction curve. The MDD increases somewhat from an untreated sample to its optimal point, but the OMC decreases in the treatment of poor subgrade layer with CCA-cement addition agents. For their different blending ratios (C: CCA) of 1 : 1, 1 : 2, 1 : 3, and 1 : 4, the ideal moisture content varied from 36.5%, 32.0%, 30.5%, 29.5%, and 26.5%.

The maximum dry density and ideal moisture content generally increased as the proportion of cement in the CCA-cement mix-ratio decreased. But as the proportion of corn cob ash in the CCA-cement mix ratio increased, the maximum dry density declined once it exceeded the optimal dose, and the optimal moisture content dramatically decreased.

When the proposed mix ratio in Table 7's proposed mix ratio has a lower percentage of cement added and a higher percentage of corn cob ash added, the California Bearing Ratio value somewhat declines. Table 8 and Figure 13 depict the results of the laboratory tests. In comparison to natural subgrade soil, the CBR swell value of stabilized subgrade soil similarly falls.

The CBR result demonstrated a notable increase in strength compared to the untreated soil sample, as can be shown in Table 7. As cement content rises rather than CCA,

Table 8: CBR and CBR swell data for C: CCA blending stabilization.

C: CCA ratio	% value		% CBR swell	Penetration (mm)	CBR (%)	Max CBR (%)	ERA requirement	Remark
	C	CCA						
0	0	0	4.11	2.54 5.08	2.62 2.45	2.62		Poor
1 : 1	4	4	2.64	2.54 5.08	6.81 5.88	6.81		Satisfied
1 : 2	2.7	5.3	2.49	2.54 5.08	6.72 5.82	6.72	>3%	Satisfied
1 : 3	2	6	2.94	2.54 5.08	6.68 6.52	6.68		Satisfied
1 : 4	1.6	6.4	3.23	2.54 5.08	5.54 5.30	5.54		Satisfied

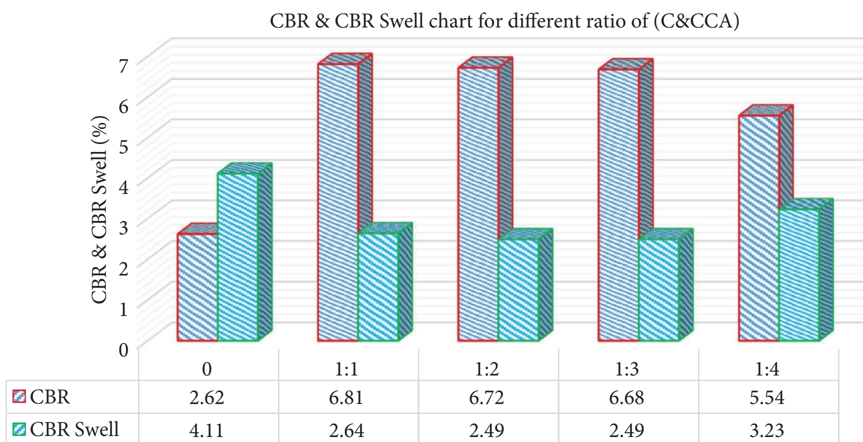

Figure 13: CBR and CBR swell data for C: CCA blending stabilization.

the results showed that CBR values of treated soils with CCA-cement mix rise. However, the CBR values of treated soil with 8% CCA alone satisfy the specification as a subgrade material in accordance with the ERA pavement design guidelines.

The considerable rise in CBR value could be attributable to chemical reactions between cement, CCA, soil, and water.

As previously established, the cation exchange reaction and adhesive property of CCA are responsible for enhancing soil load-bearing capacity, in addition to cement hydration and pozzolanic reaction. The reaction of CCA, cement, soil, and water are a new idea that is scarce in the literature. As a result, one or more of the following mechanisms may be responsible for the considerable increase in CBR values: cation exchange, hydration reaction, pozzolanic reaction, and CCA sticky property. When compared to a soil sample that had not been treated, expansive soils treated with CCA-cement exhibited a decrease in CBR swell. The highest reduction in CBR swell was produced by soil treated with corn cob ash-cement, as shown in Table 8. Due to the calcium-saturated clay's decreased water affinity and the development of a cementitious matrix that resists volumetric expansions, such reduced swell properties are typically explained [28].

4. Conclusion

The study focused on the effects of additives (cement, CCA, and cement and CCA together) on expansive soil.

The following outputs were identified based on the study's findings:

(i) According to the chemical analysis of the corn cob ash test results, the composite percent composition of the principal oxides (SiO_2, Al_2O_3, and Fe_2O_3) was 71.89%, exceeding the minimum of (70%) stipulated by ASTM (C618) which, with 2.27 specific gravity, qualifies as an excellent pozzolana.

(ii) According to the AASHTO and USCS General Soil Characteristics Systems, respectively, the soils are poor and inappropriate for use as a subgrade road building material unless they are modified.

(iii) When the mix ratio was at its ideal, the plasticity index (PI) reduced from 57.11% to 27.65% in the soil sample (1 : 2 C: CCA).

(iv) When treating expansive soil with CCA-cement addition agents, the MDD shows a modest rise while the OMC is reduced. When the mix ratio is at its ideal level, MDD rises from 1.385 g/cm^3 to 1.40 g/

cm^3 and OMC reduces from 36.5% to 30.5% (1 : 2, C: CCA). Increasing the cement in a CCA-cement mix ratio often causes the maximum dry density and optimal moisture content to increase and decrease, respectively.

(v) The initial rise for the CBR test was from the control value of 2.62% to 6.72%, at an optimal mix ratio of at (1 : 2 C: CCA). This was followed by a reduction in the CCA-cement mix ratio as CCA dosage was increased. However, all mix ratios and proportions met the minimal requirements for usage as a road subgrade material per ERA specifications.

(vi) CCA by itself does not enhance some of the technical specifications of highly flexible clay soils. However, CCA combined with cement may successfully maintain the expansive/weak/soft soil in road construction, reduce pollution and the cement content needed for stabilization purposes, and as a result, it reduces the cost of the project.

According to the results of all tests conducted for this investigation, the best outcomes were obtained at 2.7% C and 5.3% CCA by weight. Because most criteria meet the ERA standard and have the highest strength or CBR value. The best ratio for the expanding subgrade soils investigated is at (1 : 2, C: CCA). A cement-corn cob ash combination, which is less expensive than using only cement, can be used to enhance soils with comparable geotechnical attributes to the soil employed in this study, making them best suited for use as subgrade materials. This is supported by the fact that CCA-cement blends are more environmentally conscious than standard Portland cement [29].

Data Availability

The data used to support the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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