

Experimental Study on Stabilizing Expansive Clay Soils Using Bagasse Ash

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Abstract: This study presents an overview of soil types, their physical and chemical properties, behavior, and significance in construction works. It also reviews commonly used materials for stabilizing expansive clay soils and provides a brief background on sugarcane bagasse ash.

The primary objective of this research was to assess the feasibility of utilizing bagasse ash as a stabilizing agent for expansive clay soils. A series of laboratory tests were conducted, including sieve analysis, Atterberg limits (liquid and plastic limits), compaction tests, and unconfined compressive strength tests. Experimental investigations were carried out on expansive clay soil samples collected from the Kafouri and Khartoum east areas. Bagasse ash was added to the soil at replacement levels of 5%, 10%, and 15% by weight. The results indicated a noticeable reduction in the liquid limit and plasticity index with increasing bagasse ash content, reflecting an improvement in soil workability. Additionally, the maximum dry density showed a slight decrease, while the optimum moisture content increased with higher percentages of bagasse ash. The unconfined compressive strength of the stabilized soil exhibited a significant improvement, with the optimum performance observed at a specific bagasse ash content. These findings demonstrate that sugarcane bagasse ash can be effectively utilized as a sustainable and economically stabilizing material for expansive clay soils.

Keywords: soil types, physical and chemical properties, compressive strength, stabilized soil, stabilizing material.

1. INTRODUCTION

Soil is the loose and fragile surface layer that covers the Earth's crust. It is considered a mixture of mineral and organic constituents, and its composition varies because of interactions with the four major Earth systems: the hydrosphere, atmosphere, lithosphere, and biosphere (Cahyana, D., & Mulyanto, B. 2024)).

Soils are classified into several types, including fine clayey soils formed from the weathering of igneous and metamorphic rocks; coarse sandy soils composed of sand particles resulting from the disintegration of sandy rocks; and fine silty soils transported and deposited by river and valley water flows. Soil formation is influenced by several factors, most notably climate, topography, and biological processes. The main components of soil include minerals, plant matter, and animal residues (Das, B. M. (Ed.). 2011).

Expansive clay soils pose a major geotechnical challenge due to their high sensitivity to moisture variation, which leads to significant shrink-swell behavior, differential settlement, and cracking of structural foundations and pavements. These problematic soils can cause substantial economic losses and safety concerns in civil engineering projects if left untreated, necessitating effective modification or stabilization techniques during design and construction phases. Traditional stabilizing agents such as cement and lime have been widely used to enhance the engineering properties of expansive soils; however, their high cost, carbon footprint, and environmental impacts have motivated research into more sustainable alternatives (Shakil, M., et al. 2025).

Soil stabilization involves a range of engineering techniques applied to clay soils to enhance their physical indices and mechanical behavior, thereby ensuring their long-term suitability for construction applications and compliance with design specifications. The use of cementitious and chemical stabilizers alters soil behavior through physicochemical processes such as ion exchange, particle rearrangement, flocculation, and pozzolanic bonding, which collectively contribute to improved strength and durability. In general, soil stabilization methods are classified into mechanical and chemical approaches. Mechanical stabilization focuses on enhancing soil performance without changing its chemical composition and is achieved through procedures such as compaction, blending soils of different gradations, the introduction of geosynthetic reinforcement, and other mechanical improvement techniques. Chemical stabilization, on the other hand, relies on additives to modify soil structure and bonding, leading to increased bearing capacity and resistance to environmental degradation (Das, B. M., & Sobhan, K. 2018).

Sugarcane bagasse ash (SCBA) is an abundant agricultural byproduct generated from the combustion of sugarcane bagasse, often treated as waste and disposed of in landfills. SCBA is rich in silica and exhibits pozzolanic characteristics, making it a promising stabilizing additive for fine-grained soils when mixed with traditional binders (Wubshet, M., & Tadesse, S. 2014).

Recent research has demonstrated that the incorporation of bagasse ash can significantly influence key geotechnical properties of expansive soils. For example, bagasse ash has been shown to reduce plasticity indices and shrink–swell potential, while increasing bearing capacity and California Bearing Ratio (CBR) values, indicating improved workability and load-bearing performance. Studies in Ethiopia and other regions revealed that combinations of SCBA with lime yield more pronounced improvements—such as enhanced compaction and strength—compared to either material alone, highlighting the synergistic effects of blended stabilizers (Seid, F., Ali, A. 2025).

Beyond mechanical improvements, the use of bagasse ash contributes to sustainable development by repurposing an agricultural waste product, reducing the environmental burden of disposal, and potentially lowering material costs in expansive soil treatment applications. Despite promising results, optimal mix proportions, curing regimes, and long-term performance of soil stabilized with bagasse ash—either alone or in combination with chemical binders—remain active areas of investigation (Barasa, P. K., et al. 2015).

Sugarcane bagasse is the fibrous lignocellulosic residue that remains after the extraction of juice from sugarcane stalks during the sugar manufacturing process. It is produced in large quantities as an industrial byproduct when harvested cane is crushed by heavy rollers to separate the liquid component from the solid fibrous material in mills. Once considered waste, bagasse is now recognized as a valuable renewable resource due to its abundant availability and versatile properties (Parameswaran, B. 2009).

Chemically, bagasse primarily consists of cellulose (the main structural polymer), hemicellulose, and lignin, which together form its lignocellulosic structure. Typical compositions reported in the literature indicate approximately 40–50% cellulose, 20–30% hemicellulose, and 15–25% lignin by dry weight, highlighting its strong fibrous nature and potential for further processing (Thomas, B. S., et al. 2021, Meghana, M., & Shastri, Y. 2020)

Bagasse has found a wide range of industrial and environmental applications. In the sugar industry, it is commonly used as a biofuel in cogeneration systems to produce steam and electricity, often making mills self-sufficient in energy and reducing reliance on fossil fuels. Its high cellulose content also makes it suitable for sustainable paper and packaging production, biodegradable materials, and building composites (Ajala, E. O. et al. 2021).

Furthermore, after combustion, sugarcane bagasse ash (SCBA) is generated, which contains high levels of amorphous silica and other pozzolanic oxides, enabling its use as a supplementary cementitious material or stabilizer in construction and soil improvement applications (Maghraby, Y. E., et al. 2025).

Overall, the valorization of bagasse and its ash not only provide environmentally friendly alternatives to traditional industrial materials but also contributes to waste reduction and sustainable engineering practices.

2. RESEARCH PROBLEM

Cracks and deformations that occur in buildings constructed in areas underlain by expansive clay soils represent a significant engineering problem. In addition, the accumulation of sugarcane waste and the need for its proper disposal present environmental challenges. This research addresses the possibility of utilizing sugarcane bagasse ash as a stabilizing material for expansive clay soils and evaluating the extent of its effect on improving soil properties.

3. OBJECTIVES OF RESEARCH

This research aims to build existing knowledge by systematically evaluating how different proportions of sugarcane bagasse ash influence the physical, mechanical, and durability characteristics of expansive clay soils, with a focus on identifying optimum stabilization strategies suitable for sustainable geotechnical applications.

4. MATERIALS AND METHOD

The methodology outlines the procedure for preparing and stabilizing expansive clay soil with sugarcane bagasse ash (SCBA). The research follows a laboratory-based experimental approach:

4.1 Materials Preparation

- The combustion of bagasse ash

Sugarcane bagasse ash (SCBA) was produced by controlling combustion of sugarcane bagasse obtained from a local sugar mill. The bagasse was air-dried to reduce moisture content prior to burning. Combustion was carried out under control conditions to ensure complete burning and minimize unburnt carbon. The resulting ash was allowed to cool naturally, then ground and sieved through a 75 μm sieve to obtain a uniform and fine material suitable for use in soil stabilization. The prepared SCBA was subsequently stored in airtight containers to prevent moisture absorption before being mixed with expansive clay soil for laboratory as shown in Fig.1.

- Expansive Clay Soil: Collected from identified problematic areas; air-dried, crushed, and sieved (< 4.75 mm).
- Sugarcane Bagasse Ash (SCBA): Obtained from local sugar mills, sieved (< 75 μm), and characterized for chemical composition, particle size, and pozzolanic activity.

4.2 Soil Stabilization Procedure

- SCBA is incorporated into the soil at replacement levels of 5%, 10%, and 15% by weight.
- Treated soils are mixed thoroughly to ensure uniform distribution.
- Compaction is carried out using the standard Proctor method.
- Samples are cured under controlled conditions for 7, 14, and 28 days to study the effect of curing on soil properties.



Figure 1. The combustion of sugarcane bagasse to produce bagasse ash

After cooling, the resulting ash was finely ground to achieve an appropriate level of fineness, suitable for laboratory use. The prepared bagasse ash was stored in airtight containers to prevent moisture absorption. This material was subsequently incorporated into expansive clay soil to evaluate its effectiveness as a stabilizing agent, with its impact assessed through standard compaction, consistency, and strength tests. As shown in Fig.2.



Figure 2. The obtained finer and more uniform particle size

5. TEST PROGRAM AND RESULTS ANALYSIS AND DISCUSSION

In this stage, the test carried out and Bagasse ash was added to the soil at replacement levels of 0.0%, 5%, 10%, and 15% by weight. These tests were carried out by using different types of soil from different locations as mentioned above. The test program evaluates the physical, mechanical, and swelling characteristics of both untreated and SCBA-treated soils.

Chemical Analysis of Bagasse

Table. 1 shows the chemical component of the ash which contains mainly silica, calcium, magnesium and aluminum with other minor elements

Table. 1 Chemical composition of bagasse ash.

Description	Abbreviation	Ash (%)
Potassium	K ₂ O	5.5
Silica	SiO ₂	63.22
Calcium	CaO	3.5
Iron	Fe ₂ O ₃	3.59
Magnesium	MgO	1.83
Alumina	Al ₂ O ₃	1.65
Sodium	Na ₂ O	0.47
Titanium	TiO ₂	0.06
Manganese	MnO	0.48
Loss of Ignition	-	18.5

Results analysis involved comparing the properties of untreated and SCBA-treated soils to evaluate the effects of stabilization. Trends in physical and mechanical improvements were identified as SCBA content increased, with particular attention to changes in plasticity, swelling, and strength parameters. The analysis aimed to determine the optimum percentage of SCBA for effective soil stabilization, while correlating reductions in plasticity and swelling potential with observed gains in compressive and shear strength. These assessments provided a quantitative understanding of the role of SCBA in enhancing the engineering performance of expansive clay soils.

5.1 First location (Kafuri)

- Sieve analysis

Based on the particle size analysis results presented in the Table. 2 and Figure 3, the reference sample containing 0% bagasse ash exhibits a well-graded distribution.

Table 2. Sieve Analysis Results for Kafuri reference sample

Passing%	Ret%	Ret(wieght(g))	Size (mm)
86.44	13.6	339	4.75
62.44	24	600	2.36
44.28	18.2	454	1.18
20.48	23.8	595	0.6
12.08	8.4	210	0.3
4.88	7.2	180	0.15
0.08	4.8	120	0.075
	0.08	2	PAN
	100	2500	

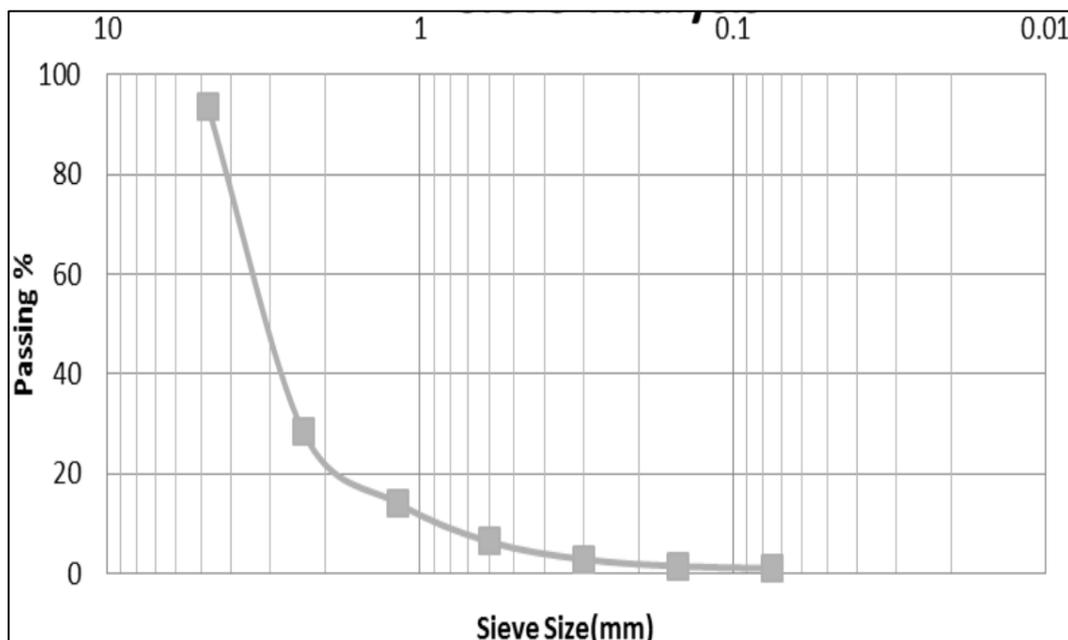


Figure 3. Sieve analysis for reference sample of Kafuri

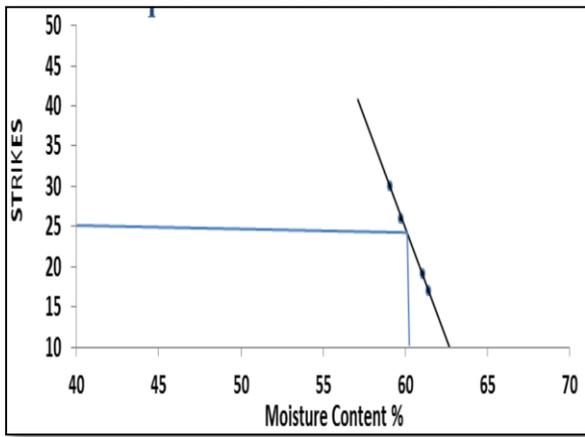
The sieve analysis shows that the soil consists mainly of sand-sized particles with a small amount of fines. A high percentage of the material (about 86%) passes the 4.75 mm sieve, indicating that coarse gravel is almost absent. As the sieve size becomes smaller, the percentage passing decreases gradually, which suggests a continuous range of particle sizes rather than a gap-graded soil. Medium sand forms a large portion of the sample, as shown by the material retained on the 2.36 mm and 1.18 mm sieves. Only a small fraction of the soil passes the finer sieves, with less than 5% passing the 0.15 mm sieve and almost no material finer than 0.075 mm. This particle size distribution indicates a well-graded soil, which is generally desirable because it allows better compaction and improved strength due to good interlocking between particles.

- Atterberg Limits Test

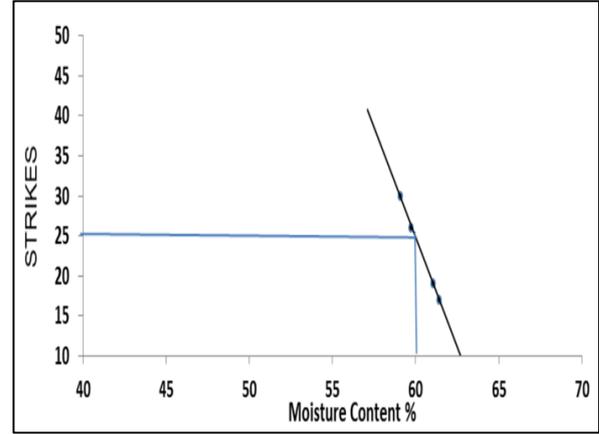
The results of Atterberg limits results for samples with different ratios of bagasse ash are shown in Table 3, while the summary op PI which concluded from this result are shown in Fig. 4 and Table 4.

Table 3. Atterberg limits for different bagasse ratios (a) 0% (b) 5% (c) 10% (d) 15%

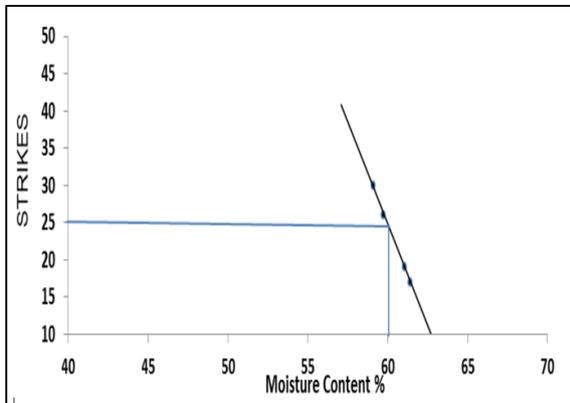
(a)							
Test No	1	2	3	4	5	6	7
Strikes	22	24	29	32	Plastic Limit		
Container	19.96	20.1	19.99	20.06	20.08	19.78	20.01
Wet+Cont	36.73	38.7	38.83	36.51	24.3	24.99	23.98
Dry+Con	30.69	31.9	32.13	30.81	23.34	23.78	23.1
Water	6.04	6.81	6.7	5.7	0.96	1.21	0.88
M.C%	56.29	57.7	55.19	53.02	29.45	30.25	28.48
(b)							
Test No	1	2	3	4	5	6	7
Strikes	20	23	26	34	Plastic Limit		
Container	26.47	26.8	26.72	26.61	26.9	26.87	26.82
Wet+Cont	49.49	51.9	49.31	43.23	30.65	30.08	29.53
Dry+Con	40.9	42.6	40.99	37.21	29.66	29.27	28.85
Water	8.59	9.28	8.32	6.02	0.99	0.81	0.68
M.C%	59.53	58.6	58.3	56.79	35.87	33.75	33.5
(c)							
Test No	1	2	3	4	5	6	7
Strikes	20	23	29	33	Plastic Limit		
Container	26.73	20	20.02	20.04	26.67	26.46	27
Wet+Cont	48.96	37.8	38.85	37	30.06	29.86	30.53
Dry+Con	40.69	31.2	31.97	30.92	29.18	28.99	29.61
Water	8.27	6.58	6.88	6.08	0.88	0.87	0.92
M.C%	59.24	58.9	57.57	55.88	35.06	34.39	35.25
(d)							
Test No	1	2	3	4	5	6	7
Strikes	17	19	26	30	Plastic Limit		
Container	19.77	20.01	20.05	19.95	19.94	27.22	26.82
Wet+Cont	41.53	38.34	39.52	36.05	22.83	29.44	29.18
Dry+Con	33.25	31.39	32.24	30.07	22.07	28.92	28.61
Water	8.28	6.95	7.28	5.98	0.76	0.52	0.57
M.C%	61.42	61.07	59.72	59.09	35.68	30.59	31.84



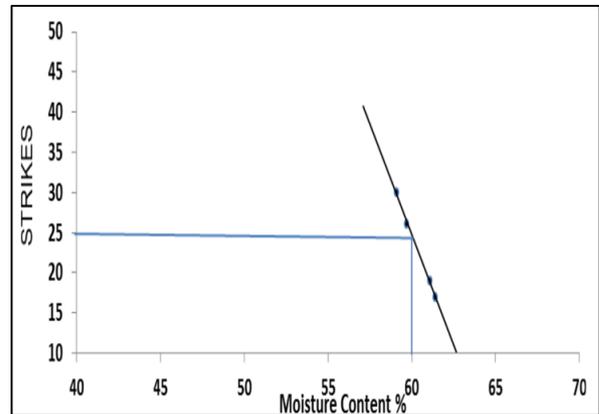
(a)



(b)



(c)



(d)

Figure 4. Atterberg limits diagram (a) 0%, (b) 5%, (c)10% and (d)15%

Table 4. Summary of PI for Kafuri samples

Sample	Liquid limit	Plastic limit	Plasticity index
0%	60.5	29.4	31.1
5%	60.1	34.38	25.72
10%	60	34.9	25.1
15%	60	32.71	27.29

The Atterberg limits results indicate that adding bagasse ash influences the soil's plastic behavior. The natural soil shows high plasticity, which is typical of expansive clay. When 5% bagasse ash is added, the liquid limit changes very little, but the plastic limit increases noticeably, causing the plasticity index to drop. This means the soil becomes less plastic and easier to handle. A similar response is observed at 10% bagasse ash, where the plasticity index reaches its lowest value, suggesting further improvement in soil behavior. However, increasing the bagasse ash content to 15% leads to a decrease in the plastic limit and a rise in the plasticity index, indicating that too much ash reduces the beneficial effect. Overall, these results suggest that small to moderate amounts of bagasse ash help reduce soil plasticity, while higher percentages may not be as effective.

- **Compaction test results:**

The compaction test results (Table 5) show that the addition of bagasse ash affects both the maximum dry density and the optimum moisture content of the soil.

Table 5. Summary of moisture content and dry densities for Kafuri samples with different contents of bagasse ash.

Sample	Maximum Dry density	O. M. C
0%	0.001815	25
5%	0.001756	27
10%	0.00173	28
15%	0.001675	29

The untreated soil exhibits the highest maximum dry density, indicating better packing of soil particles in its natural state. As bagasse ash is added, the maximum dry density gradually decreases, with the lowest value observed at 15% bagasse ash content. This reduction in dry density can be attributed to the lower specific gravity and lighter nature of bagasse ash compared to soil particles, which leads to a less dense soil–ash mixture. At the same time, the optimum moisture content increases consistently with higher bagasse ash percentages. This behavior is likely due to the higher water absorption capacity of the ash and its finer particles, which require more water to achieve proper compaction. Overall, the results suggest that while bagasse ash reduces the compacted density of the soil, it increases the moisture demand during compaction, a trend commonly observed when lightweight or pozzolanic materials are introduced into fine-grained soils.

The California Bearing Ratio (CBR) results indicate that the addition of bagasse ash influences the load-bearing capacity of the soil. The untreated soil shows a relatively low CBR value, reflecting the weak nature of expansive clay under loading conditions. With the introduction of small amounts of bagasse ash, slight changes in CBR are observed; however, the improvement is limited when bagasse ash is used alone. As the bagasse ash content increases, the CBR values tend to decrease, suggesting a reduction in soil stiffness and resistance to penetration. This behavior may be attributed to the low calcium content of bagasse ash, which limits the development of strong cementitious bonds necessary for significant strength improvement. In addition, the lighter and finer nature of the ash may disrupt particles interlocking within the soil matrix. Overall, the results suggest that while bagasse ash may improve certain index properties, its effectiveness in enhancing CBR and bearing capacity is limited when applied independently.

- Shear test

As shown by Table 6., Shear tests indicated minimal changes in internal friction angles, with slight variations in cohesion depending on the location and SCBA content which showed relatively stable shear parameters.

Table 6. Summary of direct shear test results for Kafuri samples

Sample	Cohesion (C)	Angle of Friction (ϕ)
0%	58	11.3
5%	55	11.3
10%	55	11.3
15%	56	11.3

5.2 Second location (Khartoum east)

- Sieve analysis

Based on the particle size analysis results presented in the table and figure below, the reference sample containing 0% (reference) bagasse ash exhibits a well-graded distribution. This is illustrated in Table 7. From Table 7 and Fig. 5, the sieve analysis results indicate that the soil exhibits a well-graded particle size distribution with a dominance of sand-sized fractions and a limited amount of fines.

Table 7. Sieve Analysis Results for Khartoum East reference sample

Passing%	Ret%	Ret (weight(g))	Size (mm)
85.32	14.68	367	4.75
61.16	24.16	604	2.36
43.6	17.56	439	1.18
19.52	24.08	602	0.6
10.96	8.56	214	0.3
4.16	6.8	170	0.15
0.16	4	100	0.075
	0.16	4	PAN
	100	2500	

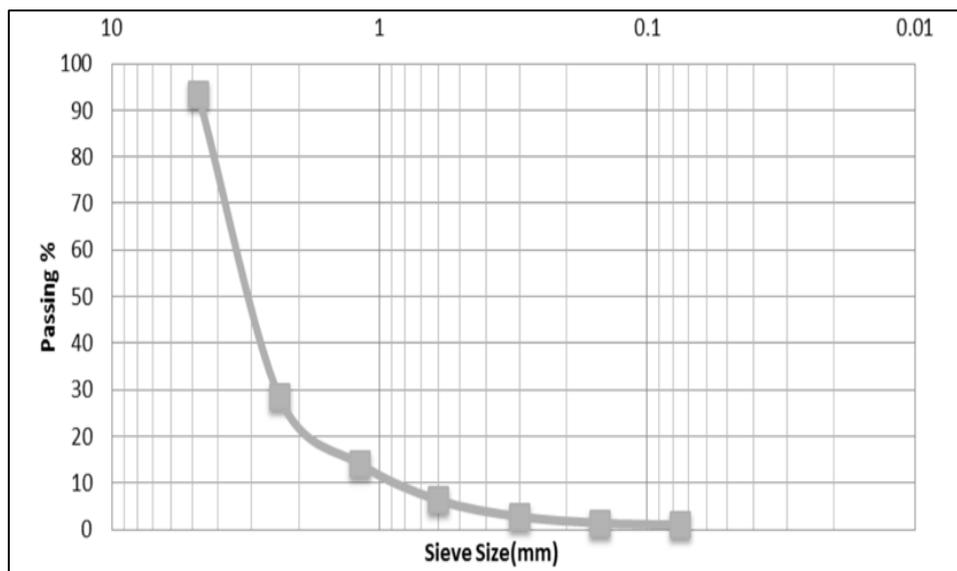


Figure 5. Sieve analysis for reference sample of Khartoum East

Approximately 85% of the material passes the 4.75 mm sieve, confirming that gravel-sized particles are negligible. As the sieve size decreases, the percentage passing reduces gradually, which reflects a continuous distribution of particle sizes rather than a gap-graded or poorly graded soil. A substantial portion of the soil is retained on the 2.36 mm, 1.18 mm, and 0.60 mm sieves, indicating that medium to fine sand constitutes the major fraction of the sample. Only a small percentage of the soil passes the finer sieves, with about 4% passing the 0.15 mm sieve and almost no material finer than 0.075 mm, suggesting a low silt content.

- Atterberg limits

As shown in Table 8, the Atterberg limits show that adding bagasse ash changes the soil's consistency and plastic behavior. The natural soil has moderate plasticity, as reflected by its plasticity index.

Table 8. Atterberg limits results for samples from Khartoum East

Sample	Liquid limit	plastic limit	plasticity index
0%	49.35	24.91	24.44
5%	48.3	20.62	27.85
10%	53.5	18.24	35.26
15%	48	15.79	32.21

With 5% bagasse ash, the liquid limit decreases slightly, while the plastic limit drops more, causing the plasticity index to increase. This suggests the soil becomes more plastic and potentially more sensitive to moisture. At 10% ash, the liquid limit rises and the plastic limit falls further, giving the highest plasticity index, which indicates even greater plasticity. When the ash content reaches 15%, the liquid limit drops again and the plastic limit is lowest, but the plasticity index remains higher than the untreated soil. Overall, the results show that small to moderate amounts of bagasse ash can affect soil plasticity, but higher amounts may not consistently improve workability.

- Companion test

The compaction test results with different bagasse ratios are illustrated in Table 9. The result showed that adding bagasse ash affects both the maximum dry density and the optimum moisture content of the soil.

Table 9. Compaction test results for samples from Khartoum East

Sample	Maximum Dry density	O. M. C
0%	0.0021	19
5%	0.00209	16
10%	0.00175	27.5
15%	0.00184	19.4

The untreated soil has the highest dry density, indicating that its particles are packed most efficiently under standard compactions. With 5% bagasse ash, the dry density decreases slightly, while the optimum moisture content also drops, suggesting that a small amount of ash may slightly reduce the soil's packing efficiency but requires less water to achieve compaction. At 10% ash, the maximum dry density decreases significantly, and the optimum moisture content rises sharply, indicating that higher ash content reduces soil density and increases water demand, likely due to the lightweight and porous nature of the ash. Interestingly, at 15% ash, the dry density increases slightly compared to 10%, and the optimum moisture content decreases, suggesting some stabilization effects may occur at this level. Overall, the results indicate that while bagasse ash reduces the compacted density of the soil, it increases water requirements at higher percentages, which should be considered when optimizing compaction for field applications.

- Shear test and CBR

The results from Table 10 show that the cohesion (C) of the sample increases significantly when the percentage increases from 0% to 10%. The cohesion rises from 23 kPa at 0% to a maximum of 33.62 kPa at 10%, indicating improved bonding and interparticle resistance. However, at 15%, the cohesion decreases slightly to 31.79 kPa, suggesting that adding more than 10% does not further enhance cohesion and may reduce effectiveness. The angle of internal friction (ϕ) initially decreases from 6.8° at 0% to 2.88° at 5% and 10%, which may be due to changes in particle arrangement or lubrication effects. At 15%, the friction angle increases to 5.27°, indicating partial recovery of frictional resistance at higher content.

Table 10. Direct shear test results for Khartoum East samples

Sample	Cohesion (C)	Angle of Friction (ϕ)
0%	23	6.8
5%	31.79	2.88
10%	33.62	2.88
15%	31.79	5.27

The California Bearing Ratio (CBR) of fine-grained soil was observed to vary with the percentage of sugarcane bagasse ash (SBA) added to the mixture. At lower SBA contents, only limited changes in CBR were recorded; however, increasing the SBA proportion generally led to a reduction in CBR values. This trend suggests that SBA, when used as a standalone stabilizing material, does not significantly enhance the bearing capacity of fine-grained soils. The reduction in CBR at higher SBA contents may be attributed to the limited availability of calcium necessary to promote strong cementitious bonding, resulting in weak or incomplete pozzolanic reactions. Consequently, although SBA may contribute to improvements in certain index properties, its effectiveness in improving soil strength and load-bearing capacity remains limited when applied independently (Ahmed, A., et al. 2024).

The CBR of the soil is closely related to its compaction characteristics and moisture content. The untreated soil, which has the highest dry density of 0.0021 g/mm³ at 19% moisture content, is expected to exhibit a baseline bearing capacity. When 5% bagasse ash is added, the dry density decreases slightly, and the optimum moisture content drops to 16%, which may slightly reduce the soil's resistance to penetration, suggesting a small decline in CBR. At 10% ash, the dry density decreases significantly to 0.00175 g/mm³ while the optimum moisture content rises sharply to 27.5%, indicating that the soil becomes lighter and requires more water to achieve compaction. This condition likely reduces the soil's load-bearing capacity, leading to a lower CBR value. Interestingly, at 15% ash, the dry density increases to 0.00184 g/mm³ and the optimum moisture content drops to 19.4%, which may partially recover the bearing capacity compared to the 10% mix. Overall, these results suggest that moderate to high percentages of bagasse ash can reduce the CBR of clayey soil due to decreased particle interlocking and increased water demand, while very small additions have minimal effect. (according to data from compaction result table above)

5.3 Comparison of results for two locations

5.3.1 Atterberg limits

Table 11. Atterberg limits for two locations (Kafuri and Khartoum East)

Location	Liquid limit		Plastic limit		Plasticity index	
	Kafuri	Kh. East	Kafuri	Kh. East	Kafuri	Kh. East
0%	60.5	49.35	29.4	24.91	31.1	24.44
5%	60.1	48.3	34.38	20.62	25.72	27.85
10%	60	53.5	34.9	18.24	25.1	35.26
15%	60	48	32.71	15.79	27.29	32.21

A comparison of the Atterberg limits results from the two locations shows noticeable differences in soil behavior (Table 11). The untreated soil from Kafuri exhibits higher liquid limit and plasticity index values than Khartoum East, indicating a more plastic and potentially expansive clay. With the addition of bagasse ash, the liquid limit at Kafuri remains almost constant, while the plasticity index generally decreases, suggesting an improvement in soil consistency. In contrast, soils from Khartoum East shows greater variability, with a reduction in plastic limit and an overall increase in plasticity index at

higher bagasse ash contents. This indicates that the response to bagasse ash is location-dependent, likely due to differences in mineral composition and soil structure. Overall, Kafuri soils appear to respond more favorably to bagasse ash treatment than those from Khartoum East. As shown from the results, both soils showed a reduction in Plasticity Index (PI) with increasing SCBA content, indicating decreased expansiveness.

5.3.2 compaction

Table 12. Compaction results for two locations (Kafuri and Khartoum East)

Location	Maximum Dry density		O. M. C	
	Kafuri	Kh. East	Kafuri	Kh. East
0%	0.001815	0.0021	25	19
5%	0.001756	0.00209	27	16
10%	0.00173	0.00175	28	27.5
15%	0.001675	0.00184	29	19.4

As shown in Table 12, the compaction results for the Kafuri soil demonstrate a consistent decrease in maximum dry density with increasing bagasse ash content, accompanied by a progressive increase in optimum moisture content. This behavior reflects the influence of bagasse ash as a lightweight and porous material that reduces soil packing efficiency and increases water demand during compaction. Due to the absence of corresponding compaction data for Khartoum East, a direct quantitative comparison between the two locations cannot be established. Nevertheless, the observed trend for Kafuri highlights the sensitivity of compaction characteristics to bagasse ash addition and suggests that similar location-dependent responses may be expected in other expansive clay soils, subject to their mineralogical and textural differences.

5.3.3 Shear test

Table 13. Shear test results for two locations (Kafuri and Khartoum East)

Sample	Cohesion (C)		Angle of Friction (ϕ)	
	Kafuri	Kh. east	Kafuri	Kh. east
0%	58	23	11.3	6.8
5%	55	31.79	11.3	2.88
10%	55	33.62	11.3	2.88
15%	56	31.79	11.3	5.27

As observed in Table 13, the variations in shear strength parameters are closely related to the compaction and CBR behavior of the soils. In the Kafuri soil, the minimal changes in cohesion and the constant angle of internal friction correspond well with the gradual reduction in maximum dry density and the limited improvement in CBR, indicating that bagasse ash does not significantly enhance load-bearing capacity or particle interlocking. In contrast, the Khartoum East soil shows an increase in cohesion with bagasse ash addition, which is consistent with the moderate improvements in compaction behavior observed at certain ash contents. However, the simultaneous reduction in the angle of internal friction explains why these gains do not translate into substantial increases in CBR, as penetration resistance depends on both cohesive and frictional components. Overall, the combined results demonstrate that while bagasse ash can modify soil structure and apparent cohesion, its influence on bearing capacity remains limited and highly dependent on soil type and compaction characteristics.

6. CONCLUSION

This study investigated the effectiveness of sugarcane bagasse ash (SCBA) as a stabilizing agent for expansive clay soils from Kafuri and Khartoum East. Laboratory tests, including Atterberg limits, compaction, direct shear, and California Bearing Ratio (CBR), were conducted on soil samples treated with SCBA at 0%, 5%, 10%, and 15% by weight. The main findings can be summarized as follows:

- For Kafuri soil, the addition of 5–10% SCBA reduced the plasticity index, indicating improved workability and reduced swelling potential. Increasing SCBA to 15% slightly increased the plasticity index, suggesting that excessive ash may diminish its beneficial effects.
- Khartoum East soils showed more variable responses, with plasticity index generally increasing at higher SCBA contents, highlighting the soil-specific nature of stabilization effects.
- The maximum dry density of soils decreased with increasing SCBA content, while the optimum moisture content increased, reflecting the lightweight and porous nature of bagasse ash. This trend was more consistent in Kafuri soils, suggesting that SCBA affects compaction characteristics depending on soil mineralogy and particle size distribution.
- Kafuri soils showed relatively stable shear parameters, whereas Khartoum East soils exhibited improved cohesion but reduced internal friction, indicating limited enhancement of overall load-bearing capacity.
- The CBR values generally decreased with increasing SCBA content, particularly at higher percentages. This indicates that SCBA alone does not significantly improve load-bearing capacity due to low calcium content and limited pozzolanic reaction.
- Moderate amounts of SCBA (5–10%) are effective for improving soil workability and reducing plasticity, making it a viable, eco-friendly additive in geotechnical applications.

Sugarcane bagasse ash demonstrates potential as a sustainable stabilizer for expansive clay soils, particularly in improving plasticity and handling characteristics. However, its effect on shear strength and bearing capacity is limited when used alone. Optimal performance is observed at moderate SCBA contents and combining SCBA with traditional stabilizers such as lime is recommended for enhanced strength and durability. The response of soil to SCBA is highly dependent on soil type and location, emphasizing the need for site-specific evaluation before practical implementation.

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