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Influence of Agro-Industrial Waste on Unconfined Compression Strength Parameters of Expansive Soil: An Experimental Investigation

Prashant Pande[1,*], Jayant Raut[1], Rajesh Bhagat[1], Boskey Bahoria [1]

[1] Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India

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ABSTRACT

Expansive soils pose a significant challenge in construction due to their potential to cause structural damage through its swelling and shrinking characteristics. Simultaneously, the disposal of numerous industrial and agricultural wastes poses challenges that contribute to environmental ecosystem damage. This experimental study explores the effect of agro-industrial waste on the mechanical properties of expansive soil. Specifically, the impact of incorporating agro-industrial waste materials, such as bagasse ash, plastic strips, and coir fiber, is investigated through assessments of unconfined compression strength. The unconfined compressive strength (UCS) test was conducted to examine various parameters of different combinations involving expansive soil, bagasse ash, coir fiber, and plastic strips. The results demonstrated notable improvements in Unconfined Compression Strength (UCS), particularly when incorporating a specific combination of 10% Bagasse Ash, 0.5% Plastic Strips, and 0.75% Coir Fiber) which resulted in a remarkable 49% increase in UCS. The findings show that including plastic strips enhances UCS by 2%, Coir Fiber improves it by 5%, and a combination of Bagasse Ash, plastic strips, and Coir Fiber leads to a 7% increase in UCS. The study on incorporating agro-industrial waste materials, such as bagasse ash, plastic strips, and coir fiber, reveals substantial improvements in the mechanical properties of expansive soil. This study contributes to the sustainable utilization of agro-industrial waste for soil improvement, offering a promising avenue for eco-friendly geotechnical solutions. Future work could explore the long-term performance and scalability of these materials in various soil conditions.

Keywords:
Black Cotton Soil; Bagasse Ash; Plastic Fiber; Coir Fiber; UCS

1. Introduction

The expansive clayey soils in India, known as Black Cotton Soil, pose significant challenges due to their minimal bearing and drainage capabilities, and potential for structural damage due to their swelling-shrinking behavior. These soils are predominant in central and western regions, covering 16.6% of India's total geographical area, including Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Telangana, Karnataka, and Tamil Nadu as presented in. In Maharashtra, Black Cotton Soil

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[*] *Corresponding author - Prashant*
E-mail address: pbpande@ycce.edu

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covers approximately 56% of the state's total geographical area, mainly in Vidarbha, Marathwada, and parts of the Deccan Plateau. The incorporation of additives in geotechnical engineering is crucial to enhance soil properties, particularly for lightweight structures like road pavements. Simultaneously, the disposal of industrial and agricultural wastes poses environmental challenges.

The swelling-shrinking and low drainage properties of these soils are the difficult challenges in construction, as they have the potential to induce structural damage [1,2]. Utilizing agricultural waste to generate electricity and thermal energy, energy recycling is proposed as a viable solution. In the field of geotechnical engineering, the incorporation of additives becomes crucial to enhance the soil properties, particularly when dealing with the performance of lightweight structures, especially in road pavement [3]. Simultaneously, the disposal of industrial and agricultural wastes poses environmental challenges, contributing to ecosystem damage [4]. It was estimated that India generates approximately 9.4 million tonnes (MT) of plastic waste per annum (Central Pollution Control Board (CPCB), March 2019). India generates a substantial amount of Bagasse ash, totalling 44,000 tonnes per day [5]. Several researchers have investigated the use of agricultural waste ash as an alternative source for renewable energy fuels solution [7]. Utilizing agricultural waste to generate electricity and thermal energy, energy recycling is proposed as a viable solution [6]. Therefore, there is a pressing need for sustainable solutions to effectively utilize waste materials. Numerous remedies have been successfully demonstrated to improve the strength and other characteristics of the expansive soils, such as use of chemical alternation additive. Figure 1 show the Indian soil deposit.

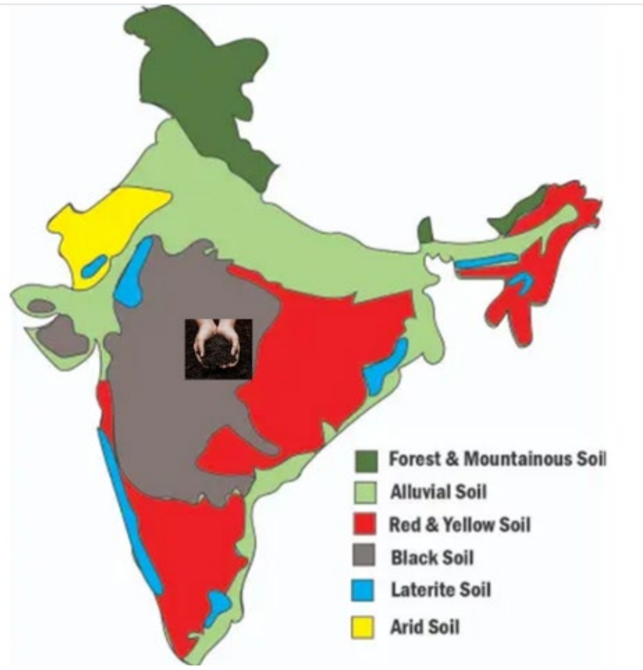


Fig. 1. Indian soil deposit (source: currentaffairs.adda247.com)

Many researchers frequently utilize soil stabilizers, including substances like marble waste powder, fly ash, eggshell powders, and lime powder [8-10]. The process essentially entails incorporating a range of external materials, such as polymers, plastics, coir fibers, and various other waste materials, into construction materials [11-13]. Researchers have independently noted the presence of cementitious compounds in soil mixtures with varying types of bagasse ash [14,15]. Bagasse is the fibrous material remains of sugarcane stalks are crushed to extract their juice. Sugarcane, cultivated globally in around 110 countries with an annual production of over 2000 of million tons, is a significant agricultural crop [16]. India contributes approximately 400 million tons of sugarcane each year [17]. The processing of sugarcane in various factories generates bagasse ash as a byproduct, which is rich in silica. When introduced to soil, bagasse ash effectively reduces soil's plasticity without compromising its engineering properties [18]. Numerous studies have shown that bagasse ash not only enhances soil performance but also reduces material costs, making it an economically and environmentally sustainable solution for waste management [19].Recent studies have indicated that plastic waste has the potential to enhance the strength and drainage properties of soil [20]. Coir fibre, a by-product of the coir industry obtained during coconut husk fiber extraction, is a bio-waste [21]. Improper disposal of coir fibre can lead to unhygienic conditions in the vicinity [22]. Kodicherla *et al.,* [23] incorporated coir fiber proportions ranging from 0% to 2% based on the dry weight of the soil along with fly ash for stabilization of clayey soil.

Bagasse ash, coir fiber, and plastic strips are promising agro-industrial wastes with limited research on their combined use for soil stabilization. Bagasse ash is rich in silica, which contributes to its cementitious properties. SiO_2 is the predominant component, averaging 60%, while the remaining 40% consists of alumina and other components. Also, silica reduces soil plasticity without compromising engineering properties [23]. Coir fiber, a by-product of the coconut industry, generally possesses a tensile strength of 105 to 593 MPa and a Young's modulus of 2 to 8 GPa. This material improves soil's tensile strength and reduces brittleness [24]. Plastic strips have the potential to enhance soil strength and drainage, need further investigation.

The literature review reveals a substantial research work on expansive soil stabilization, employing combinations of various admixtures like fly ash, stone dust, granulated blast furnace slag, lime, cement kiln dust, and cement. However, there is limited research on the combination of bagasse ash, plastic strips, and coir fiber for expansive soil's stabilization. The sustainable materials such as Bagasse Ash, Coir Fiber, and Plastic Strips have emerged as a promising solution to reinforce subgrade and enhance stability in earth embankments. whereas plastic strips have shown potential in soil stabilization and drainage improvement.

This paper aimed to study the influence on the strength properties of bagasse ash, coir fiber and plastic strips mixtures in expansive soil. The study uses varying proportions of bagasse ash 10 % by dry weight of soil, coir fiber (0%, 0.25%, 0.5, 0.75 and 1%) by dry weight of soil and plastic strips (0%, 0.25%, 0.5, 0.75 and 1%) by dry weight of soil. Further details of the experimental program, materials used, and their physical properties are discussed in the subsequent sections.

2. Methodology

2.1 Materials

Soil for the study was obtained from the Vidarbha region of India. Table 1 offers a summary of the soil characteristics in the Vidarbha region.

Figure 2 shows the particle size distribution curve for the Expansive soil used in this study. The distinct size fractions show that the soil is fine grained soil with Gravel at 0.42%, Sand at 39.24%, and Fines at 60.34%.%. Additionally, liquid limit, plastic limit, free swell index was performed as resulted in the Table 1. Lastly, the soil was classified according to [28], resulting in its classification as “CH” (High plastic clay), providing valuable insights into its cohesive and plastic properties.

Bagasse ash was obtained from a sugar factory in Bela, Maharashtra, located near Nagpur as shown in Figure 3(a). It is a blend of bagasse ash and fly ash, both exhibiting pozzolanic properties. Analysis of the mineral composition reveals that silica (SiO_2) predominates in the sample, comprising a significant 73% of the material. Additionally, smaller quantities of alumina ($Al2O_3$) and iron ($Fe2O_3$) are detected, accounting for 6.7% and 6.3%, respectively. Calcium (CaO) and magnesium (MgO) are also present as minor components, making contributions of 2.8% and 3.2%, respectively.

Table 1
Various aspects of Soil Sample

Aspect (m)	Value/Result
Location of Soil Sampling	Vidarbha Region
Specific Gravity [24]	2.56
Grain Size Distribution [25]	
- Gravel	0.42%
- Sand	39.24%
- Fines	60.34%
Liquid Limit (%) [26]	59%
Plastic Limit (%) [26]	30%
Plasticity Index (%) [26]	29%
Free Swell Index (%) [27]	64%
Soil Classification [28,29]	98.40
California bearing ratio (soaked) (%) [31]	6.92

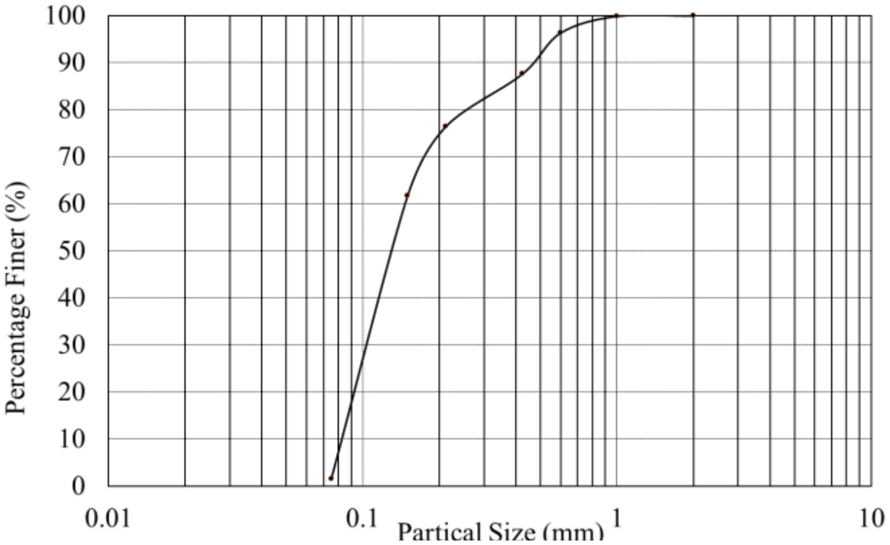


Fig. 2. Soil Gradation Curve

Fig. 3. Additive Material (a) Bagasse Ash, (b) Plastic Strips (c) Coir Fiber

The locally availed waste plastic water bottles are collected and cut into the strips manually with scissor in the average dimension of .8mm width and 15mm length as shown in Figure 3(b). Coir fibers were introduced to increase the cohesion among soil particles as shown in Figure 3(c), thereby fortifying and augmenting the soil's shear strength. Coir fiber, characterized by a density of 1.26 g/cm3, manifests a lightweight property deemed essential for weight-sensitive applications. Its notable tensile strength, ranging from 131 to 503 MPa, highlights its efficacy in applications prioritizing strength and durability through effective resistance to stretching. Furthermore, the material's Young's Modulus, falling within the range of 4 to 6 GPa.

2.2 Sampling

This investigation encompasses a comprehensive examination involving Unconfined Compression Test (UCS). The unconfined compressive strength (UCS) tests were conducted on samples prepared in different proportions [31]. The peak strength of these samples was recorded at 98.40 kPa. This value is compared to the soil without any additives, which is equivalent to medium stiff clay. as presented in Figure 4(a).

The Standard Proctor Test was conducted on varying proportions of bagasse ash, plastic strips, and coir fiber. A total of 36 samples, compacted at Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). The various combinations and their corresponding designations are outlined in Table 2.

Table 2
Compositions of soil with various additives

Test Designation	Soil (%)	Bagasse Ash (%)	Plastic Strips (%)	Coir Fibre (%)
S	100	0	0	0
SB1	100	5	0	0
SB2	100	10	0	0
SB3	100	15	0	0
SB4	100	25	0	0
SB5	100	50	0	0
SBP0	100	10	0	0
SBP1	100	10	0.25	0
SBP2	100	10	0.5	0
SBP3	100	10	0.75	0
SBP4	100	10	1	0
SBC0	100	10	0	0
SBC1	100	10	0	0.25
SBC2	100	10	0	0.5
SBC3	100	10	0	0.75
SBC4	100	10	0	1
SBP1C0	100	10	0.25	0
SBP1C1	100	10	0.25	0.25
SBP1C2	100	10	0.25	0.5
SBP1C3	100	10	0.25	0.75
SBP1C4	100	10	0.25	1
SBP2C0	100	10	0.5	0
SBP2C1	100	10	0.5	0.25
SBP2C2	100	10	0.5	0.5
SBP2C3	100	10	0.5	0.75
SBP2C4	100	10	0.5	1
SBP3C0	100	10	0.75	0
SBP3C1	100	10	0.75	0.25
SBP3C2	100	10	0.75	0.5
SBP3C3	100	10	0.75	0.75
SBP3C4	100	10	0.75	1
SBP4C0	100	10	1	0
SBP4C1	100	10	1	0.25

The Black Cotton soil initially dried drying in ambient conditions followed by pulverization, after which it was sieved through a 4.75 mm IS sieve. The sampling process involved the incorporation of mixtures with diverse combinations of additives as specified in the accompanying Table 2. The water content was adjusted in accordance with the optimal moisture content determined for each combination. The mixture was then placed for 1 to 2 hours to get uniformity in soil sample as shown in Figure 4. The soil samples were prepared with the help of sampling tubes of dimensions of 37.5 mm in diameter and 75 mm in height, involved compaction at the optimum moisture content, with subsequent extraction of samples from the standard Proctor compaction mold.

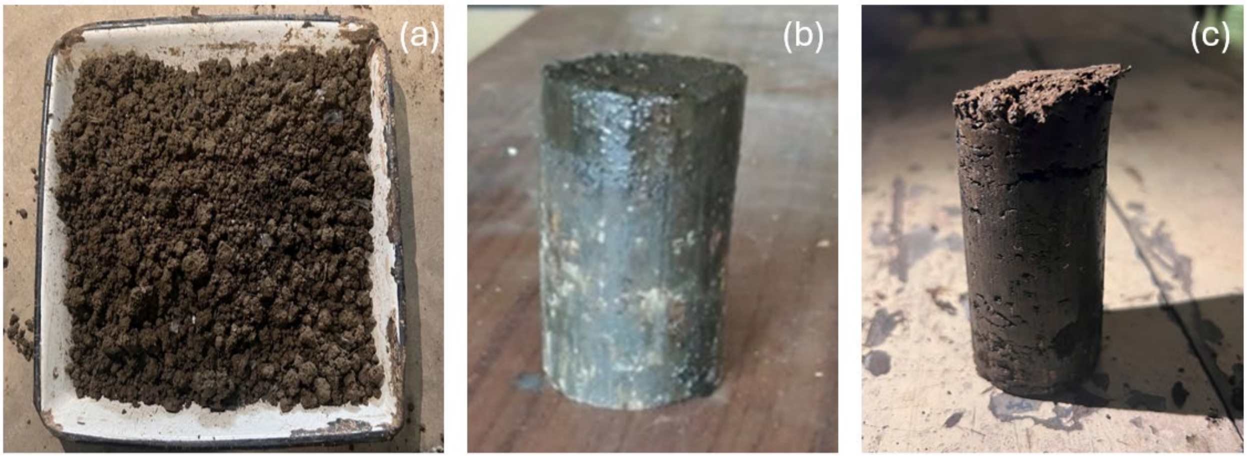


Fig. 4. Soil Sampling (a) Mixing (b) Soil and Bagasse Ash (c) Soil, Bagasse Ash, Coir fibre and Plastic Strip

The sampling of Black Cotton soil and Bagasse ash is illustrated in Figure 4(a), showcasing the individual collection of these materials, which are crucial for soil stabilization due to their chemical and physical properties. Figure 4(b) demonstrates the combined sampling of Black Cotton soil, Bagasse ash, plastic strips, and coir fibre. This combination aims to leverage the stabilizing effects of Bagasse ash, along with the mechanical reinforcement provided by plastic strips and the natural fibers from coir. These figures provide a comprehensive overview of the materials used in the experimental setup, highlighting the diverse approaches taken to improve the soil's structural integrity and performance.

2.3 Testing of soil sample

An unconfined compressive strength (UCS) test was conducted on samples prepared in different proportions [31]. The peak strength of these samples was recorded at 98.40 kPa. This value is compared to the soil without any additives, which is equivalent to medium stiff clay (Figure 5(a)).

The soil subgrade strength under the most adverse ground conditions was evaluated using the soaked California Bearing Ratio (CBR) test [30]. The CBR value for standard loading is 6.92% at maximum dry density. Additionally, a series of standard Proctor tests were conducted on various soil samples [32].

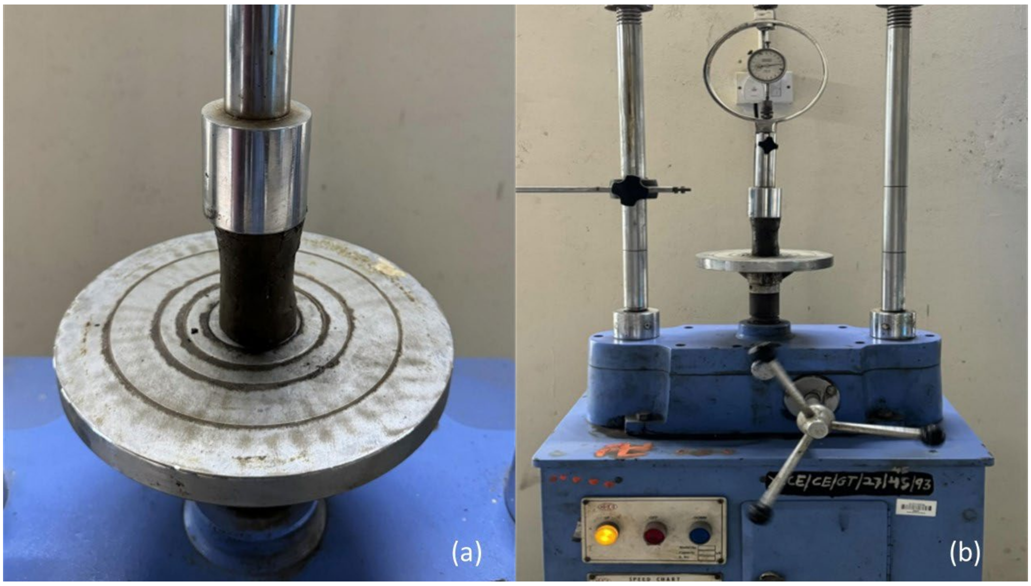
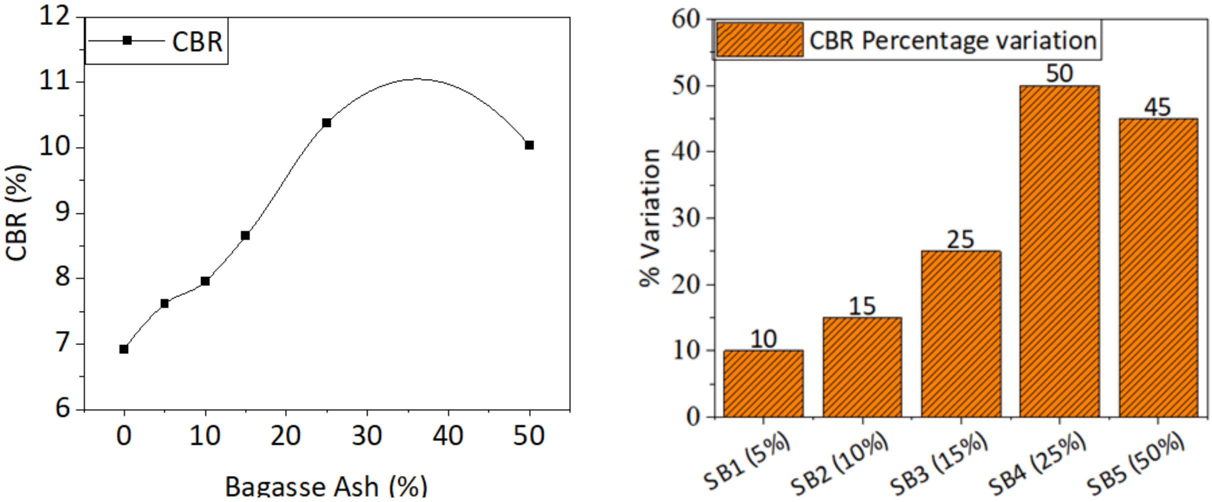


Fig. 5. Experimental setup (a) Sample failure (b) Unconfined compressive strength

3. Results and Discussions

3.1 Effect of Bagasse Ash on CBR

The California Bearing Ratio (CBR) results show an increasing trend in subgrade strength from S to SB5 designations, with CBR percentages ranging from 6.92% to 10.034% (Figure 6). This suggests a progressive improvement in soil stability, reflecting the varying performance of different soil samples under the conducted tests. The highest CBR value of 10.38% is observed for SB4, indicating superior strength in comparison to other designations. The percentage increase in subgrade strength, as indicated by the California Bearing Ratio (CBR) results, demonstrates a notable improvement across designations. The increments range from 10% for SB1 to a substantial 50% for SB4, showcasing an ascending trend in soil stability. As the amount of Bagasse ash increases, it enhances the California Bearing Ratio (CBR) but concurrently diminishes the Maximum Dry Density (MDD) of the soil. This phenomenon has been observed by many researchers and discussed further.



(a) (b)

Fig. 6. Soil and Bagasse Ash combination (a) Effect on CBR (b) Percentage Variation of CBR

The California Bearing Ratio (CBR) results indicate a clear improvement in subgrade strength from the S to SB5 designations, with values ranging from 6.92% to 10.034% (Figure 6). This trend underscores a progressive enhancement in soil stability across different samples. Notably, SB4 exhibits the highest CBR value of 10.38%, reflecting superior strength relative to the other samples. The incremental increase in CBR percentages, ranging from 10% for SB1 to a remarkable 50% for SB4, highlights a significant improvement in soil stability.

It is evident that the addition of Bagasse ash contributes to the enhancement of the CBR values, suggesting improved load-bearing capacity. However, it is also observed that the increase in Bagasse ash content results in a reduction of the Maximum Dry Density (MDD) of the soil. This inverse relationship between Bagasse ash content and MDD has been documented by various researchers, further supporting the findings of this study. The observed trends are consistent with existing literature, which confirms the dual effect of Bagasse ash on soil properties: enhancing strength while reducing density. Experimental results indicated that increasing the Bagasse ash content beyond 10% did not proportionately enhance the soil's strength. In fact, higher percentages of Bagasse ash (e.g., 15% or 25%) led to a decrease in UCS. This is likely due to the dilution of the soil matrix, where the excessive Bagasse ash particles might interfere with the cohesive properties of the soil rather than complementing them.

3.2 Effect of Bagasse Ash on Unconfined Shear Strength

Bagasse Ash is a well-established additive for soil stabilization. Initially, the enhancement of various parameters was investigated through the combination of soil and Bagasse Ash. The soil underwent testing with incremental increases in Bagasse Ash percentage by 10%. The resulting combinations, designated as SB1, SB2, SB3, SB4, and SB5, represented 10%, 20%, 30%, 40%, and 50% Bagasse Ash, respectively. The obtained Unconfined Compressive Strength (UCS) results indicate a significant improvement at 10% Bagasse Ash, with further additions leading to a decline in the UCS of the soil as shown in Figure 7(a).

The experimental findings reveal distinct variations in the improvement of the tested parameter across different combinations, as expressed by percentage increases. SB1, SB2, SB3, SB4, and SB5 are associated with percentage increases of 20%, 35%, 25%, 22%, and 2%, respectively as illustrated in Figure 7(b). Specifically, SB1 exhibits a 20% increase compared to the UCS of plain soil, while SB2 demonstrates the most substantial improvement with a significant 35% increase. SB3 and SB4 also show favorable enhancements, with percentage increases of 25% and 22%, respectively. In contrast, SB5 displays a more modest increase of 2% compared to the control. The observed variations highlight the influence of specific amendments on the measured parameter, with SB2 standing out as the most effective combination, suggesting a synergistic effect.

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The Unconfined Compressive Strength (UCS) results indicated a significant improvement at 10% Bagasse ash, with further additions leading to a decline in UCS (Figure 7a). Specifically, the highest UCS improvement was observed for SB2 (20% Bagasse ash), which exhibited a substantial 35% increase compared to plain soil, suggesting a synergistic effect at this concentration. For SB3 (30% Bagasse ash), the UCS showed a favorable enhancement of 25%, but this combination did not outperform SB2. Interestingly, SB4 (40% Bagasse ash) produced a 22% increase in UCS, indicating that higher concentrations of Bagasse ash might not proportionally enhance soil strength and could introduce diminishing returns beyond a certain threshold.

SB5 (50% Bagasse ash) showed the lowest percentage variation, with only a 2% increase in UCS compared to the control, which could be attributed to the excessive Bagasse ash content leading to an adverse effect on soil strength. This demonstrates that while Bagasse ash is beneficial, there is an optimal concentration range, beyond which the stabilization effect diminishes. The combination of 25% Bagasse ash, 0% Plastic strips, and 0% Coir fiber produced a significant 25% increase in UCS. This notable variation may be due to the specific interaction between soil particles and Bagasse ash at this concentration, optimizing the pozzolanic reactions and enhancing soil structure without the dilution or interference effects that might occur at higher ash contents or with additional additives.

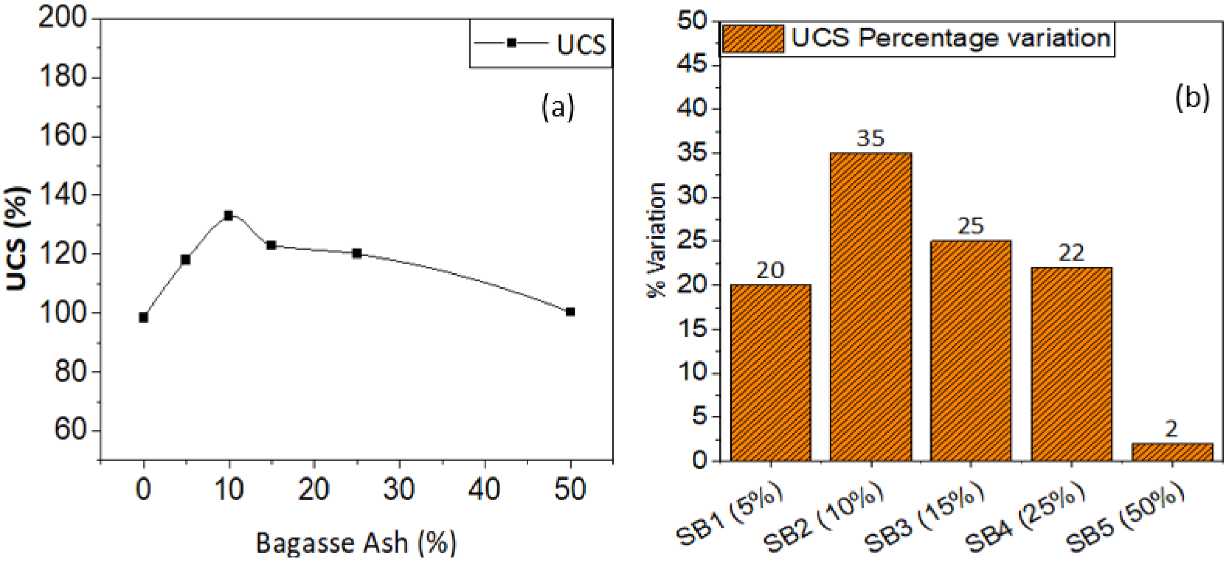

Fig. 7. Variation of UCS of Soil and Bagasse Ash combination (a) Effect on UCS (b) Percentage Variation of UCS

Bagasse ash, rich in silica (SiO_2) and alumina (Al_2O_3), reacts with calcium hydroxide [$Ca(OH)_2$] in the soil to form calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H). These cementitious compounds bind soil particles together, increasing strength and durability. The reaction equations are: $SiO_2 + Ca(OH)_2 \rightarrow$ C-S-H and $Al_2O_3 + Ca(OH)_2 \rightarrow$ C-A-H. Adding Bagasse ash reduces the soil's plasticity, making it less prone to swelling and shrinking, resulting in better load-bearing capacity and improved structural integrity. The fine particles of Bagasse ash fill the voids between soil particles, enhancing compaction and reducing permeability, leading to a denser soil structure and increased strength. The 10% Bagasse ash content in the SB2 sample appears to be the optimal proportion for enhancing soil strength. Beyond this point, additional Bagasse ash does not proportionately improve strength, likely due to the dilution of soil particles and the potential reduction in the effectiveness of the pozzolanic reaction.

3.3 Effect of Bagasse Ash and Plastic Strips on Unconfined Shear Strength

The Unconfined Compressive Strength (UCS) results indicate marginal variations among the plastic fiber-reinforced soil designations as shown in Figure 8(a). The UCS values range from 129.89 MPa for SBP4 to 134.81 MPa for SBP2. Despite subtle differences, the overall UCS trend suggests relatively consistent strength levels among the tested designations. The influence of inclusion of plastic strips is only seen at the initially, but the further increase in plastic strips does not significantly affect the UCS of soil which can be observed in Figure 8(b). The Unconfined Compressive Strength (UCS) in the soil, with increasing percentages from 0 to 1%. The percentage increase in UCS ranges from 32% for SBP4 to 37% for SBP2, indicating that the reinforcement with plastic fibers marginal enhancement of the overall strength of the soil. This suggests a potential for optimizing plastic fiber content to achieve improved drainage property of soil.

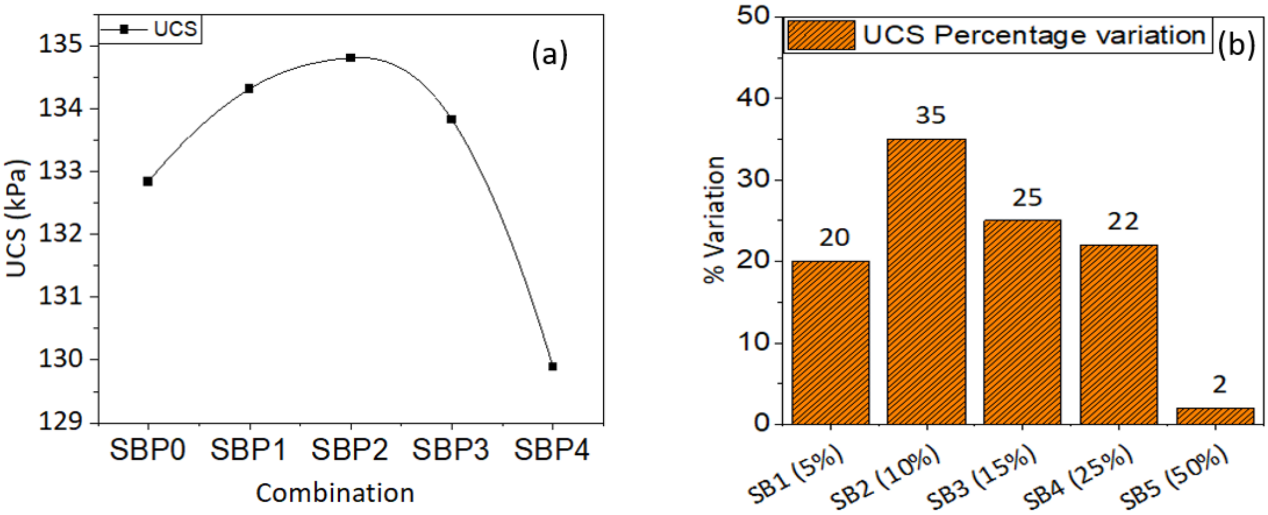

Fig. 8. Soil, Bagasse Ash and Plastic Strips combination (a) Effect on UCS (b) Percentage Variation of UCS

The percentage increase in UCS ranges from 32% for SBP4 to 37% for SBP2, indicating that the reinforcement with plastic fibers marginal enhancement of the overall strength of the soil. This suggests a potential for optimizing plastic fiber content to achieve improved drainage property of soil.

3.4 Effect of Bagasse Ash and Coir Fiber on Unconfined Shear Strength

The study investigates the impact of coir fiber additives on Unconfined Compressive Strength (UCS) as shown in Figure 9(a) and Figure 9(b). The experiment involves testing the unconfined shear strength of plain soil and soil with varying coir fiber content (0%, 0.25%, 0.5%, 0.75%, and 1%), combined with a 10% optimum addition of Bagasse Ash based on previous research. The data shows a consistent increase in Unconfined Compressive Strength (UCS) with the addition of coir fiber in varying percentages. The UCS values range from 132.84 for SBC0 to 139.728 for SBC3, indicating a positive impact of coir fiber on soil strength. The highest UCS is observed at 0.75% coir fiber content (SBC3), suggesting that this concentration is particularly effective in enhancing the soil's compressive strength.

The results indicate a progressive increase in Unconfined Compressive Strength (UCS) with the incorporation of coir fiber Figure 9(b). The % increase in UCS ranges from 35% for SBC0 to 42% for SBC3, demonstrating that the optimal enhancement is achieved at 0.75% coir fiber content. This suggests that coir fiber can effectively contribute to the improvement of soil stability, with SBC3 representing the most favorable balance between fiber content and UCS increase.

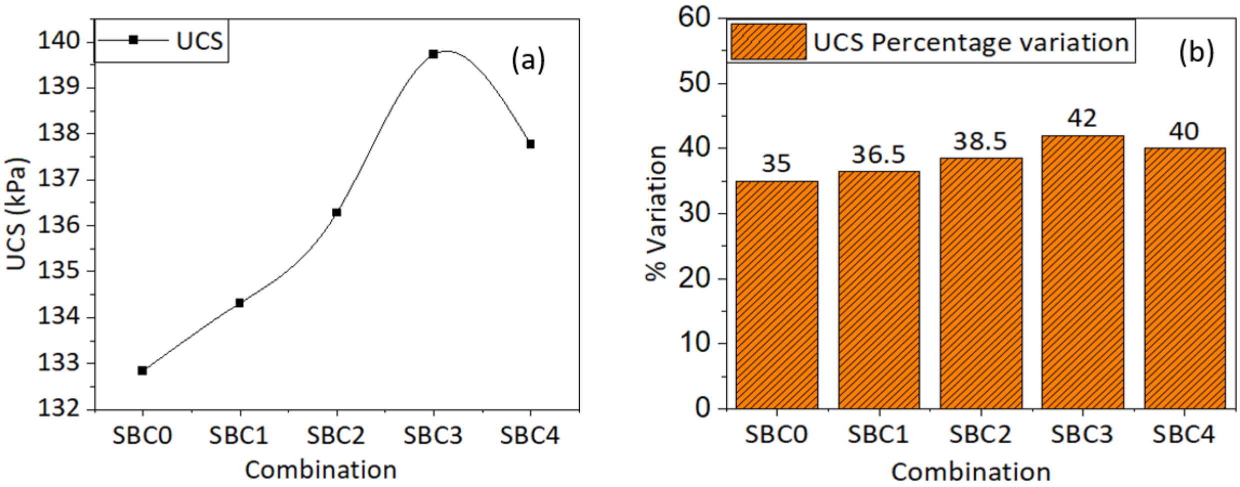

Fig. 9. Soil, Bagasse Ash and Coir Fiber combination (a) Effect on UCS (b)Percentage Variation of UC

3.5 Effect of Bagasse Ash, Plastic Strips and Coir Fibre on Unconfined Shear Strength

The unconfined compressive strength (UCS) of stabilized soil was investigated with varying proportions of Bagasse Ash, Plastic Strips, and Coir Fiber and presented in Figure 10. The Bagasse Ash quantity was kept constant to 10% and further variation were done in the percentage of Plastic Strips and Coir Fiber in the range of (0 to 1%). Notably, the highest UCS of soil is observed for SBP2C3 with 0.5% Plastic Strips, 0.75% Coir Fiber, and 10% Bagasse Ash, reaching 146.62 KN/m^2.

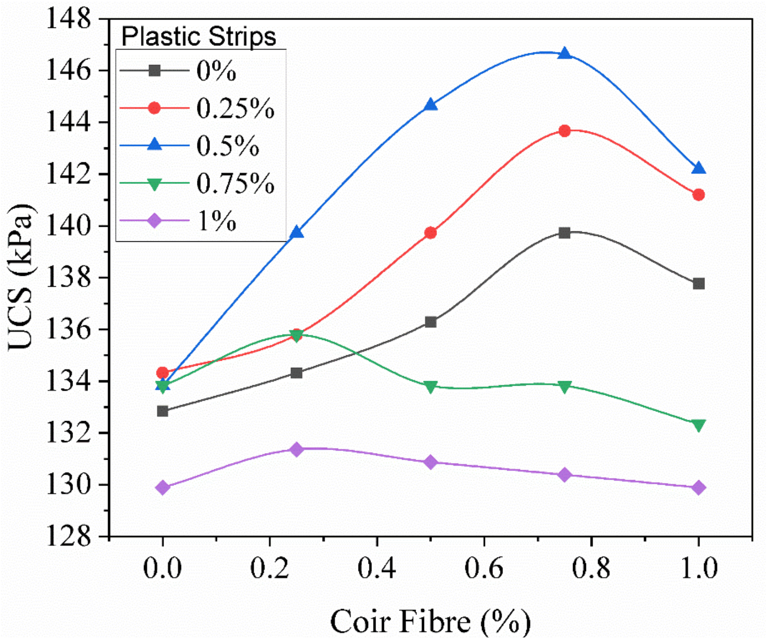

Fig. 10. Variation in UCS for different combinations of soil, Bagasse Ash, Plastic Strips, and Coir Fiber

Plastic Strips exhibited impact on Unconfined Compressive Strength (UCS) up to a 0.5% by weight of soil as shown in Figure 10. However, further additions, such as 0.75% and 1%, resulted in a reduction of UCS by 2 to 3%. The decrease in Unconfined Compressive Strength (UCS) associated with the addition of plastic strips exceeding 0.5% is attributed to a reduction in cohesion. This reduction, in turn, affects the inter-particle bonding within the soil matrix, further impacting UCS. Consequently, it is recommended to limit the use of plastic strips, ensuring proper dimensions in terms of length and width. This controlled application is suggested to effectively enhance the strength and drainage characteristics of expansive soil, thereby optimizing its performance in engineering applications.

Coir Fiber exhibited a notable effect, particularly at lower Plastic Strips content, with the peak UCS recorded at 0.25% Plastic Strips (135.792 MPa) as shown in Figure 10. The gradual Increase in UCS can be seen up to 0.75 % coir fiber further increase in coir fiber reduces the strength by 2 to 4% up to the significantly raised. The various combinations such as 0.25%, 0.5%, and 0.75% of coir fiber with 0.25%, 0.5% of plastic fiber gives positive results as compared to other combinations.

The percentage increase in UCS indicates that the combination of 0.5% Plastic Strips, 0.75% Coir Fiber, and 10% Bagasse Ash leads to the most significant enhancement, with a 49% increase compared to the baseline as illustrated in in Figure 11. This suggests that specific combinations of additives can yield optimal improvements in soil strength, highlighting the importance of considering multiple factors in soil stabilization efforts.

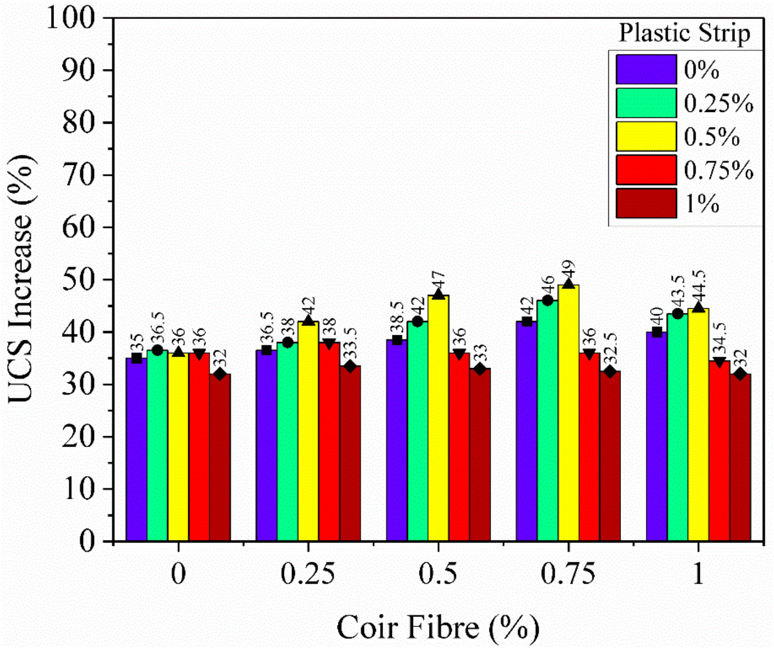

Fig. 11. Percentage variation of UCS for various Plastic Fiber and Coir Fiber

Initially, the addition of Bagasse Ash alone resulted in a 35% increase in Unconfined Compressive Strength (UCS). Subsequently, when combined with plastic strips, the UCS improved to 37%, and with the addition of Bagasse Ash and Coir Fiber, the UCS further increased to 42%. The combination of Bagasse Ash, plastic strips, and Coir Fiber collectively raised the UCS value to 49%. This indicates that the UCS improvement is 2% with the inclusion of plastic strips, 5% with Coir Fiber, and 7% with the combined addition of Bagasse Ash, plastic strips, and Coir Fiber.

3.6 Data Validation

The combinations employed in this study were validated through the assistance of Design Expert, and the data underwent statistical analysis using the central composite method. Table 3 provides a summary of statistical findings, showcasing the results of an analysis that assesses the significance of various factors and their interactions. The Table 3 highlights the statistical significance of these factors and interactions, with particularly small p-values signifying a high degree of significance in the analysis.

For the overall model, the p-value is less than 0.0001, demonstrating that the model is highly significant. The p-value for Bagasse Ash (A) is also less than 0.0001, indicating a very significant effect on the soil's strength. Conversely, the p-values for Plastic Strips (B) and Coir Fibre (C) are 0.6707 and 0.3757, respectively, indicating that these factors do not significantly impact the strength at the levels tested. The interaction terms AB and AC have p-values of 0.8119 and 0.0053, respectively, showing that while the interaction between Bagasse Ash and Coir Fibre (AC) is significant, the interaction between Bagasse Ash and Plastic Strips (AB) is not. The interaction between Plastic Strips and Coir Fibre (BC) has a p-value of 0.0897, suggesting a marginally significant impact. These p-values emphasize the dominant role of Bagasse Ash in enhancing soil strength, with minimal contributions from Plastic Strips and Coir Fibre within the tested range.

Table 3
p-value identification

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0775	6	0.0129	77.02	< 0.0001	significant
A-Bagasse Ash	0.0535	1	0.0535	319.38	< 0.0001	
B-B Plastic strips	0	1	0	0.2037	0.6707	
C-C Coir Fibre	0.0002	1	0.0002	0.9448	0.3757	
AB	0	1	0	0.0629	0.8119	
AC	0.0037	1	0.0037	22.14	0.0053	
BC	0.0007	1	0.0007	4.41	0.0897	

Figure 12 presents a one-factor diagram comparing the influence of different factors, namely Bagasse ash, Plastic strip, and Coir Fiber, on the Unconfined Compressive Strength (UCS). It suggests that Bagasse ash has a more substantial impact on UCS compared to Plastic strip and Coir Fiber, as indicated by the steep upward trend. Figure 12(a) shows Gradual increase in UCS with increase in percentage of Bagasse ash, Figure 12(b) shows Normal variation in UCS with increase in percentage of Plastic Strips Figure 12(c) shows Mild increase in UCS with increase in percentage of Coir Fiber.

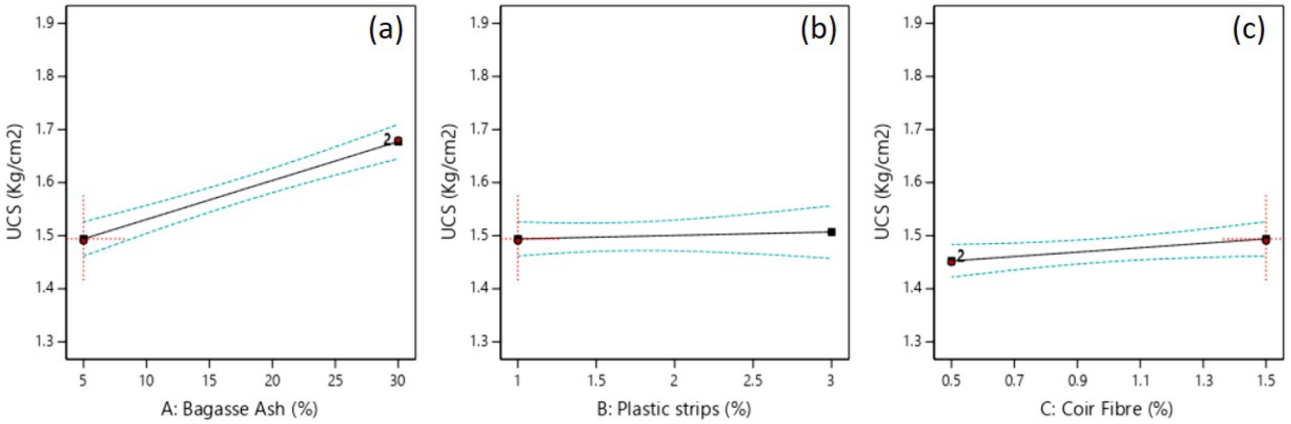

Fig. 12. One Factor Diagram for Variation in UCS (Kg/cm^2)

Bagasse ash has a more pronounced effect on UCS compared to Plastic strip and Coir Fiber. The steep upward trend in the figure reinforces the idea that as the amount of Bagasse ash increases, the UCS of the material also increases substantially. This indicates a strong positive correlation between Bagasse ash content and experimental UCS values. Overall, this one-factor diagram visually highlights the significant impact of Bagasse ash on UCS, making it a crucial factor to consider in the context of material strength enhancement.

4. Conclusion

In conclusion, this experimental study effectively addresses the dual challenges posed by expansive soils in construction and the environmental impact of industrial and agricultural waste disposal. The investigation into the incorporation of agro-industrial waste materials, including bagasse ash, plastic strips, and coir fiber, demonstrates significant enhancements in the mechanical properties of expansive soil. Particularly noteworthy is the finding that the combination of 10% Bagasse Ash, 0.5% Plastic Strips, and 0.75% Coir Fiber results in a remarkable 49% increase in Unconfined Compression Strength (UCS). The study also reveals that the inclusion of plastic strips alone does not contribute to strength improvement due to its smooth surface, which reduces strength. To mitigate this effect, it is recommended to use plastic strips with a rough surface material. Consequently, coir fiber acts as a collaborative additive with plastic strips, synergistically enhancing the overall strength of the stabilized soil. Furthermore, this study can be extended by examining the influence of these additives on various other soil parameters across different soil types.

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