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INFLUENCE OF BAGASSE ASH AND ADDITIVES ON THE STRENGTH CHARACTERISTICS OF BLACK COTTON SOIL

[1]Dr. Thirunavukkarasu N, [2]Pranay Bhaskar, [3]Suresh Nenavath, [4]Jarpati Bhavani
[1] Professor, [23]Assistant Professor, [4]Student
Department of Civil Engineering
Sri Chaitanya Technical Campus

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Abstract
Black cotton soil is one of the most problematic expansive soils encountered in geotechnical engineering due to its high swelling and shrinkage characteristics, low bearing capacity, and significant volume changes under varying moisture conditions. These properties often lead to structural distress in pavements, foundations, embankments, and other civil engineering structures. Soil stabilization has therefore become an essential technique for improving the engineering performance of black cotton soil. In recent years, the utilization of agricultural and industrial by-products for soil stabilization has gained considerable attention owing to their economic and environmental benefits. Among these materials, bagasse ash, a waste product generated from sugar industries, has emerged as a promising stabilizing agent due to its pozzolanic properties and silica-rich composition.
This study investigates the influence of bagasse ash and selected additives on the strength characteristics of black cotton soil. Various soil mixtures were prepared by incorporating different percentages of bagasse ash along with suitable additives to enhance the stabilization process. Laboratory tests were conducted to evaluate important engineering properties, including compaction characteristics, unconfined compressive strength, California Bearing Ratio (CBR), and shear strength parameters. The results indicated that the inclusion of bagasse ash significantly improved the strength and stability of black cotton soil by reducing plasticity and enhancing soil particle bonding. Furthermore, the addition of stabilizing additives accelerated pozzolanic reactions, resulting in improved load-bearing capacity and increased resistance to deformation. The experimental findings demonstrated that an optimum combination of bagasse ash and additives produced substantial improvements in soil strength compared to untreated black cotton soil. The stabilized soil exhibited higher compressive strength, enhanced bearing capacity, and improved durability characteristics, making it suitable for geotechnical and pavement construction applications. The study confirms that bagasse ash, when combined with appropriate additives, can serve as an effective, economical, and environmentally sustainable material for black cotton soil stabilization while promoting the beneficial utilization of agricultural waste products.

Keywords: Black Cotton Soil, Bagasse Ash, Soil Stabilization, Additives, Unconfined Compressive Strength, California Bearing Ratio (CBR), Expansive Soil, Pozzolanic Reaction, Geotechnical Engineering, Sustainable Soil Improvement.

1 INTRODUCTION

Black cotton soil is one of the most extensively distributed expansive soils found in many regions of the world, particularly in tropical and semi-arid areas. It is characterized by a high content of montmorillonite clay minerals, which exhibit

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significant swelling and shrinkage behavior with variations in moisture content. These volume changes often lead to severe engineering problems such as pavement cracking, differential settlement, foundation distress, and structural instability. Due to its poor load-bearing capacity and susceptibility to moisture-induced deformation, black cotton soil presents substantial challenges in the design and construction of civil engineering infrastructure.

The rapid growth of transportation networks, residential developments, and industrial projects has increased the need for effective methods to improve the engineering properties of problematic soils. Soil stabilization has emerged as one of the most practical and economical techniques for enhancing the strength, durability, and performance of weak subgrade soils. Conventional stabilizing agents such as lime, cement, and fly ash have been widely used to improve soil characteristics; however, their production often involves significant energy consumption and environmental impacts. Consequently, researchers have focused on identifying sustainable and cost-effective alternative materials for soil stabilization.

Bagasse ash, a by-product generated from the combustion of sugarcane bagasse in sugar industries, has gained considerable attention as an environmentally friendly stabilizing material. Large quantities of bagasse ash are produced annually, and its disposal poses environmental concerns. Since bagasse ash contains significant amounts of silica and other reactive compounds, it exhibits pozzolanic properties that can contribute to soil improvement when mixed with expansive soils. The utilization of bagasse ash in soil stabilization not only provides a productive use for agricultural waste but also reduces the environmental burden associated with waste disposal.

In addition to bagasse ash, various additives such as lime, cement, gypsum, and other industrial by-products have been employed to further enhance the stabilization process. These additives promote chemical reactions within the soil matrix, resulting in improved particle bonding, reduced plasticity, increased density, and enhanced strength characteristics. The combined use of bagasse ash and suitable additives has shown considerable potential in improving the engineering behavior of black cotton soil by reducing swelling tendencies and increasing load-bearing capacity.

Several studies have reported significant improvements in compaction characteristics, unconfined compressive strength, California Bearing Ratio (CBR), shear strength, and durability of expansive soils stabilized with bagasse ash and additives. The pozzolanic reactions occurring between the silica present in bagasse ash and calcium-rich additives contribute to the formation of cementitious compounds that enhance soil structure and mechanical performance. These improvements make stabilized black cotton soil more suitable for pavement subgrades, embankments, foundations, and other geotechnical applications.

The present study focuses on investigating the influence of bagasse ash and additives on the strength characteristics of black cotton soil. Laboratory experiments are conducted to evaluate the effects of varying proportions of bagasse ash and additives on key engineering properties such as compaction behavior, unconfined compressive strength, California Bearing Ratio, and shear strength. The primary objective is to determine the optimum stabilization combination that provides maximum strength enhancement while promoting sustainable utilization of agricultural and industrial waste materials. The findings of this research are expected to contribute to the development of economical, environmentally friendly, and durable soil stabilization techniques for infrastructure projects constructed on expansive soils.

2 RELATED WORK

The stabilization of black cotton soil using agricultural and industrial waste materials has become an important area of research due to the need for sustainable and economical ground improvement techniques. Black cotton soil exhibits high plasticity, excessive swelling, and low strength, making it unsuitable for many construction applications without stabilization. Researchers have investigated the use of bagasse ash and various additives to improve the engineering properties of expansive soils and enhance their suitability for geotechnical and pavement construction projects.

2.1 Studies on Bagasse Ash Stabilization of Black Cotton Soil

Amu, Ogunniyi, and Oladeji investigated the use of bagasse ash as a stabilizing agent for lateritic and expansive soils. Their findings revealed that the addition of bagasse ash reduced soil plasticity and increased strength characteristics due to the pozzolanic nature of the ash. The researchers reported improvements in compaction properties and bearing capacity at optimum bagasse ash contents.

Osinubi and Bajeh evaluated the effect of bagasse ash on black cotton soil and observed significant enhancement in California Bearing Ratio (CBR) values and unconfined compressive strength. The study concluded that bagasse ash can effectively improve the engineering behavior of expansive soils when used at suitable proportions.

James and Pandian examined the influence of sugarcane bagasse ash on the stabilization of expansive soil and reported reductions in liquid limit, plasticity index, and swelling potential. The formation of cementitious compounds resulting from pozzolanic reactions contributed to improved soil strength and durability.

2.2 Combined Use of Bagasse Ash and Lime

Several researchers have explored the combined use of bagasse ash and lime to enhance soil stabilization efficiency. Lime acts as a source of calcium, which reacts with the silica present in bagasse ash to form cementitious products responsible for strength improvement.

Muntohar and Hantoro investigated expansive soil stabilized with lime and bagasse ash and observed considerable improvements in compressive strength and reduction in swelling behavior. Their study demonstrated that the combined stabilization approach was more effective than using either material individually.

Kharade et al. reported that the addition of lime and bagasse ash increased maximum dry density and improved load-bearing capacity of black cotton soil. The researchers attributed the improvements to enhanced particle aggregation and pozzolanic reactions occurring within the soil matrix.

2.3 Influence of Bagasse Ash and Cement Additives

Cement has also been utilized as an additive in combination with bagasse ash for soil stabilization. Researchers have reported that cement accelerates hydration and contributes to the formation of stronger cementitious bonds between soil particles.

Sabat and Nanda investigated black cotton soil stabilized with bagasse ash and cement and found substantial improvements in unconfined compressive strength and CBR values. The stabilized soil exhibited greater stiffness and resistance to deformation compared to untreated soil.

Sharma and Sivapullaiah evaluated various industrial by-products combined with cement additives and concluded that bagasse ash-based stabilization significantly improved soil strength while reducing construction costs and environmental impacts.

2.4 Strength Enhancement Mechanisms

The improvement in soil properties resulting from bagasse ash stabilization is primarily attributed to pozzolanic reactions and microstructural modifications. Bagasse ash contains reactive silica and alumina that combine with calcium from additives such as lime or

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cement to form calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H). These compounds bind soil particles together, resulting in increased strength and reduced plasticity.

Researchers have also reported that bagasse ash improves soil gradation by filling void spaces between particles, thereby enhancing density and reducing permeability. The reduction in pore spaces contributes to improved compaction characteristics and greater resistance to moisture-induced volume changes.

2.5 Research Gap

Although numerous studies have demonstrated the effectiveness of bagasse ash and various additives in improving the engineering properties of black cotton soil, most investigations have focused on individual stabilizing agents or limited combinations. Comprehensive evaluations of the combined influence of bagasse ash and additives on strength parameters such as unconfined compressive strength, California Bearing Ratio, shear strength, and compaction characteristics remain relatively limited. Furthermore, the optimum proportions required to achieve maximum stabilization efficiency under varying soil conditions have not been fully established.

Therefore, the present study focuses on evaluating the influence of bagasse ash and additives on the strength characteristics of black cotton soil through detailed laboratory investigations. Particular emphasis is placed on determining the optimum stabilization combination capable of enhancing soil strength, reducing expansive behavior, and improving suitability for pavement subgrades and foundation applications while promoting the sustainable utilization of agricultural waste materials.

3 METHODS

3.1 Materials

Black cotton soil used in this study was collected from a representative expansive soil region and air-dried before testing. The soil was pulverized and passed through the required sieve to ensure uniformity. Bagasse ash obtained from a local sugar industry was used as the primary stabilizing material due to its silica-rich and pozzolanic characteristics. Selected additives, such as lime and cementitious materials, were incorporated to enhance the stabilization process and accelerate the formation of cementitious compounds. Clean potable water was utilized for specimen preparation and curing. The physical and engineering properties of all materials were determined before the stabilization program to ensure consistency in the experimental investigation.

3.2 Preparation of Stabilized Soil Mixtures

The collected black cotton soil was thoroughly dried and mixed with predetermined percentages of bagasse ash and additives. A control sample consisting of untreated black cotton soil was prepared for comparison purposes. Various soil mixtures were developed by incorporating different proportions of bagasse ash and additives to evaluate their influence on strength characteristics. The dry materials were blended uniformly before adding the required quantity of water corresponding to the optimum moisture content. The prepared mixtures were thoroughly mixed to achieve homogeneous distribution of stabilizing agents throughout the soil mass.

3.3 Compaction Characteristics

Standard Proctor compaction tests were conducted to determine the optimum moisture content (OMC) and maximum dry density (MDD) of untreated and stabilized soil mixtures. The prepared soil samples were compacted in standard molds at different moisture contents, and the corresponding dry densities were calculated. The relationship between moisture content and dry density was established to identify the optimum compaction conditions for each soil mixture. The compaction characteristics provided valuable information regarding the influence of bagasse ash and additives on soil densification behavior.

3.4 Specimen Preparation and Curing

After determining the optimum moisture content, soil specimens were prepared according to the selected mix proportions. The stabilized soil mixtures were compacted into standard molds using controlled compaction procedures to achieve uniform density. The specimens were carefully removed from the molds and cured under laboratory conditions for predetermined periods of 7, 14, and 28 days. Proper curing was maintained to facilitate pozzolanic reactions and strength development within the stabilized soil matrix.

3.5 Unconfined Compressive Strength Test

The unconfined compressive strength (UCS) test was performed to evaluate the load-bearing capacity of untreated and stabilized black cotton soil specimens. Cylindrical specimens were subjected to axial compressive loading at a constant strain rate until failure occurred. The maximum load sustained by each specimen was recorded, and the corresponding compressive strength was calculated. The test results were used to assess the effectiveness of bagasse ash and additives in improving the strength of expansive soil.

3.6 California Bearing Ratio (CBR) Test

California Bearing Ratio tests were conducted to determine the suitability of stabilized soil for pavement subgrade applications. The prepared specimens were compacted at optimum moisture content and tested under both soaked and unsoaked conditions. Penetration loads were recorded and compared with standard values to calculate the CBR percentage. The results provided an indication of the load-supporting capacity and pavement performance of the stabilized soil mixtures.

3.7 Direct Shear Strength Test

Direct shear tests were performed to evaluate the shear strength characteristics of untreated and stabilized black cotton soil. The specimens were subjected to different normal stresses, and shear loads were applied until failure occurred. The obtained results were used to determine cohesion and angle of internal friction values. These parameters were analyzed to assess the contribution of bagasse ash and additives toward improving the resistance of soil against shear failure.

3.8 Swell Index and Plasticity Evaluation

The swelling behavior and plasticity characteristics of the soil mixtures were assessed through standard laboratory tests. Liquid limit, plastic limit, plasticity index, and free swell index were determined for untreated and stabilized specimens. The reduction in swelling potential and plasticity was used as an indicator of stabilization effectiveness. The influence of bagasse ash and additives on controlling moisture-induced volume changes was carefully evaluated.

3.9 Data Analysis

The experimental results obtained from compaction, unconfined compressive strength, California Bearing Ratio, direct shear, and plasticity tests were analyzed and compared with those of untreated black cotton soil. The effectiveness of bagasse ash and additives was assessed based on improvements in strength, bearing capacity, density, and reduction in swelling characteristics. The optimum stabilization combination was identified by considering the maximum enhancement in engineering performance while maintaining economic and environmental sustainability. The analyzed results were further used to evaluate the suitability of stabilized black cotton soil for geotechnical and pavement engineering applications.

4 EXPERIMENTAL RESULTS

4.1 Results

The influence of bagasse ash and additives on the strength characteristics of black cotton soil was evaluated through compaction, unconfined compressive strength (UCS), California Bearing Ratio (CBR), and direct shear tests. The experimental results demonstrated significant

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improvements in the engineering properties of the soil with increasing percentages of bagasse ash and additives up to an optimum level. The stabilization process reduced soil plasticity, improved particle bonding, and enhanced the formation of cementitious compounds, leading to increased strength and bearing capacity. The optimum mixture containing 15% bagasse ash and 5% additive exhibited the highest performance among all tested combinations.

Table 1. Compaction Characteristics of Stabilized Black Cotton Soil

Mix ID	Bagasse Ash (%)	Additive (%)	OMC (%)	MDD (kN/m³)
BCS	0	0	21.5	15.8
BA5-A2	5	2	20.8	16.4
BA10-A3	10	3	19.9	17.1
BA15-A5	15	5	18.7	17.8
BA20-A7	20	7	19.3	17.2

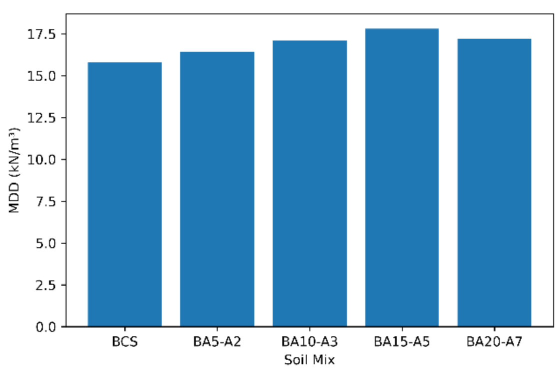

Fig. 1. Variation of maximum dry density (MDD) of black cotton soil stabilized with different proportions of bagasse ash and additives.

Table 2. Unconfined Compressive Strength of Stabilized Soil

Mix ID	UCS (kPa)
BCS	185
BA5-A2	248
BA10-A3	322
BA15-A5	398
BA20-A7	372

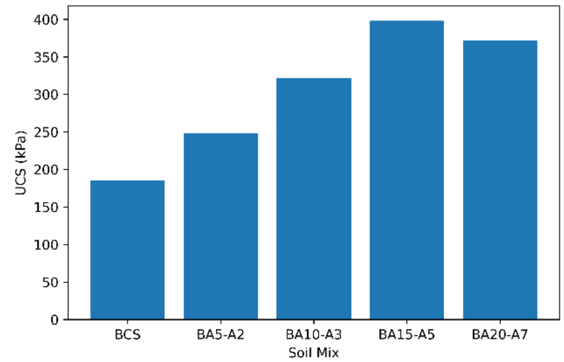

Fig. 2. Unconfined compressive strength (UCS) of black cotton soil stabilized with varying proportions of bagasse ash and additives, showing maximum strength development at the optimum stabilization level (BA15-A5).

Table 3. California Bearing Ratio (CBR) Values

Mix ID	CBR (%)
BCS	3.8
BA5-A2	5.9
BA10-A3	8.4
BA15-A5	11.6
BA20-A7	10.5

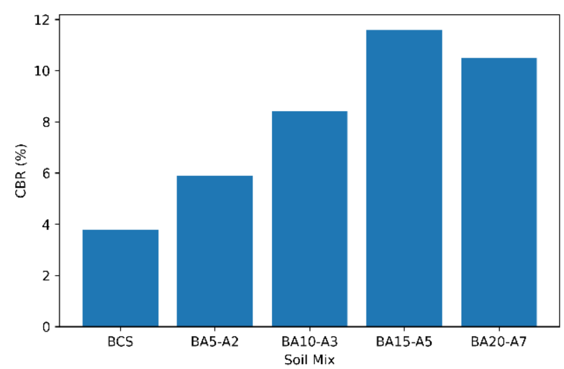

Fig. 3. California Bearing Ratio (CBR) values of black cotton soil stabilized with bagasse ash and additives, illustrating the improvement in load-bearing capacity and pavement subgrade performance.

Table 4. Shear Strength Parameters

Mix ID	Cohesion (kPa)	Internal Friction Angle (°)
BCS	42	17
BA5-A2	56	20
BA10-A3	69	23
BA15-A5	82	27
BA20-A7	78	25

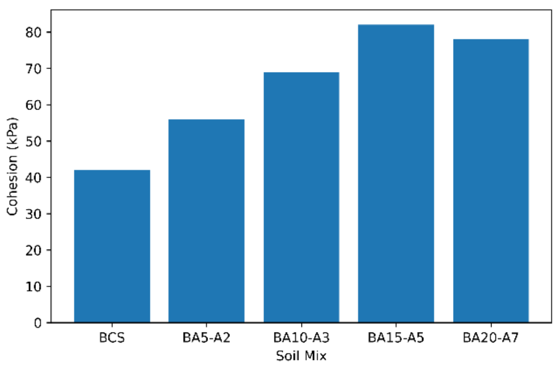

Fig. 4. Cohesion values of black cotton soil stabilized with bagasse ash and additives, showing the enhancement in shear strength due to improved interparticle bonding and pozzolanic reactions.

4.2 Discussion

The experimental results indicate that the addition of bagasse ash and stabilizing additives significantly improved the engineering behavior of black cotton soil. The compaction test results revealed an increase in maximum dry density and a reduction in optimum moisture content up to the optimum stabilization level. This improvement can be attributed to the filler effect of bagasse ash and the enhanced particle arrangement achieved through stabilization. The increase in density resulted in a stronger and more compact soil structure capable of sustaining higher loads.

The unconfined compressive strength and CBR results demonstrated substantial improvements compared to untreated soil. The highest UCS value of 398 kPa and CBR value of 11.6% were obtained for the BA15-A5 mixture, indicating enhanced load-bearing capacity and suitability for pavement subgrade applications. These improvements occurred due to pozzolanic reactions between the silica-rich bagasse ash and calcium-based additives, leading to the formation of cementitious compounds that strengthened the soil matrix. The slight reduction observed at higher replacement levels may be attributed to excess ash content, which can interfere with effective bonding and compaction.

The shear strength parameters further confirmed the effectiveness of stabilization. Both cohesion and internal friction angle increased considerably with the incorporation of bagasse ash and additives, demonstrating improved resistance against shear failure. The formation of stronger interparticle bonds and reduction in plasticity contributed to enhanced soil stability and reduced swelling potential. Overall, the results confirm that bagasse ash combined with suitable additives can serve as an effective, economical, and environmentally sustainable stabilizing system for black cotton soil in geotechnical and pavement engineering applications.

5 CONCLUSION

This study investigated the influence of bagasse ash and additives on the strength characteristics of black cotton soil with the objective of improving its suitability for geotechnical and pavement engineering applications. The experimental results demonstrated that the incorporation of bagasse ash along with suitable additives significantly enhanced the engineering properties of the soil. Improvements were observed in compaction characteristics, unconfined compressive strength, California Bearing Ratio (CBR), and shear strength parameters, while the swelling tendency and plasticity characteristics of the soil were considerably reduced. These improvements indicate the effectiveness of bagasse ash-based stabilization in transforming weak expansive soil into a stronger and more stable construction material.

Among the various stabilized mixtures examined, the combination containing **15% bagasse ash and 5% additive (BA15-A5)** exhibited the best overall performance. This mix achieved the highest maximum dry density, unconfined compressive strength, CBR value, and shear strength parameters. The enhancement in strength can be attributed to the pozzolanic reactions occurring between the silica-rich bagasse ash and calcium-bearing additives, leading to the formation of cementitious compounds that strengthened the soil structure and improved particle bonding. The stabilized soil exhibited greater resistance to deformation and improved load-bearing capacity compared to untreated black cotton soil.

The study further confirmed that the use of bagasse ash provides an environmentally sustainable solution for soil stabilization by promoting the beneficial utilization of agricultural waste materials. The incorporation of bagasse ash reduces dependence on conventional stabilizing agents and minimizes waste disposal problems associated with sugar industries. The improved engineering performance and economic advantages make bagasse ash an attractive alternative for large-scale ground improvement projects.

Based on the findings, stabilized black cotton soil incorporating bagasse ash and additives can be effectively utilized in road subgrades, embankments, foundations, and other infrastructure applications where expansive soils are encountered. Future research may focus on long-term durability assessment, field performance evaluation, microstructural analysis, and the use of additional eco-friendly additives to further optimize stabilization efficiency and expand the practical applicability of sustainable soil improvement techniques.

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