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COMPACTION AND SHEAR STRENGTH CHARACTERISTICS OF CLAYEY SOIL USING CEMENT AND BAGASSE ASH

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Abstract
This study investigates the compaction and shear strength characteristics of clayey soil treated with cement and bagasse ash. The addition of cement and bagasse ash is evaluated for its potential to improve the engineering properties of clayey soil, commonly used in construction projects. Various tests, including compaction and shear strength, are performed to assess the effects of different proportions of cement and bagasse ash on the soil's stability and strength. Results demonstrate significant improvements in compaction properties and shear strength, suggesting that cement and bagasse ash are effective stabilizing agents for enhancing clayey soil performance in engineering applications.
Keywords: Clayey soil, shear strength, light compaction, cement, bagasse ash;

Introduction

Increased load-bearing capacity, improved shear strength, and reduced settlement issues make soil stabilization a crucial technique for ensuring long-term stability in infrastructure projects. Various methods are employed for soil stabilization, including mechanical, chemical, and biological approaches. Among these, chemical stabilization using cement, lime, fly ash, and geopolymers has gained prominence due to its effectiveness in altering soil properties to meet engineering requirements [11].

Recent advancements in soil stabilization focus on sustainable and eco-friendly solutions, such as utilizing industrial by-products like bagasse ash, silica fume, and ground granulated blast furnace slag (GGBS), which not only enhance soil strength but also contribute to waste minimization and circular economy principles [13][15]. Additionally, innovative techniques, such as enzymeinduced calcite precipitation (EICP) and microbial-induced calcite precipitation (MICP), offer promising alternatives for improving soil properties without excessive environmental impact [17]. Furthermore, research indicates that stabilization methods incorporating nanomaterials can significantly enhance soil characteristics, including reduced permeability and increased cohesion, offering new possibilities for infrastructure development in challenging terrains [19][21]. Given the increasing demand for sustainable and resilient construction practices, the integration of advanced soil stabilization techniques plays a vital role in ensuring the durability and performance of infrastructure while minimizing environmental footprints [23].

Moreover, studies highlight the importance of adopting performance-based soil improvement techniques tailored to specific geotechnical conditions, ensuring that structural loads are effectively transferred and distributed [25]. Future research in this field aims to integrate AI-driven predictive models for optimizing soil stabilization processes and reducing dependency on traditional empirical methods [27][29].

- Improves Strength and Bearing Capacity: Stabilization enhances the strength of the soil, increasing its load-bearing capacity.
- Cost-Effective and Energy Efficient: Strengthening the soil is more economical compared to installing deep or raft foundations.
- Increases Stability: It provides additional stability to soils on slopes or other challenging terrains.
- Prevents Soil Erosion and Dust Formation: This is particularly beneficial in dry and arid climates.
- Enhances Water Resistance: Stabilization can make the soil water-resistant, preventing water infiltration and maintaining its strength.
- Minimizes Volume Changes: It reduces soil volume fluctuations caused by temperature or moisture variations.
- Improves Workability and Durability: Stabilization increases the soil's overall usability and longevity.

Globally, researchers are increasingly focused on utilizing industrial and agricultural wastes as raw materials for construction purposes. This approach not only promotes cost-effectiveness but also contributes to environmental pollution control [11]. The reuse of waste materials is crucial, and this study aligns with that objective [13].

Bagasse, a fibrous residue left after sugarcane is processed in sugar mills, is one such waste material [15]. Traditionally, bagasse was burned as a means of waste disposal. However, with the rising costs of fuel oil, natural gas, and electricity, bagasse has evolved into a valuable fuel source for sugar mills [17]. As per recent statistics w.r.t the Indian scenario, one ton of sugarcane generates approximately 280 kilograms of bagasse [19]. The economic and environmental challenges associated with bagasse have spurred global efforts to explore its management, including its utilization, storage, and disposal [21]. Recent advancements in bagasse utilization have explored its application in construction materials such as adobe bricks and geopolymer concrete, enhancing their mechanical and durability properties [23]. Studies indicate that incorporating bagasse ash as a supplementary cementitious material improves compressive strength and resistance to sulfate attack in cement-based composites [25]. Furthermore, sustainable construction strategies increasingly emphasize the circular economy approach, where waste materials like bagasse contribute to resource efficiency and carbon footprint reduction [27]. Future research aims to develop optimized bagasse-based composites with tailored physical and chemical characteristics, ensuring long-term sustainability in the construction sector [29].

Literature Review

Soil stabilization plays a crucial role in enhancing the geotechnical properties of problematic soils by incorporating industrial by-products and alternative stabilizers. Various studies have explored the effectiveness of different waste materials, including sugarcane straw ash, rice husk ash, bagasse ash, and lime, in improving soil characteristics such as strength, compaction, swelling potential, and California Bearing Ratio (CBR). This literature review synthesizes key findings from previous research to establish a foundation for the present study.

1. Effect of Sugarcane Straw Ash on Lateritic Soil Stabilization

Amu, Ogunniyi, and Oladeji (2011) conducted preliminary investigations on three lateritic soil samples (A, B, and C) by performing identification, classification, and consistency limit tests. Their study aimed to evaluate the feasibility of using sugarcane straw ash (SCSA) as a cost-effective and sustainable alternative to conventional soil stabilizers. Experimental results demonstrated that incorporating SCSA led to significant improvements in the strength properties of lateritic soil. The progressive increase in SCSA percentage enhanced the soil’s geotechnical performance, making it a viable stabilizer for lateritic soil stabilization.

2. Influence of Lime and Rice Husk Ash Combinations on Geotechnical Properties

Mtallib and Bankole (2011) analyzed the effects of lime and rice husk ash (RHA) on soil stabilization through an extensive study of index properties and geotechnical characteristics. The Atterberg limits exhibited notable variations when lime and RHA were used as admixtures. Their research highlighted a decrease in maximum dry density (MDD) and an increase in optimum moisture content (OMC), indicating changes in the soil’s compaction behavior. Additionally, the treated soil samples displayed significantly higher CBR values compared to untreated samples, confirming enhanced load-bearing capacity. However, the results suggested that the stabilized soil did not meet the stringent requirements for major or urban roads but could be effectively used as a sub-base material for lightly trafficked roads.

3. Enhancement of Expansive Soil Stability Using Bagasse Ash

Gandhi (2012) explored the use of bagasse ash (BA) to improve the engineering behavior of expansive soils in the Surat region. As bagasse ash contains high concentrations of silica, calcium, and other essential minerals, it contributed to reducing the swelling potential and enhancing the stability of expansive clay. Laboratory tests were conducted with varying percentages of bagasse ash to assess its impact on swelling pressure and soil properties. The findings indicated that bagasse ash significantly reduced the swell potential by displacing some of the volume previously occupied by expansive clay minerals, thereby improving the soil's overall performance.

4. Effect of Bagasse Ash on Cement-Treated Lateritic Soil

Mohammed Abdullah (2012) investigated the influence of bagasse ash on plasticity and particle size distribution in cement-treated lateritic soil. The study revealed that increasing the bagasse ash content led to a reduction in the liquid limit and plasticity index, while the plastic limit exhibited an increasing trend. Additionally, the particle size distribution analysis indicated a substantial decrease in fine particles, attributed to the agglomeration of soil particles into heavier pseudo-particles. The percentage of fines passing through BS Sieve No. 200 was reduced from 63% to nearly zero. Based on these observations, the study recommended an optimum bagasse ash content of 4% to 6% for effective soil stabilization.

5. Strength Improvement of Clayey Soil with Lime and Calcium Chloride

Chandran and Padmakumar (2014) examined the effect of lime solution and calcium chloride on the stabilization of kaolinite-rich clayey soil from Thonnakal in Trivandrum. The study employed various concentrations of lime solution and calcium chloride, with stabilization effects monitored over multiple curing periods (7, 14, 21, 28, and 35 days). The results demonstrated a progressive increase in unconfined compressive strength (UCS) up to 28 days, beyond which no further appreciable improvement was observed. The research concluded that an optimal lime concentration exists, beyond which no significant strength enhancement occurs, highlighting the importance of selecting the appropriate dosage for soil stabilization applications.

6. Performance of Bagasse Ash and Cement in Stabilizing Marshy Soil

Pallavi et al. (2016) focused on the stabilization of marshy soil using bagasse ash and cement. The study reported a notable improvement in the California Bearing Ratio (CBR) values with the inclusion of these stabilizers. The presence of bagasse ash and cement significantly improved the load-bearing capacity, making the soil more suitable for construction purposes. This research reaffirmed the efficacy of industrial by-products as sustainable and cost-effective stabilizers in geotechnical applications.

Summary and Research Gap

From the above-reviewed literature, it is evident that various industrial by-products, including sugarcane straw ash, rice husk ash, bagasse ash, and lime, have been successfully employed for soil stabilization. These materials have shown significant improvements in compaction characteristics, shear strength, swelling potential, and CBR values. However, most studies have focused on specific soil types and stabilization techniques, leaving gaps in understanding their long-term durability and performance in different environmental conditions.

The present study aims to investigate the engineering properties of cement-treated clayey soil admixed with bagasse ash to evaluate its shear strength, compaction behavior, and stability characteristics. A detailed experimental program will be conducted to assess the effectiveness of bagasse ash as a supplementary stabilizer, contributing to a more sustainable and economical approach in soil stabilization.

Materials Used in the Study

The materials used in this research include clayey soil, bagasse ash, Ordinary Portland Cement (OPC) of 53 grade, and potable water. Each material was carefully selected and prepared to ensure consistency and accuracy in experimental investigations.

1. Soil

The soil utilized in this study is clayey soil, collected from Mysore district, Karnataka, India [11]. The selection of soil was based on its plasticity characteristics and suitability for stabilization studies [13]. Soil samples were extracted from depths representative of the soil stratum, ensuring that they were collected from a minimum depth of 0.5 meters below the natural ground surface to avoid contamination from organic matter and surface disturbances [15]. Upon collection, the soil samples were stored in jute bags to preserve their moisture content and prevent contamination [17]. The samples were then transferred to a controlled environment in the Geotechnical Engineering Laboratory to ensure that the intrinsic properties of the soil remained intact before testing [19]. Further laboratory analysis was conducted to determine key geotechnical properties, including liquid limit, plastic limit, specific gravity, and grain size distribution, which play a critical role in soil stabilization studies [21]. Studies indicate that controlled curing conditions and proper sample preparation significantly influence the effectiveness of stabilization techniques applied to clayey soils [23].

Additionally, innovative soil improvement methods, such as enzyme stabilization and bio-mediated treatments, have shown promising results in enhancing the strength and durability of clayey soils, making them suitable for sustainable construction applications [25]. Future research aims to integrate advanced soil characterization techniques using AI-based modeling for improved predictive analysis and performance evaluation [27][29].

Prior to conducting laboratory tests, the soil samples underwent **preliminary preparation**:

- **Oven drying:** The samples were dried at **105°C to 110°C** in a laboratory oven to remove excess moisture.
- **Sieve analysis:** The dried soil was **sieved through a 4.75 mm aperture** to remove coarser particles and ensure uniformity in sample grading.
- **Storage:** The processed soil was stored in airtight containers to prevent moisture absorption before further testing.

2. Bagasse Ash

Bagasse ash is a by-product derived from sugarcane processing in sugar mills [11]. It is the fibrous cellulose-rich residue left after sugarcane is crushed and its juice is extracted [13]. Traditionally, bagasse was used as fuel in sugar mills or burned as a method of solid waste disposal [15]. However, with increasing environmental concerns, the reuse of bagasse ash in construction and geotechnical applications has gained significance due to its high silica content and pozzolanic properties [17]. Recent studies highlight that bagasse ash, when incorporated as a supplementary cementitious material, improves the strength and durability characteristics of concrete and stabilized soils [19]. The presence of reactive silica in bagasse ash enhances its binding properties, making it a suitable alternative to conventional stabilizers like cement and lime in soil stabilization projects [21]. Additionally, bagasse ash utilization aligns with sustainable construction practices by reducing landfill waste and promoting a circular economy approach [23]. Research indicates that optimized proportions of bagasse ash in cementitious composites can improve resistance to sulfate attacks, enhance permeability properties, and reduce the carbon footprint of traditional construction materials [25].

Future advancements in geotechnical engineering are exploring the integration of nano-engineered bagasse ash composites to enhance soil stabilization techniques, providing long-term benefits for infrastructure development in challenging terrains [27][29].

Source and Availability

The bagasse ash used in this study was obtained from a sugar mill located in Mandya district, Karnataka, India. Karnataka is one of India's major sugarcane-producing states, along with Uttar Pradesh, Tamil Nadu, Gujarat, and Andhra Pradesh, which collectively contribute significantly to India's total sugar production. Globally, Brazil remains the largest producer of sugarcane, generating substantial amounts of bagasse ash as a residual waste material.

Processing of Bagasse Ash

To ensure uniformity and enhance its suitability as a stabilizing agent, the bagasse ash was subjected to the following preparatory steps before use:

- Drying: The bagasse ash was dried to remove residual moisture.
- Grinding: The dried ash was ground into finer particles to improve its reactivity with soil and cement.
- Sieving: It was sieved through a 75-micron sieve to remove coarser particles and ensure consistency in stabilization experiments.

The inclusion of bagasse ash in soil stabilization is beneficial due to its silica-rich composition, which reacts with cementitious materials to enhance soil strength and durability.

3. Cement

The cement used in this study is Ordinary Portland Cement (OPC) of 53 grade, which is widely known for its high compressive strength and rapid setting properties. OPC 53 grade cement is preferred for soil stabilization applications due to its superior binding ability and higher early strength gain compared to lower-grade cements.

Procurement and Packaging

The cement was procured from a local vendor in Mysore district, Karnataka, India. It was supplied in 50 kg bags, ensuring proper storage and handling. The cement was stored in a dry, moisture-free environment to prevent premature hydration, which could compromise its effectiveness in stabilization.

4. Water

Potable water was used throughout the study for soil preparation, mixing, and curing processes. The water was sourced from a reliable municipal supply, ensuring that it met the required standards for concrete and soil stabilization applications. The pH level and chemical composition of the water were monitored to ensure that it did not contain any impurities or deleterious substances that could affect the chemical interactions between soil, bagasse ash, and cement.

Here is the rewritten and expanded **Methodology** section with enhanced technical depth, clarity, and structured flow:
Methodology

This study involves an extensive experimental investigation to assess the impact of bagasse ash and cement on the engineering properties of clayey soil. Laboratory tests were performed on untreated clayey soil as well as on soil–bagasse ash–cement mixtures with varying percentages of bagasse ash (4%, 8%, and 12%). The following standardized geotechnical **tests** were conducted to evaluate the stabilization effectiveness:

- **Proctor's Standard Compaction Test**
- **Unconfined Compression Test (UCC)**

The methodology adopted for each test is outlined in detail below.
2.1.1 1. Proctor's Standard Compaction Test

The Proctor's Standard Compaction Test was conducted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the soil and its stabilized variants. The test was performed following the guidelines specified in IS 2720 Part 6 (1974).

1. **Soil Sample Preparation:**
   - The clayey soil was oven-dried at **105°C–110°C** for 24 hours.
   - The dried sample was sieved through a **4.75 mm sieve** to ensure uniform grading.
   - Weighed quantities of bagasse ash and cement were added to the soil in proportions of **4%, 8%, and 12%**, respectively.
   - The soil–bagasse ash–cement mixtures were thoroughly blended to achieve **homogeneous mixing**.
2. **Compaction Process:**
   - The blended sample was gradually mixed with water and compacted in a Proctor mold (1000 cc capacity) using a 2.5 kg rammer.
   - The soil was compacted in three layers, with 25 evenly distributed blows per layer.
   - The compacted specimen was carefully extruded from the mold, and the bulk density was measured.

3. **Determination of OMC and MDD:**
    - The test was repeated for multiple trials with increasing moisture content.
    - A moisture-density relationship curve was plotted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for each soil mixture.

2.1.2 2. **Unconfined Compression Test (UCC)**

The **Unconfined Compressive Strength (UCS) Test** was performed to evaluate the **shear strength and load-bearing capacity** of the stabilized soil. The testing procedure adhered to **IS 2720 Part 10 (1973)**.

Sample Preparation and Curing:

- **Specimens were prepared using static compaction to ensure a consistent initial dry density.**
- **The test samples were compacted at their Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) as determined from the Proctor compaction test.**
- **The cylindrical specimens (38 mm in diameter and 76 mm in height) were carefully molded and cured for different durations (7, 14, and 28 days) to observe the strength gain over time.**

Testing Procedure:

1. **Specimen Placement:**
    - The prepared specimens were positioned between the loading platens of the **UCC testing machine**.
2. **Application of Load:**
    - The load was applied at a **constant strain rate of 1.5 mm/min**, ensuring uniform stress distribution.
3. **Failure Criteria:**
    - The axial load was continuously increased until the sample **failed due to shear deformation**.
    - The **peak load at failure** was recorded, and the **Unconfined Compressive Strength (qu) was calculated**
4. **Strength Enhancement Analysis:**
    - The UCS values for **untreated clayey soil, soil mixed with bagasse ash, and soil stabilized with bagasse ash and cement** were compared to determine the **optimum stabilizer percentage**.

Experimental Program

A systematic experimental program was designed to assess the influence of **bagasse ash and cement** on the **compaction behavior, strength properties, and shear resistance** of clayey soil. Table 1 provides a comprehensive summary of the experimental tests conducted in this study.

Table 1: Experimental Programme

Type	**Other additives used**	**Compaction test**	**UCC test**	**Total no of tests**
Clayey soil	No additive	1	1	2

Clayey Soil+ 4% Baggase Ash	4% Cement	1	1	2
	8% Cement	1	1	2
	12% Cement	1	1	2
Soil + 8% Bagasse Ash	4% Cement	1	1	2
	8% Cement	1	1	2
	12% Cement	1	1	2
Soil + 12% Bagasse Ash	4% Cement	1	1	2
	8% Cement	1	1	2
	12% Cement	1	1	2

Table 2: The characteristics of clayey soil

Properties	**Values**
Gravel (%)	0
Sand (%)	27.9
Fine (Silt + clay) (%)	72.2
IS Classification	CH
Specific Gravity (G)	2.71
Optimum moisture content (OMC) (%)	21
Maximum dry density (MDD) (g/cc)	1.38
Unconfined Compressive Strength (N/mm²)	29.06

Results and Discussions

Compaction test results obtained for 4% Bagasse ash with different %s of cement

The compaction characteristics, including Optimum Moisture Content (OMC) and Maximum Dry Density (MDD), were evaluated for clayey soil stabilized with 4% bagasse ash and different percentages of cement. The results of these tests are graphically represented in Figure 1, which illustrates the influence of cement content on compaction behavior.

Variation in OMC and MDD with Cement Content

From the observed trends in **Figure 1,** the following key findings were noted:

- **Increase in MDD with Cement Addition:**

The **Maximum Dry Density (MDD)** exhibited an increasing trend with the addition of **cement up to 12%**, indicating improved soil packing. This enhancement is attributed to the **higher specific gravity of cement compared to soil**, which results in increased **particle rearrangement and densification**.

- **Effect on Optimum Moisture Content (OMC):**

- The **Optimum Moisture Content (OMC) increased with cement addition up to 8%**, reaching its peak value.
- Beyond **8% cement addition**, the OMC **declined at 12% cement content**, suggesting that excessive cement reduces the water demand due to a stronger cementitious bonding effect.

- **Maximum MDD and OMC Values:**
  - The maximum dry density of 1.56 g/cc was obtained for the mix containing 4% bagasse ash and 12% cement.
  - The highest optimum moisture content of 28% was recorded for the mix containing 4% bagasse ash and 8% cement.

2.1.3 Interpretation of Results

- The increase in **MDD** indicates that the presence of **cement improves the compactability** of the clay-bagasse ash mixture.
- The initial **increase in OMC** (up to 8% cement) suggests that **hydration reactions require additional water,** facilitating better **soil-cement interaction.**
- The **reduction in OMC beyond 8% cement** suggests that **cement particles occupy void spaces, reducing water absorption.**
- The **higher density at 12% cement** confirms that cement **acts as a binder,** enhancing soil stability through **improved particle bonding and densification.**

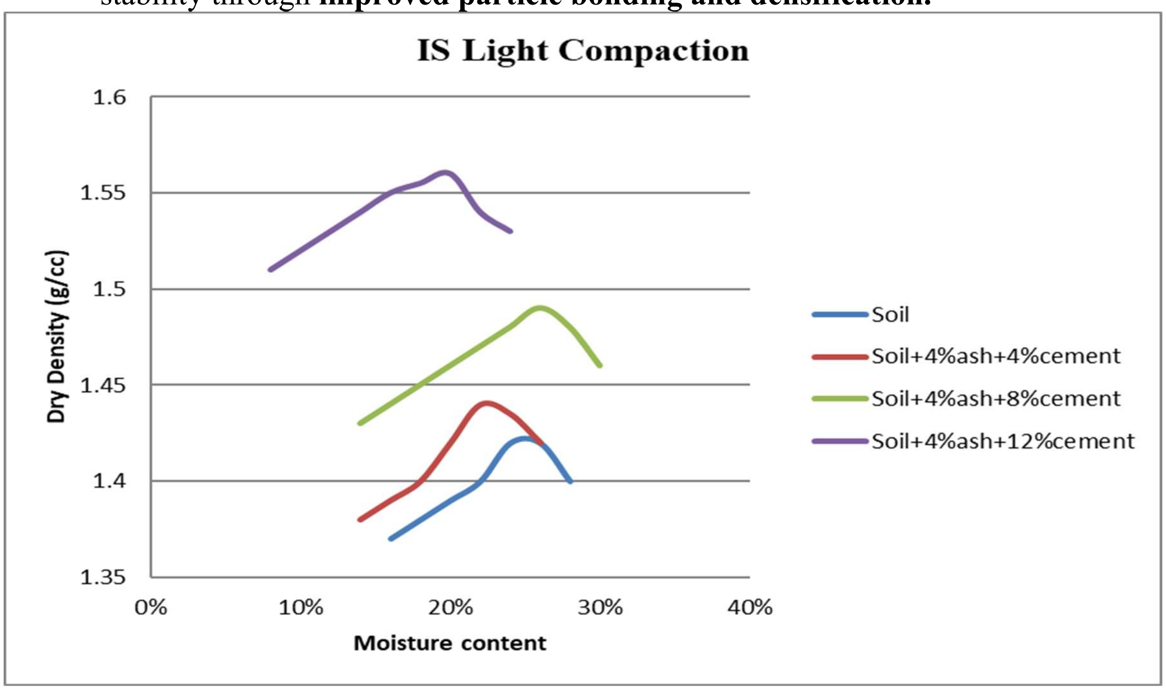

Figure 1: Compaction curves of clayey soil stabilized with 4% bagasse as + different %s of cement

Compaction test results obtained for 8% Bagasse ash with different %s of cement

The effect of 8% of Bagasse ash with different % of cement are shown in figure 2.The results shows an initial increase in MDD until 4% cement after which density decrease with the increase in cement content. Whereas the moisture content increases upto 8% cement and reduces after further addition, this is due to extra water required for hydration and pozzolanic action to take place. The 8%ash + 4%cement mix proportion yielded dry density of 1.52g/cc and for mix proportion of 8% +8%cement yielded optimum moisture content of 28%.

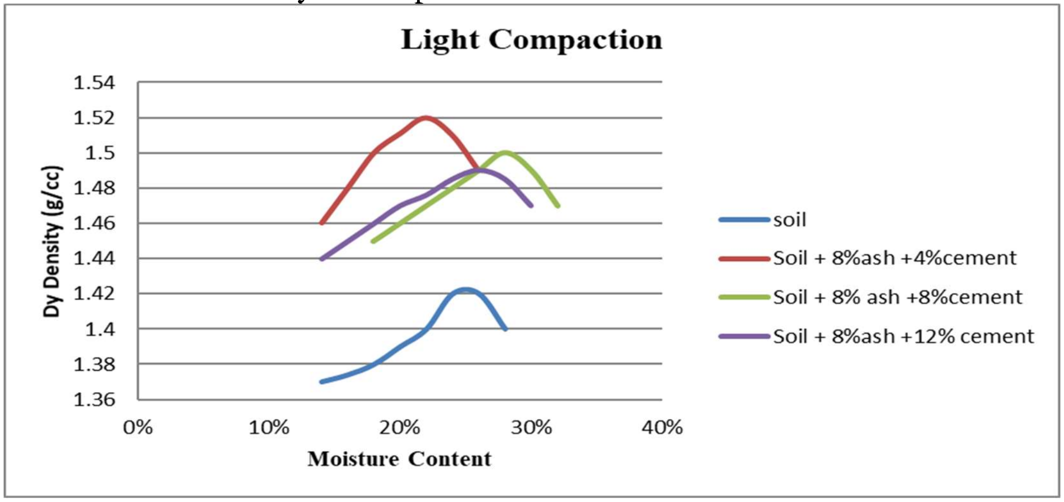

Figure 2: Compaction curves of clayey soil Stabilized with 8% bagasse ash + different % of cement

Compaction test results obtained for 12% Bagasse ash with different %s of cement

The variations of OMC and MDD stabilized with 12%ash and different %s of cement are presented in figure 2. From the figure, it is observed that there is a increase in OMC and MDD with the addition of bagasse ash and cement when compared to the compaction characteristics of clayey soil. There is an increase in OMC and MDD with the increase in ash and cement, but the moisture content increases up to 8%cement and decreases for other mix proportions.

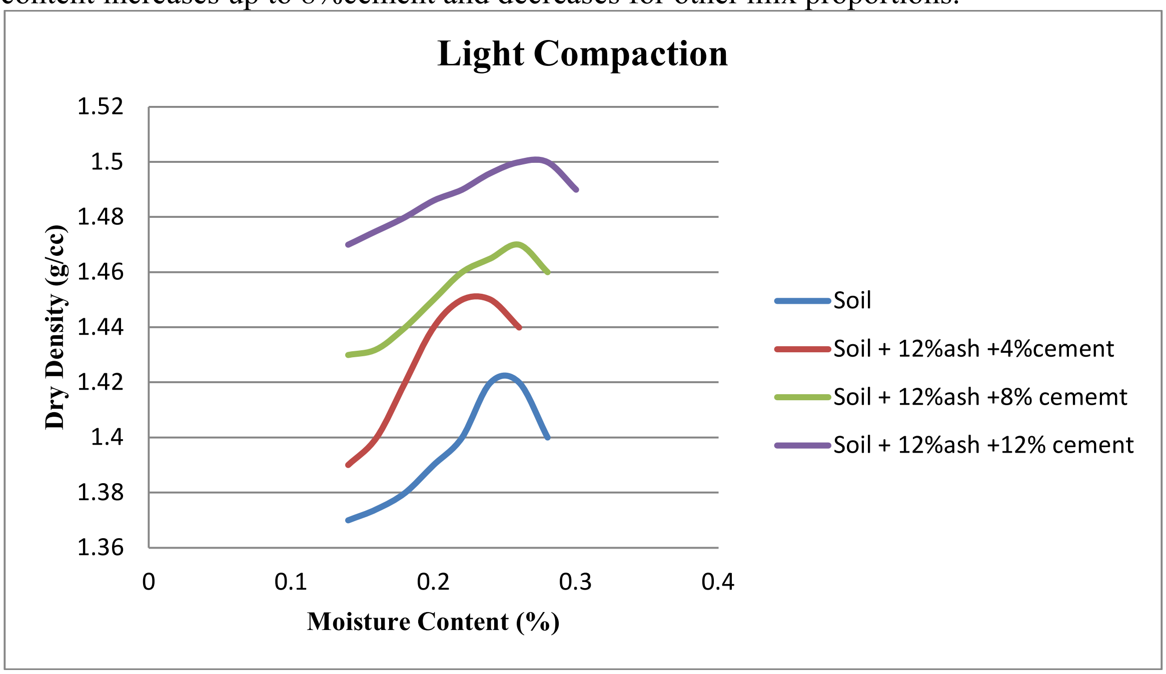

Figure 3: Compaction curve of clayey soil stabilized with 12% bagasse ash + different %s of cement

Unconfined Compression test results obtained for 4%bagasse ash with varying % of cement

The results of unconfined strength of soil stabilized with 4% bagasse ash for various parentages of cement mixtures are shown below. Generally, strength of soil increases with the increase in cement and ash blend. The increase can be attributed primarily to the formation of various compounds such as calcium silicate and calcium aluminates, which are responsible for strength development. The Peak UCS value is recorded from 32.06N/mm² for the natural soil, to 114.22 N/mm² for stabilization with 4%ash / 12%cement.

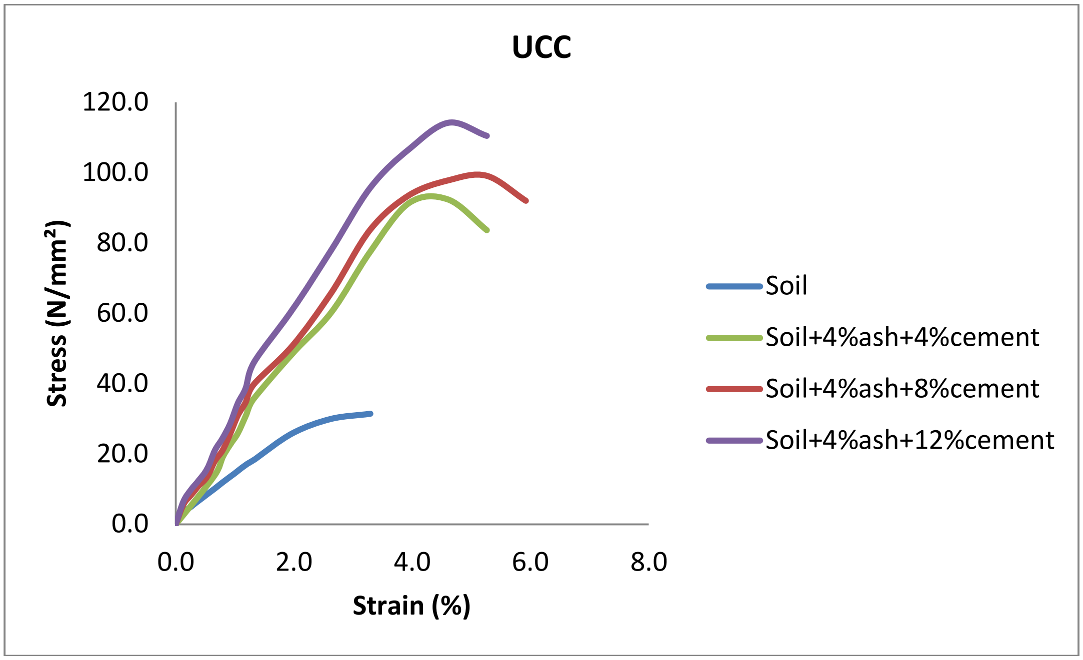

Figure 4: Stress-Strain response for soil stabilized with 4% bagasse ash + different %s of Cement

Unconfined Compression test results obtained for 8 %bagasse ash with varying % of cement

The variations of stress – strain response of soil stabilized with 8% bagasse ash and different %s of cement are presented below. From the figure it is observed that the strength increases significantly with the increase in the %s of cement. The peak UCS value is 125.52N/mm² which is obtained by the addition of 8%ash/12%cement.

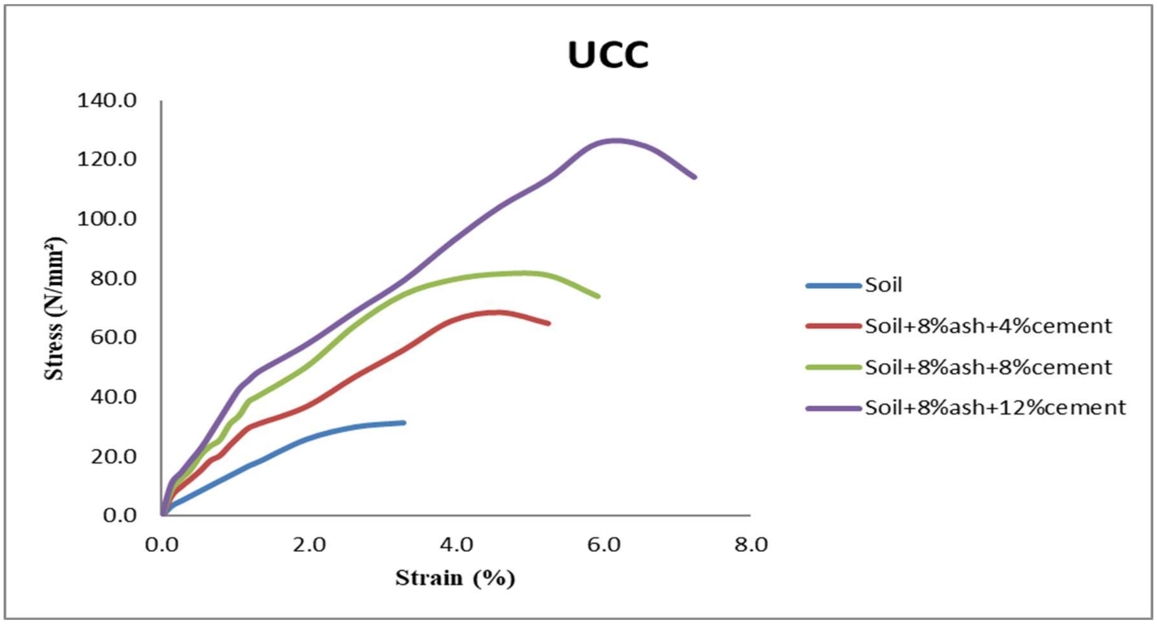

Figure 5: Stress-Strain response for soil with 8% bagasse ash+ different % of Cement

Unconfined Compression test results obtained for 12% bagasse ash with varying % of cement

The results of stress- strain response of clayey soil stabilized with 12%ash and different % of cement are presented in figure.5. From the figure, it is observed that strength of the sample has been increased with the addition of ash and cement. The optimum value of 110.95 N/mm² is recorded by the addition of 12% ash and 12% cement.

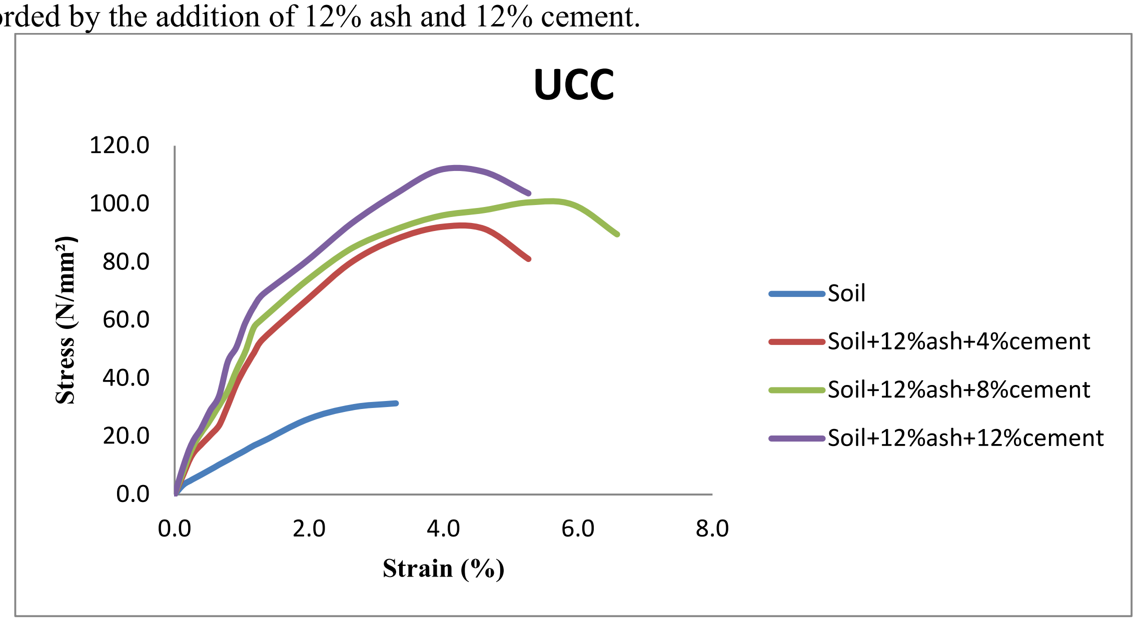

Figure 6: Stress-Strain response for soil with 12% bagasse ash + different % of Cement

Conclusion

A study was conducted to assess the effect bagasse ash, cement blend on Clayey soil. The clayey soil was stabilized with these additives in variations of 4, 8, and 12%. The results obtained indicate that:

- From the present study it is observed that there is a remarkable influence on the compaction characteristics and unconfined strength with the addition of bagasse ash
- Addition of varying percentage of bagasse ash, cement had a significant effect on maximum dry density and optimum moisture content. It is observed that MDD of soil has been improved to 20% on the addition of 4% ash and 12% cement whereas the OMC of soil is increased by 1.56g/cc on the addition of 4% ash and 12% cement
- In the unconfined compression test, Ucc value increases gradually for different mix proportion. The soil stabilized with 8% ash /12% cement recorded the peak value of 125.52 N/mm^2

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