STRENGTH AND COMPACTION CHARACTERISTICS OF SANDY SOIL STABILIZED WITH RICE HUSK ASH AND CEMENT

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ABSTRACT

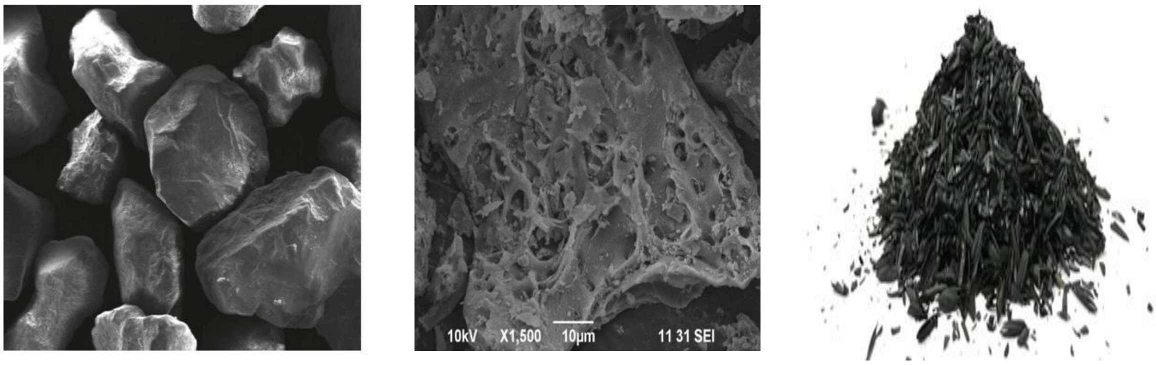
Sandy soils, especially in their loose form, exhibit poor load-bearing capacity, often necessitating stabilization for construction applications. Traditional methods frequently rely on chemical additives, which can be costly and environmentally harmful. This study investigates the feasibility of using rice husk ash (RHA), an abundant agricultural byproduct, in combination with cement to enhance the engineering properties of sandy soil. In the experimental program, rice husk ash was added at proportions of 0%, 5%, 10%, and 15% by dry weight of sand, while cement content was maintained at 3%, 6%, and 9%. Standard proctor compaction tests were conducted to assess the moisture-density relationship for each mix, and the unconfined compressive strength (UCS) test was conducted later to evaluate strength improvement, with specimens cured under controlled laboratory conditions. Experimental results indicated that the addition of RHA affected compaction behavior, typically resulting in a slight decrease in maximum dry unit weight and an increase in optimum moisture content. Notably, the mix containing 9% cement and 10% RHA achieved approximately three times higher compressive strength than the base soil. Beyond this RHA content, strength gains plateaued or decreased, indicating an optimal replacement threshold. Utilizing RHA as a stabilizer for sandy soil can reduce carbon footprint and material costs while significantly enhancing load-bearing capacity, making this method particularly beneficial for developing regions with abundant rice husk resources.

Keywords: *Unconfined compressive strength, Soil stabilization, Rice husk ash*

1. INTRODUCTION

Sandy soil is loose and poorly graded, making it unsuitable for construction work. Sandy soil has good drainage quality, but there is a high risk of shear failure, erosion, and liquefaction. Once, it was a tradition that to do construction work, sandy soil must be avoided for soil stabilization concerns. But gradually the land use pattern changes, and engineers are now constructing heavy structures on sandy soil. The expansion of cities has reduced the number of available lands. But engineering marvels have made soil stabilization more reliable, cost-effective, and environment friendly (Firoozi et al., 2017). The performance of sand was significantly moderated by different treatments to improve stability in various studies. At the end, ordinary Portland cement was approved as the most workable binder to improve the stability of sandy soil. Also, some other substitutes are lime, cement dust, and the cement lime mixture. But as we know, cement production and usage have a serious environmental impact (O'Lear et al., 2021). Therefore, there is room for using a better material. Soil stabilization can enhance the engineering properties of soil in biological, chemical, and mechanical means. But mostly, researchers are focused on mechanical stabilization and chemical stabilization (Phoon et al., 2016).

Rice husk is an agricultural waste. When rice husk is undergone through combustion, CO_2 is released. But as a remaining, silicon dioxide (SiO_2) is found (Raheem & Kareem, 2017). The reason behind this is that silicon dioxide is a non-combustible material. When rice husk is burned at 500-800^o C, silicon dioxide is converted into amorphous silica, which is more reactive and useful for construction work (Khana et al., 2014). Basically, when cement is mixed in the soil for soil stabilization, silica content is the main element that plays the major role in binding. Therefore, the presence of silica in RHA is an asset. To solve the settlement issue as well as environmental benefits, RHA is more suitable for mixing with sandy soil for stabilization (Basha et al., 2005; Roy, 2014).



(a) Untreated soil (b) RHA-treated soil (c) Rice husk ash

Figure 1: Impact of RHA in soil (Abdeliazim Mustafa Mohamed, 2021)

2. METHODOLOGY

2.1 Material Collection

In this study, local sand was collected from Betagi at Raozan. After surveying different sites, a few locations were examined, and the most suitable place was confirmed. Based on distance and accessibility, the site had been confirmed. A large quantity of sand was about to be carried to the Geotechnical Lab of CUET for the necessary tests. Rick Husk Ash is a suitable material to replace cement for soil stabilization. Amorphous silica in RHA can form a CSH gel (Abood Habeeb & Bin Mahmud, 2010). As RHA is porous and contains multiple layers with small voids within its structure, it has a high capability of water absorption and benefits from an improvement in some geotechnical properties. From Figure 2, it is seen that the material was kept closed, so water content may not change due to the surroundings. Cement is so far the best binder that is used for soil stabilization (Jan & Mir, 2018). By mixing OPC in sandy soil, it is possible to obtain better strength, compaction, and load-bearing capacity. By mixing OPC in soil, a reduction in permeability of soil, controlled swelling and shrinkage of expensive soil, and better drainage are obtained (James & Pandian, 2016). In this study, the rice husk ash and ordinary Portland cement were used as binders.

(a) Sand

(b) Rice Husk Ash

(c) Cement

Figure 2: Materials used

2.2 Material Properties

Sand used in this study had a D10 of 0.085 mm, D30 of 0.14 mm, D50 of 0.165 mm, and D60 of 0.192 mm, indicating a fine-to-medium grain size. The C_u (2.26) and C_c (1.23) values indicate that the sand is poorly graded. A fineness modulus (FM) of 0.97 and fine content of 4.4% suggest the sand contains mostly fine particles, suitable for geotechnical use. The grain size distribution of sand and rice husk ash is illustrated in Figure 3

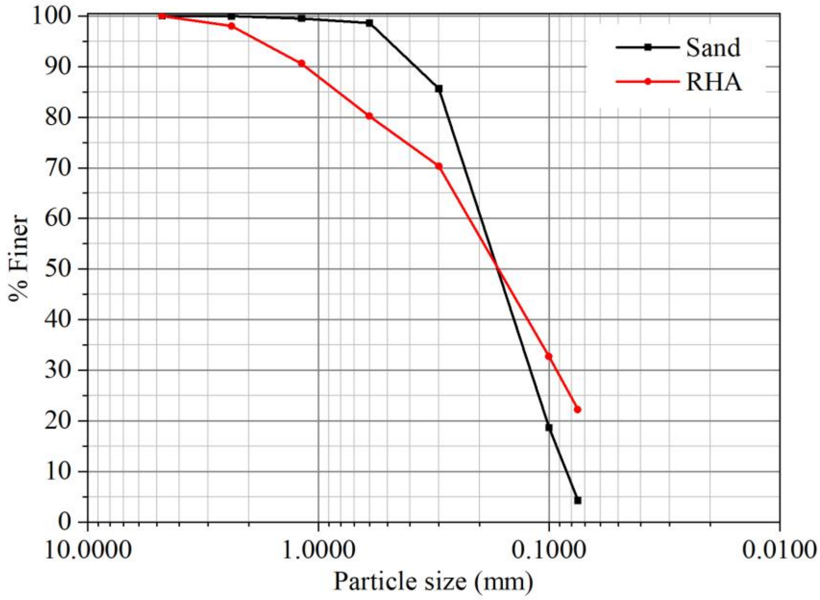


Figure 3: Grain size distribution curve of the used materials

For Rice Husk Ash (RHA), the D_{30}, D_{50}, and D_{60} values were 0.91 mm, 0.17 mm, and 0.23 mm, indicating a broader and coarser distribution than sand, making it potentially useful as a stabilizing agent. Compaction results showed an Optimum Moisture Content of 14.47% and a Maximum Dry Unit Weight of 18.225 kN/m³, essential for determining proper field compaction.

2.3 Mix Proportion of RHA

Sand was used as the base material, whereas OPC and RHA were mixed as stabilizing agents (Raman et al., 2024). Cement was added in different percentages (3%, 6%, 9%) by replacing the dry weight of sand. On the other hand, RHA was incorporated at four different levels, like 0%, 5%, 10%, and 15%. For each mix design, the remaining portion was filled with sand. In total, 12 unique mix combinations are formed by varying the OPC and RHA contents. For each of the combinations, the optimum moisture content was determined individually by conducting a standard proctor test. The test is necessary because the OMC value is used to calculate the exact amount of water required for sample preparation. All materials are initially mixed in a dry condition. Then necessary water is added as per OMC. Hand mixing was employed for mixing, and standard compaction moulds were used in the test. To ensure accuracy, three identical samples were prepared for each result. Also, samples were cured for 7, 14, and 28 days to observe strength development. This yielded a total of 108 samples. Figure 4 shows the workflow of the current study.

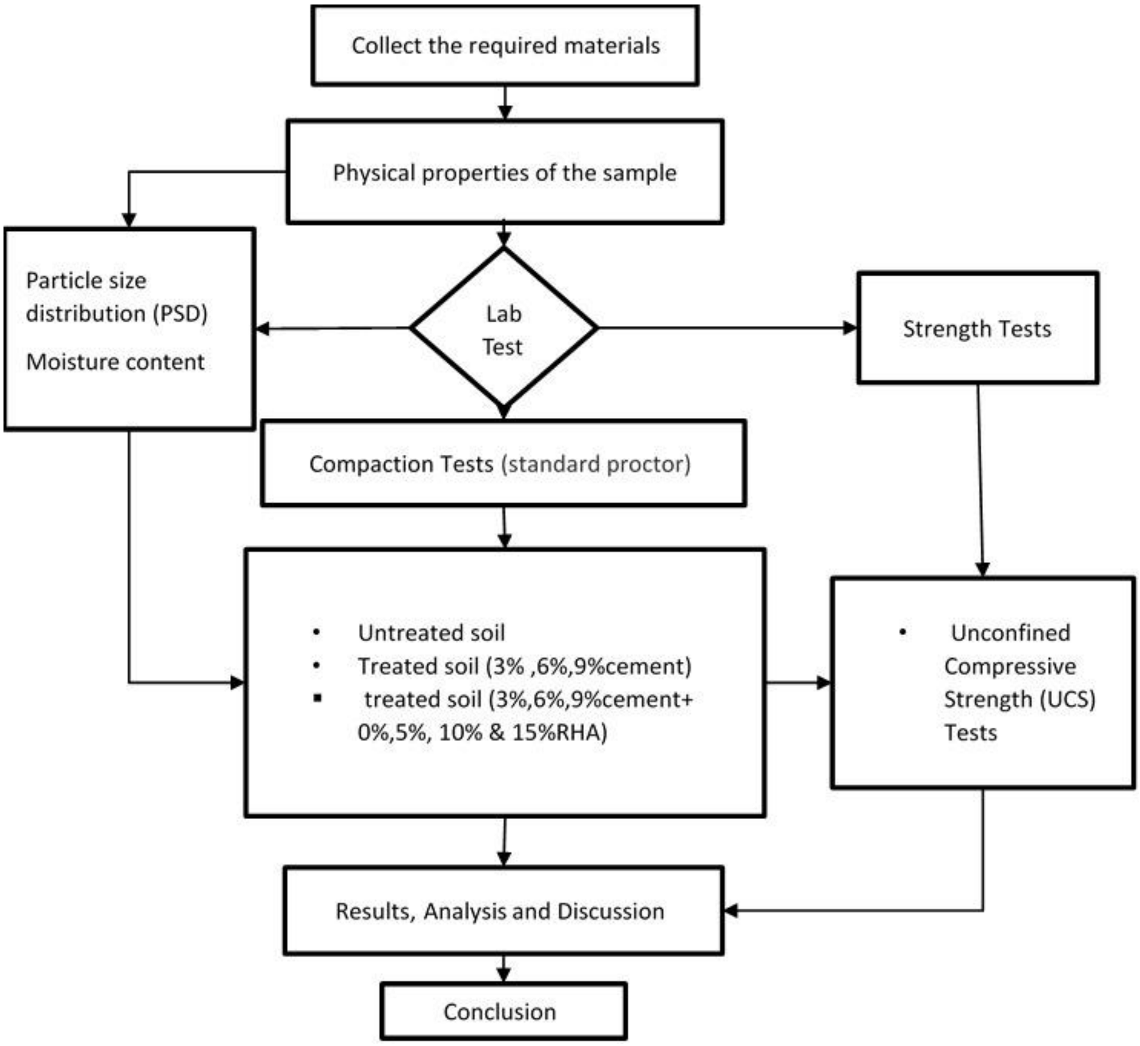


Figure 4: Workflow of the study

2.4 Experimental Methods

In this research, two tests are found most convenient for analysing the stability. Standard proctor test and unconfined compressive strength test offer an understanding of the required compaction and strength characteristics. Figure 4 illustrates the various experimental programs.

2.4.1 Standard Proctor Test

The proctor test was conducted using a 4-inch-diameter, 6-inch height cylindrical mold in accordance with standard specifications. Twelve mix combinations were tested with cement at 3%, 6%, and 9%, and rice husk ash at 0%, 5%, 10%, and 15%; the remaining was sand. Each mix was compacted in three layers with 25 blows per layer using a Proctor hammer, as specified in ASTM D698 (Perez N et al., n.d.). After compaction, the samples were weighed, and their moisture content and maximum dry unit weight were determined for each mix and used in preparing strength test specimens.

2.4.2 Unconfined Compressive Strength

The unconfined compressive strength test was conducted to find out the strength development of soil samples stabilized with cement and rice husk ash. For each mix and curing period, which was 7 days, 14 days, and 28 days, three UCS specimens were prepared and tested, and stress-strain curves were plotted to study the load-deformation behavior. Initially, larger molds were used, but unfortunately, they caused difficulty in demolding. To overcome this, smaller molds with a 2.8-inch diameter and 5.4-inch height were adopted, providing better compaction and easier sample removal. Each specimen was compacted in three layers, applying 15 blows per layer with a standard compaction hammer having a 5.5lb weight and a 12-inch dropping height, achieving an equivalent compaction energy as per ASTM D 698.

(a) (b) (c)

Figure 5: Illustration of various experimental setup

3. RESULT AND DISCUSSION

3.1 Effect of RHA on Compaction Characteristics

After conducting the tests, the comparison of the Optimum Moisture Content (OMC) and the Maximum Dry Unit Weight of parent soil and treated soil is made. For 3% cement, the Optimum moisture content increases with increasing RHA content in the mix. For 3% cement, OMC increased by approximately 3% when RHA was increased from 0% to 5%, 1.4% from 5% to 10%, and a significant 17% from 10% to 15%. In the case of 6% cement, the OMC increased by around 2.7% from 0% to 5%, followed by a 1% increase from 5% to 10%, and a more noticeable 16% rise from 10% to 15%. Similarly, for 9% cement, the OMC rose by about 3.5 percent from 0% to 5%, 2.8 percent from 5% to 10%, and further 14.7 percent from 10% to 15%. RHA is a highly porous element with a broad surface area (Venkatanarayanan & Rangaraju, 2013). When the porosity is high, the water absorption capacity also increases (Roy, 2014). Therefore, more water is required to achieve optimal compaction. From Figure 6, it is clear that the OMC increases with increasing RHA content. However, a 10%-15% increase in RHA content accounts for the majority of the increase in OMC. Also, at higher cement percentages, there is a minor increase in OMC. Cement particles require water for the chemical process of hydration (Ludwig & Zhang, 2015).

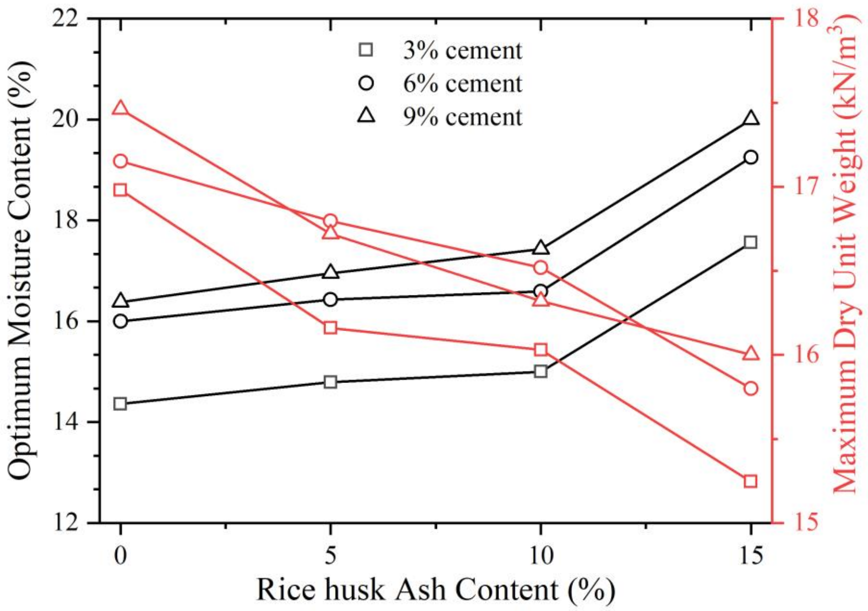


Figure 6: Variation of Optimum Moisture Content and Maximum Dry Unit Weight with RHA content

On the other hand, the Maximum Dry Unit Weight showed a decreasing trend. For the 3% cement mix, the unit weight decreased by approximately 4.83% when RHA increased from 0% to 5%, followed by a further 0.81% decrease from 5% to 10%, and an additional 4.9% reduction from 10% to 15%, leading to a total decrease of around 10.2%. In the 6% cement mix, the Maximum Dry Unit Weight declined by approximately 2.08% from 0% to 5%, 1.63% from 5% to 10%, and a more substantial 4.33% from 10% to 15%, for a total reduction of approximately 7.88%. For the 9% cement mixture, the Maximum Dry Unit Weight decreased by roughly 4.26% from 0% to 5%, 2.39% from 5% to 10%, and 1.96% from 10% to 15%, for an overall decrease of 8.61%. This reduction in the Maximum Dry Unit Weight also occurred due to the physical properties of RHA, which is a low-density, porous, and highly absorptive material (Fernandes et al., 2016).

When RHA content increases, the soil's density decreases because lighter ash particles replace heavier soil particles, and the ash's high absorption and porous nature prevent tight packing. As a result, higher RHA levels reduce density, creating a trade-off between strength improvement and compacted density (Roy, 2014).

3.2 Effect of RHA on Strength Characteristics

In this study, UCS test specimens containing 3%, 6%, and 9% cement were prepared with varying proportions of Rice Husk Ash (0%, 5%, 10%, and 15%), and their compressive strengths were measured at curing ages of 7, 14, and 28 days. Across all cement contents, the highest strength gains were observed when 5% RHA was used. Figure 7-9 illustrates the variation of UCS with RHA content at different curing ages.

In the 3% cement mix, a significant improvement in strength was observed when 5% RHA was added. The UCS increased from 17 kPa (with 0% RHA) to 33 kPa at 7 days (an increase of approximately 94%) and from 50 kPa to 91 kPa at 28 days (an increase of approximately 82%). In the 6% cement mix, a more notable improvement in strength was recorded. With 5% RHA, a UCS value of 201 kPa was achieved at 28 days (a 136% increase from the control value of 85 kPa), while 10% RHA resulted in the highest strength of 241 kPa (an increase of 183%).

In the 9% cement mix, the highest overall strength was obtained with 10% RHA, reaching 306 kPa at 28 days, a 53% increase over the control (200 kPa). Overall, the reduction was caused as there was a lacking calcium hydroxide due to a low cement mix. But on the other side, the RHA content was left untreated. That's why there is a rise in strength with increased cement content. Also, here, cement is the only C-S-H gel producer. Therefore, the binding becomes more stable with the higher cement content.

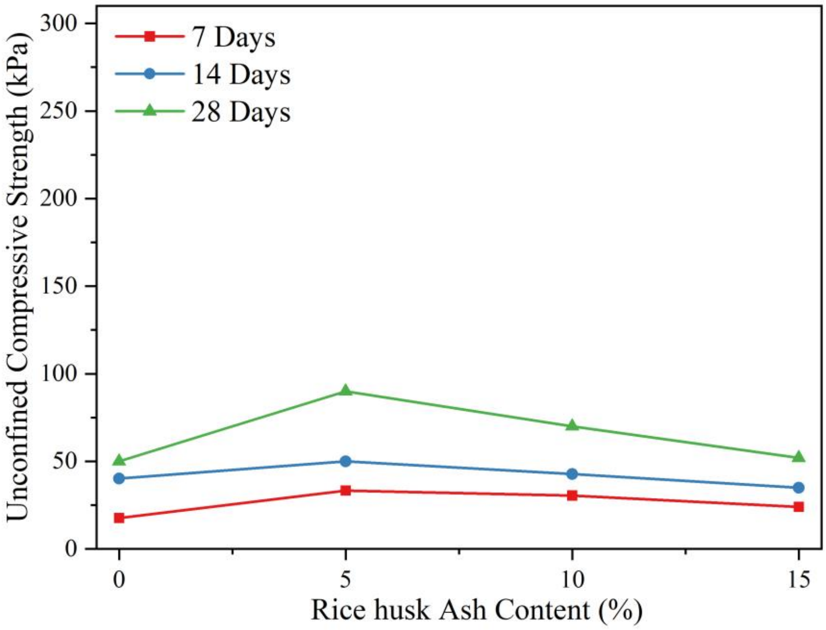


Figure 7: Comparison of UCS with RHA for 3% cement

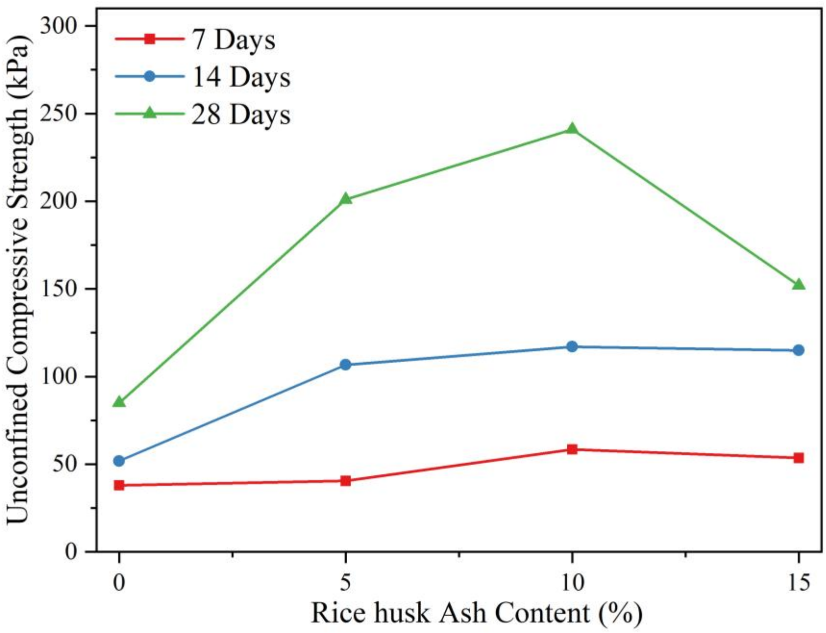


Figure 8: Comparison of UCS with RHA for 6% cement

To highlight the effect of RHA content only, further analysis was conducted using the 28-day UCS data. For each cement–RHA mix group, the UCS value at 28 days for the 0% RHA content was taken as the reference strength, and the percentage improvement was calculated accordingly. The results indicate that 5% RHA performed best with 3% cement, whereas 10% RHA was most effective in mixes containing 6% and 9% cement. Beyond these levels, strength decreased due to insufficient cement content to sustain complete pozzolanic reactions. The highest 28-day compressive strength (306 kPa) was achieved with 9% cement and 10% RHA, indicating optimal pozzolanic activity. Strength declined at 15% RHA due to dilution effects and the presence of unreacted ash.

In addition to the Optimum Moisture Content (OMC), the water–cement (w/c) ratio plays a critical role in controlling cement hydration and strength development in cement–RHA–sand mixtures. In this study, specimens were compacted at their respective OMC values, and the corresponding w/c ratios were calculated based on the actual water content determined from OMC and the cement content of each mix. The results show that the w/c ratio decreased consistently with increasing RHA content for all cement percentages.

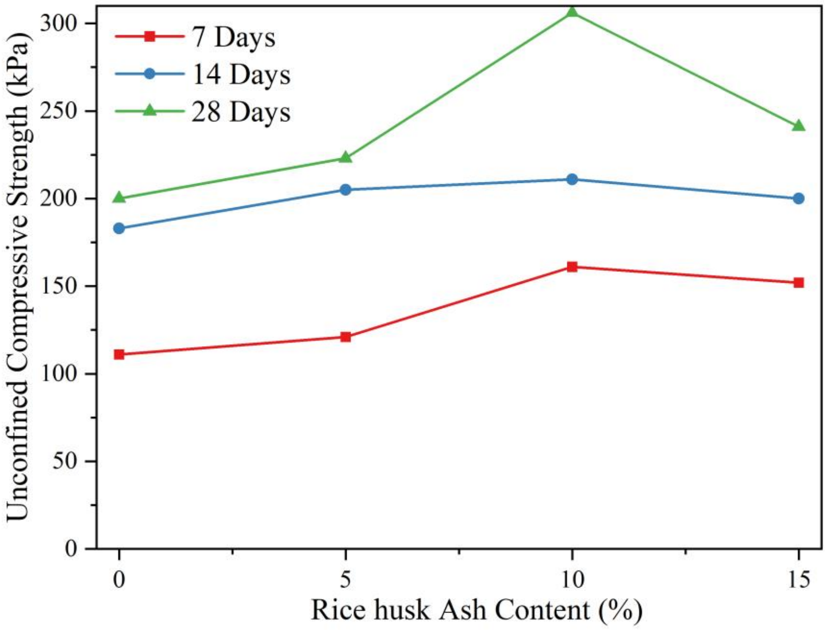


Figure 9: Comparison of UCS with RHA for 9% cement

For example, at 3% cement content, the w/c ratio reduced from 0.21 at 0% RHA to 0.17 at 15% RHA, while for 9% cement it decreased from 0.55 to 0.45 over the same RHA range. This reduction occurs because RHA increases OMC due to its high specific surface area and porous structure, while the cement content remains constant. Consequently, a larger portion of the added water is absorbed by RHA particles and soil pores rather than remaining available for cement hydration.

At low RHA contents (5–10%), the moderately reduced w/c ratio appears to be beneficial. The available water is sufficient to ensure effective cement hydration, while RHA contributes to improved particle packing and secondary pozzolanic reactions, leading to a denser microstructure and higher UCS values. This explains the observed strength enhancement at 5% RHA for 3% cement and at 10% RHA for 6% and 9% cement mixes.

However, at higher RHA content (15%), the effective w/c ratio becomes comparatively low, limiting the availability of free water required for complete hydration of cement. In addition, the calcium hydroxide generated from relatively low cement content becomes insufficient to sustain effective pozzolanic reactions with excess RHA. As a result, a portion of the RHA remains unreacted, leading to reduced cementitious bonding and lower UCS values despite the higher OMC. This effect is more pronounced in mixes with lower cement content, where cement is the primary source of C–S–H gel formation. Therefore, the strength behavior observed in this study is governed by the combined effects of OMC and w/c ratio. An optimal balance between water demand and cement hydration was achieved at moderate RHA levels (5–10%), beyond which reduced effective w/c ratio and dilution effects dominated, resulting in strength reduction. Future studies may separately control OMC and w/c ratio to isolate their individual contributions to strength development.

3.3 Failure Pattern

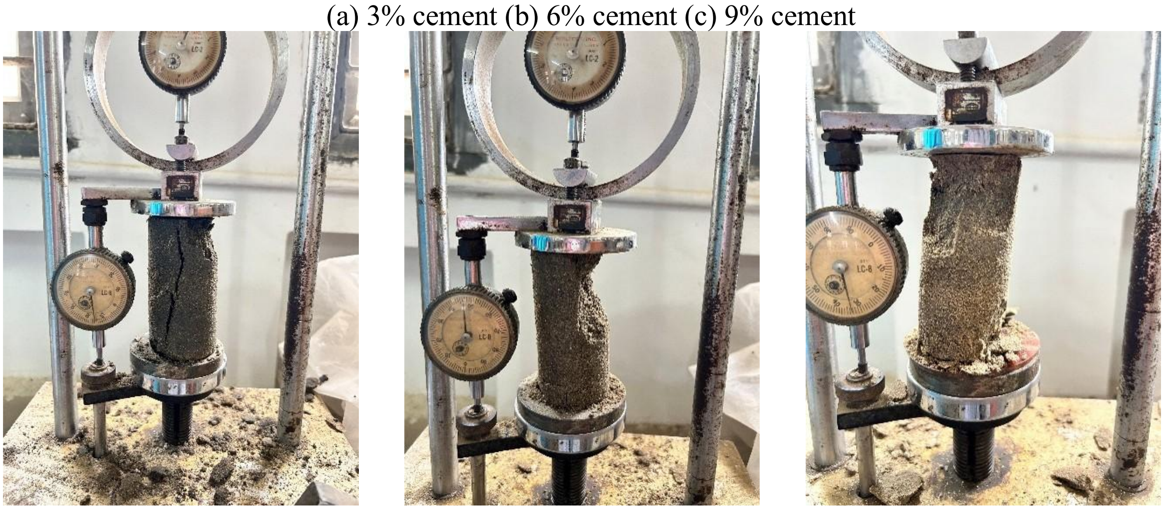
During the UCS tests, moulded soil specimens showed distinct failure patterns influenced by cement and RHA content and curing period. Common modes included shear failure and vertical cracking. Higher RHA content or shorter curing often caused bulging and irregular cracking. Cement-stabilized samples exhibited more brittle, defined shear failure, while RHA addition produced slightly more ductile behaviour (Jan & Mir, 2018). These patterns reflect the composite response of the soil, cement, and RHA matrix under axial loading.

Photographs (Figure 10-11) from the UCS tests showed clear differences in failure patterns between untreated samples(sand-cement) and treated samples(sand-cement-RHA). Sand-cement specimens showed clean vertical or diagonal cracks, indicating brittle failure due to the rigid cement matrix (Basha et al., 2005). In contrast, sand-cement-RHA samples showed more irregular, distributed cracking with swelling, reflecting a more ductile response. The fibrous nature of RHA likely enhanced strain capacity, demonstrating that RHA alters both the strength and failure behaviour of the composite material (Muntohar, 2009).

(a) (b) (c)

Figure 10: Failure pattern for soil and cement mixture samples

(a) 3% cement (b) 6% cement (c) 9% cement



(a) (b) (c)

Figure 11: Failure pattern for 5% RHA-treated soil sample
(a) 3% cement (b) 6% cement (c) 9% cement

4. CONCLUSIONS

The effects of varying percentages of Rice Husk Ash (RHA) on the strength behaviour of sand have been investigated. The study focused on changes in compaction characteristics, including Optimum Moisture Content and Maximum Dry Unit Weight. Unconfined compressive strength (UCS) was also evaluated to assess the development of strength over time. The influence of RHA content on the overall improvement of sand's engineering properties was systematically studied. The key findings of this study were summarized below:

1) OMC increased by approximately 5-22% with rising RHA content from 0% to 15% across all cement percentages. Maximum OMC increase of about 20-22% was observed at 15% RHA.
2) Maximum Dry Unit Weight decreased consistently by around 5-15% when RHA content increased from 0% to 15%. The largest decline in Maximum Dry Unit Weight, approximately 12-15%, was seen at 15% RHA content. Excessive RHA (>10%) may negatively affect compaction due to lower density and increased porosity.
3) UCS improved significantly, with increases ranging from 40% to 183%, for RHA content between 5% and 10% at different cement contents. At 15% RHA, strength decreased by approximately 10-20%, likely due to dilution of cement and increased voids. Optimal strength enhancement occurs around 5-10% RHA, while higher amounts show reduced effectiveness. The maximum improvement was observed for (9% Cement + 10% RHA) at 28 days curing, with a value of 306kPa.
4) The water–cement ratio decreased with increasing RHA content due to higher OMC demand of RHA. Moderate reduction in w/c ratio (at 5–10% RHA) enhanced hydration efficiency and strength, whereas excessive reduction at 15% RHA limited cement hydration and reduced UCS.

DECLARATION

The authors declare that artificial intelligence (AI) tools were used only for writing assistance, including language editing, grammar correction, and improvement of clarity and academic expression during the preparation of this manuscript. AI tools were not used in the research design, experimental methodology, data analysis, interpretation of results, or generation of figures and tables. All scientific content and conclusions are the responsibility of the authors.

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