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Research Article

# Effect of Rice Husk Ash on Soil Stabilization at Dinajpur City

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**Keywords**

*Rice husk ash,*
*Cement,*
*Soil stabilization,*
*Unconfined compressive strength,*
*Dry density.*

**Abstract**

Understanding local conditions is crucial for applying soil stabilization principles from other regions to a specific country for effective and sustainable stabilization methods. This investigative study delves into the suitability of locally available Rice Husk Ash (RHA) for incorporation into local building construction practices at Dinajpur, Bangladesh, aiming to minimize the volume of waste disposed of in the environment, thereby mitigating environmental pollution. Conventional soil stabilization techniques are becoming increasingly expensive due to the rising costs of stabilizing agents such as cement. Replacing a portion of the stabilizing agent with RHA could potentially reduce the cost of stabilization while also minimizing environmental harm. RHA comprises 85-90% silica, making it an excellent substitute for silica in soil stabilization. Silica is recognized as an effective binding agent alongside cement. The soil sample selected for this research is a highly plastic clay (CH), which necessitates significant strength enhancement. Three soil samples were stabilized with varying percentages of RHA and a minimal amount of cement. Observations were made to assess the changes in soil properties, including Maximum Dry Density (MDD), Optimum Moisture Content (OMC), and Unconfined Compressive Strength (UCS). The results obtained indicate that increasing RHA content leads to an increase in MDD but a decrease in OMC. Additionally, the UCS of the soil exhibits substantial improvement to up to 88% with increasing RHA content up to 10%. Based on the observed maximum strength enhancement, a 10% RHA content combined with 6% cement is recommended as the optimal combination for practical applications.

## 1. Introduction

Civil engineering projects often encounter soft or weak soils, necessitating the improvement of soil properties through various stabilization techniques. Soil stabilization has become an integral part of diverse engineering projects, with its most common application being in building foundation construction. The primary goals of soil stabilization include enhancing soil strength and stability while minimizing construction costs by utilizing locally available materials effectively. In this context, the use of agricultural waste, such as rice husk ash (RHA), offers a promising solution. RHA's incorporation into soil stabilization significantly reduces construction costs while mitigating the environmental hazards associated with its disposal. Therefore, the utilization of RHA for soil improvement should be actively encouraged.

RHA has been effectively employed to enhance soil properties, either when used independently or in conjunction with hydraulic activators like cement or lime [[1]–[3]]. Use of other wastes like, fly ash, Sewage Sludge Ash, waste marble powder have also be explored by researchers [[4]–[6]]. Alhassan attributes the observed decrease in Unconfined Compressive Strength (UCS) beyond a certain RHA content to the excess RHA that remains unreactive due to the saturation of alkaline reactions [7]. Alhasan also noted an increase in CBR values upon stabilizing a clayey soil with RHA up to 6% and 12% for 6-day, 1-day soaking, and unsoaked conditions, respectively [8]. The combination of RHA and lime in soil stabilization is particularly advantageous for road pavements, offering cost-effective construction, reduced disposal costs, minimized environmental impact, and resource conservation by preserving higher-grade materials for more critical applications [9]. Generally, RHA cannot be used solely for soil stabilization due to its lack of inherent cementitious properties [10].

Several studies investigated the impact of incorporating RHA alone on plasticity, unconfined compressive strength (UCS), and California Bearing Ratio (CBR) of a lateritic soil with 45% passing the #200 sieve (75 µm). Results indicated that UCS and CBR increased by 20% and 18%, respectively, within the first day of RHA addition, before gradually declining [11]. RHA's potential as an extender for imported Portland cement was also explored [12]. The RHA contains around 90% of silica which makes it an ideal soil stabilizer [13], [14]. The addition of Rice Husk Ash (RHA) and lime or cement to clayey, clayey sandy, silty clayey, and silty sandy soils has been shown to enhance Unconfined Compressive Strength (UCS) [15], [16]. For a given lime or cement content there is an optimum value of RHA content which corresponds to the maximum UCS, which varies depending on the type of soil, ash characteristics, hydraulic activator and curing time [1], [17]. Furthermore, the incorporation of RHA into clayey soil-lime specimens further enhanced UCS at a defined lime content. This increase was rapid between 0 and 4% RHA content but exhibited a diminishing rate from 6 to 8% RHA content at a specified curing period. Finding a cost-effective solution for soil stabilization in developed countries like Bangladesh is particularly needed where traditional way of soil compaction is still followed for building structures [18]. Moreover, sound foundation health is a prime need for structural safety in Bangladesh for being situated near active seismic faults [19]–[21].

The paper explores three key objectives: firstly, enhancing the soil's properties at the construction site to prevent it from yielding under the weight of the building structure. Secondly, minimizing the excessive use of cement for this purpose by employing supplementary materials that can effectively serve the same function. These alternative materials are often recycled, which is crucial as their presence in the environment can pose significant harm due to the large volume of space they occupy in landfills. One such material, as mentioned earlier, is rice husk ash. Its production is

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steadily increasing, generating a substantial quantity. Rice husk ash comprises 85-90% silica, making it an excellent substitute for silica in soil stabilization. Silica is recognized as a powerful binding agent alongside cement. However, cement prices are on the rise, necessitating the adoption of new materials for geotechnical applications.

## 2. Methodology

The experimental methodology involved collecting disturbed soil and transporting it to the laboratory for physical properties analysis. The soil samples were collected from three different places of Dinajpur city, Bangladesh, and named as sample 1, sample 2 and sample 3, respectively. As construction was ongoing in those places, the collection area is kept confidential. Grain size analysis and Atterberg limits analysis were employed to characterize the soil's physical properties. Subsequently, the soil sample was compacted into three layers using the compaction test. After extraction from the mold, three identical soil layers were obtained. This procedure was repeated for samples containing varying amounts of additives: 5%, 10%, and 15% rice husk ash, each combined with 6% cement. The RHA was collected from the local rice husking mill. Upon completion of the compaction test, all the prepared soil samples were subjected to the UCS test to determine their unconfined compressive strength.

### 2.1. Water content test

The moisture content of the soil was determined from the ratio between moisture mass in soil to the oven dried mass of soil.

### 2.2. Determination of specific gravity

Specific gravity is a dimensionless quantity that represents the relative density of a substance compared to a reference substance. It is calculated as the ratio of the density of the substance of interest to the density of the reference substance. Alternatively, it can be expressed as the ratio of the mass of the substance to the mass of the reference substance for the same given volume. The specific gravity was determined as per ASTM D 854-00.

### 2.3. Atterberg limits

In 1911, Swedish agricultural scientist Albert Atterberg devised a method to characterize the consistency of fine-grained soils across varying moisture levels. He proposed five distinct "limits" that define the transitions between different soil states. These critical water contents, known as consistency limits or Atterberg limits, provide valuable insights into the behavior of fine-grained soils under different moisture conditions. ASTM D 4318 - Standard was adopted for determining Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

### 2.4. Grain size analysis

Grain size analysis involves two primary methods: the hydrometer test and the sieve analysis test. The hydrometer test is typically conducted first, following its established procedure. Once the soil sample is placed in the cylinder and the hydrometer gauge readings begin, an observation is made to check if any solid soil particles have floated to the surface. These floating solids are then collected and subjected to the sieve analysis test.

After conducting the hydrometer test, it was observed that no soil particles floated to the surface. This indicates that the soil is of fine-grained nature, and further sieve analysis is not required. This study employed the ASTM D 422 method for grain size analysis.

### 2.5. Proctor compaction test

The Proctor compaction test, a cornerstone of geotechnical engineering, establishes the relationship between moisture content and dry density for a given compactive effort. Compactive effort refers to the amount of mechanical energy imparted to the soil mass during compaction. ASTM D 698 and ASTM D 1557 methods were followed for compaction test.

### 2.6. Unconfined Compression Strength Test

The unconfined compression test (UCS) is a widely used laboratory procedure to determine the unconfined compressive strength of clay soils, a crucial parameter for assessing their stability and behavior under unconfined conditions. The value is defined, according to the ASTM standard, as the compressive stress at which an unconfined cylindrical specimen of clay fails under axial loading. It was measured by ASTM D 2166 standard.

## 3. Result and discussion

### 3.1. Moisture content and specific gravity

Figure 1 shows the moisture level and specific gravity of three soil samples. As it can be seen from Fig. 1 that depending on sample location the natural moisture content of the soils is different. The moisture levels of the three samples are 15.2, 17.3, and 20.4% respectively. While the specific gravity was determined as 2.66, 2.65 and 2.65 respectively.

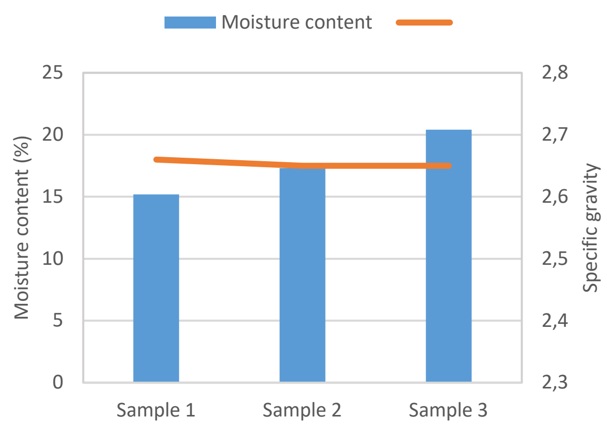


Figure 1. Moisture content and specific gravity of test soil samples

### 3.2. Atterberg limit

Figure 2 displays the Atterberg limit of the tested samples. The soil class is determined by the liquid limit and plastic limit results. We observed that the plasticity index of sample 1 was 24.12%, with a liquid limit of 50.82%. Sample 2 exhibited a plasticity index of 24.49% and a liquid limit of 50.12, while sample 3 had a plasticity index of 24.42 and a liquid limit of 49.8%. According to the Plasticity chart in the British system (BS 1377-2: 1990), all three soil samples were classified as CH (Clayey soil with high plasticity).

Following the grain size analysis and the hydrometer test, no coarse soil was observed to rise to the top of the mixture. Therefore, a sieve analysis was unnecessary, confirming that the soil is fine. The moisture content obtained from the moisture content test was 15.2% for sample 1, 17.28% for sample 2, and 20.37 for sample 3.

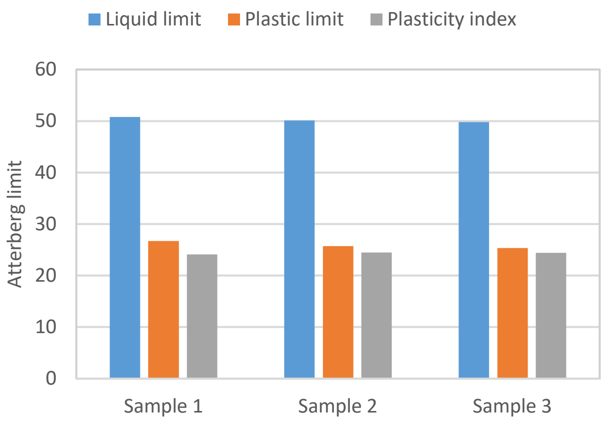


Figure 2. Atterberg limit of soils.

### 3.3. Proctor compaction test

Figure 3 displays the water content vs dry density at different mix proportions of RHA at 6% constant cement content.

The compaction curve in Figure 3 for the control mix of sample 1 reveals the relationship between water content and dry density. As the water content increases from 8% to 16%, the dry density also increases, indicating an improvement in the cohesiveness of the soil particles. This suggests that the addition of water facilitates the rearrangement and packing of soil particles, leading to a denser and more stable soil structure. However, further increasing the water content to 18% results in a decrease in dry density, indicating a decline in cohesiveness. This can be attributed to the presence of excessive water, which disrupts the interparticle bonds and weakens the soil structure. The water molecules start to occupy the voids between soil particles, preventing them from forming strong intermolecular forces and reducing the overall cohesiveness of the soil. The optimal moisture content for this soil sample is determined to be 18.5%, corresponding to the peak dry density of 1.52 g/cm³. This point on the compaction curve represents the balance between water content and soil particle arrangement, where the cohesiveness between the particles is at its maximum. At this moisture level, the soil has sufficient water to facilitate particle rearrangement without compromising the interparticle bonds, resulting in the highest achievable dry density.

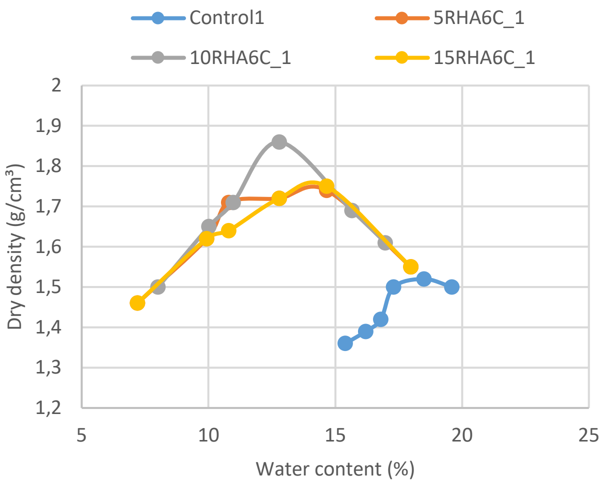


Figure 3. Dry density vs water content for sample 1

Addition of RHA significantly increased the dry density of sample 1. The optimal moisture content is determined by locating the peak of the compaction curve. For instance, sample 10RHA6C_1, as the water content is increased from 8% to 12%, the cohesiveness is increased. Beyond this moisture level, the dry density decreased. The maximum dry density of 1.87 g/cm³ is achieved at an optimal moisture content of 12.8%, indicating that the soil particles are most cohesive at this moisture level. The optimum moisture content for maximum dry density of sample 1 at different additive level is tabulated in Table 1 (adopted from fig. 3).

Interestingly, our observation of increasing dry density and decreasing moisture content with increasing RHA contrasts with some prior studies [22]. This potential discrepancy could be attributed to the presence of cement in our mix. The use of cement or lime in soil stabilization is known to cause an increase in dry density and a decrease in moisture content as their proportions rise [23]. This suggests that the interaction between RHA and cement in our study influenced the overall moisture-density behavior in a distinct way.

Table 1. Optimum conditions for Sample 1.

| Additives | Optimum moisture content % | Maximum dry density g/cm³ |
|---|---|---|
| Control mix_1 | 18.5 | 1.52 |
| 5% RHA and 6% Cement (5RHA6C_1) | 14.2 | 1.75 |
| 10% RHA and 6% Cement (10RHA6C_1) | 12.8 | 1.87 |
| 15% RHA and 6% Cement (15RHA6C_1) | 14.3 | 1.76 |

Table 2 summarizes the changes in optimum moisture content and maximum dry density for different RHA percentages in samples 2 and 3. Sample 3 exhibited a similar behavior to samples 1 and 2 (Tables 1and 2). The highest moisture content was observed for the control mix sample. However, it tended to decrease with increasing RHA content due to the lightweight nature of RHA, which allowed it to fill voids in the sample and hinder moisture absorption, resulting in lower moisture content.

Interestingly, the moisture content increased when 15% RHA was used. This is attributed to the excessive weight of RHA, which prevented it from interacting with the soil sample and remained unbound. As a result, these unbound RHA particles absorbed and retained water within their structure.

The increase in dry density for 5% and 10% RHA additions can be explained by the effective interaction between RHA and soil particles. RHA particles effectively filled voids in the soil, preventing water from entering the soil specimen and forming crystalline structures. However, the subsequent decrease in dry density observed for 15% RHA addition is attributed to the excess free RHA particles that did not interact with the soil particles. These extra particles absorbed more water, leading to an increase in moisture content and a decrease in dry density.

Table 2. Optimum conditions for Sample 2 and 3.

| Additives | Optimum moisture content % | Maximum dry density g/cm³ |
|---|---|---|
| Control mix_2 | 19.5 | 1.48 |
| 5% RHA and 6% Cement (5RHA6C_2) | 14.8 | 1.57 |
| 10% RHA and 6% Cement (10RHA6C_2) | 11.2 | 1.79 |
| 15% RHA and 6% Cement (15RHA6C_2) | 13.9 | 1.65 |
| Control mix_3 | 20.9 | 1.32 |
| 5% RHA and 6% Cement (5RHA6C_3) | 14.7 | 1.57 |
| 10% RHA and 6% Cement (10RHA6C_3) | 12.3 | 1.81 |
| 15% RHA and 6% Cement (15RHA6C_3) | 15.9 | 1.65 |

### 3.4. Unconfined compressive strength (UCS)

Figure 4 illustrates the positive influence of RHA on the UCS of soil. The UCS of sample 1 is found to be 69, 98, 125, and 109 Kpa, respectively for 0%, 5%, 10%, and 15% RHA replacement. For the control sample (0% RHA), the UCS increased by approximately 80% with RHA additions up to 10%. However, further RHA additions (15%) resulted in a slight decrease in UCS. This initial increase in UCS is attributed to the formation of cementitious compounds between cement and pozzolans present in RHA, enhancing soil strength. The subsequent decrease in UCS after 10% RHA addition is likely due to the excess RHA weakening the bonds between soil and the cementitious compounds.

The impact of varying RHA percentages on samples 2 and 3 is evident in Figures 5 and 6, respectively. Similar to sample 1, both samples 2 and 3 exhibited a notable increase in UCS upon RHA replacement up to 10%. This observation underscores the significant role of RHA in enhancing soil strength. Consistently, the control mix in all three samples demonstrated the lowest UCS values, highlighting the positive influence of RHA on soil structure and cohesion. For sample 2 (Figure 5), the UCS values were 70, 98, 124, and 112 kPa for 0%, 5%, 10%, and 15% RHA replacement, respectively. The initial increase in UCS, particularly at 5% and 10% RHA, can be attributed to the formation of cementitious compounds between the cement and the pozzolans present in RHA. These compounds enhance the cohesion between soil particles, leading to improved strength characteristics. However, the slight decrease in UCS observed with 15% RHA suggests that excessive RHA may hinder the effectiveness of the pozzolanic reaction, potentially weakening the soil structure.

Similarly, sample 3 (Figure 6) exhibited a similar trend, with UCS values of 68.5, 101, 130, and 106 kPa for 0%, 5%, 10%, and 15% RHA replacement, respectively. The optimal UCS value was achieved at 10% RHA, indicating that this proportion of RHA effectively enhanced soil strength without compromising the pozzolanic reaction. The subsequent decrease in UCS with 15% RHA further reinforces the notion that excessive RHA can negatively impact soil structure and cohesion.

In all cases, the addition of up to 10% RHA resulted in increased strength of soil. These findings are supported by Okafor et al [24], who showed RHA's beneficial utilization of sub-grade soil.

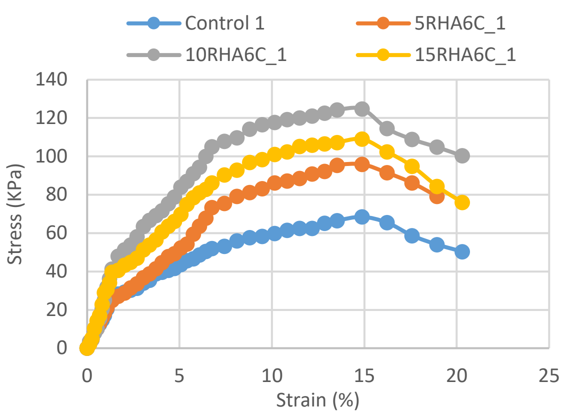


Figure 4. UCS of soil sample 1

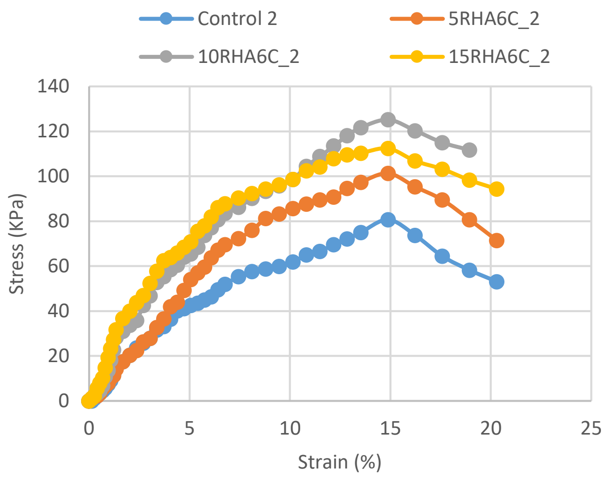


Figure 5. UCS of soil sample 2

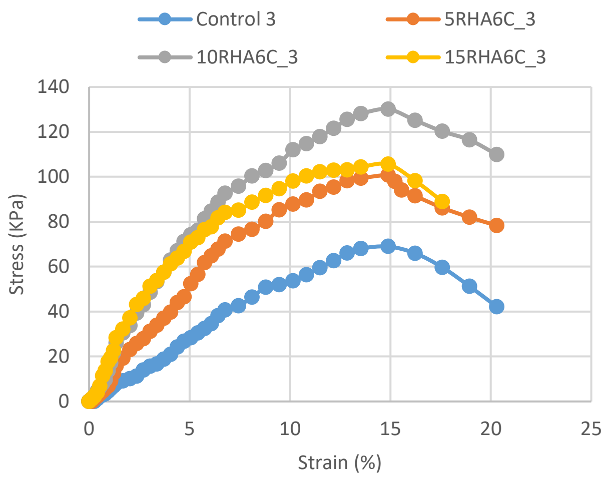


Figure 6. UCS of soil sample 3

These findings demonstrate the potential of RHA as a valuable soil stabilizer, particularly when used at optimal concentrations. However, careful consideration of RHA proportions is crucial to ensure effective soil strengthening without compromising soil structure and cohesion.

## 4. Conclusion

This study delved into the potential of RHA as an effective soil stabilizer for applications in Dinajpur city, Bangladesh. Through a series of experiments, the study evaluated the influence of RHA on the unconfined compressive strength (UCS), moisture content, and dry density of stabilized soils. The findings of this study reveal several key conclusions regarding the effectiveness of RHA in soil stabilization:

- The soil samples studied here are all classified as clayey soil with high plasticity (CH). Proctor test results showed that all three samples obtained maximum dry density at 10% RHA replacement.
- From UCS test, up to 10% replacement of RHA showed increased strength to up to 88%.
- The study recommends using 10% RHA and 6% cement as the optimal combination for soil stabilization to achieve maximum strength improvement in practical applications.

## Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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