

Effect Of Rice Husk Ash On Unconfined Compressive Strength Of Jamshoro Shale

Suhail Zaffar

Council for Works and Housing Research, Ministry of Science and Technology, Government of Pakistan, Karachi 75730, Sindh, Pakistan

Aneel Kumar

Department of Civil Engineering, Mehran University of Engineering and Technology, Jamshoro 76062, Sindh, Pakistan

Abdullah Saand

Department of Civil Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah 67480, Sindh, Pakistan

Naeem Aziz

Department of Civil Engineering, Mehran University of Engineering and Technology, Jamshoro 76062, Sindh, Pakistan

Amjadullah Panhwar

Agriculture, Supply, and Prices Department, Government of Sindh

ABSTRACT

This study investigates the effect of rice husk ash (RHA) on the unconfined compressive strength (UCS) of Jamshoro shale in a compacted state. Shale samples were blended with RHA at 0%, 2%, 4%, 6%, 8%, 10%, and 12% by weight, compacted at optimum moisture content, and tested for unconfined compressive strength, undrained shear strength, and stress-strain modulus. Results showed that the unconfined compressive strength (q_u) increased progressively from 6.93 kg/cm² at 0% RHA to 11.83 kg/cm² at 12% RHA, representing an increase of approximately 70.7%. Undrained shear strength (S_u) followed the same trend, rising from 3.465 kg/cm² to 5.915 kg/cm², while the stress-strain modulus (E_s) increased from 1.50 kg/cm² to 2.20 kg/cm², an increase of approximately 46.7%. These findings indicate that RHA is an effective additive for enhancing the strength characteristics of Jamshoro shale, likely due to pozzolanic reactions between the RHA and the clay fraction of the soil, improving its suitability for use as a subgrade or embankment material in highway construction.

Keywords: Rice Husk Ash, Jamshoro Shale, Unconfined Compressive Strength, Undrained Shear Strength, Stress-Strain Modulus

INTRODUCTION

Shale is a fine-grained sedimentary rock composed predominantly of clay minerals, and is frequently encountered in geotechnical engineering practice across Sindh, including in the vicinity of Jamshoro. As an expansive soil, shale presents one of the most challenging ground conditions for geotechnical engineers: with variation in moisture content, it exhibits variable strength, compressibility, and swelling behavior, resulting in reduced bearing capacity and differential settlement of structures built upon it. These characteristics make shale a problematic subgrade material, often requiring stabilization to achieve adequate strength and stability before use in embankments, subgrades, or foundation applications.

Unconfined compressive strength (UCS) is a key geotechnical parameter used to evaluate the load-bearing capacity and stability of cohesive soils, and is directly linked to related parameters such as undrained shear strength and stress-strain modulus, which together characterize the strength and deformation behavior of the soil under load. Improving the UCS of problematic soils such as shale is therefore essential for their safe and economical use in construction, particularly for subgrade and embankment applications in highway engineering.

Traditional stabilizers such as lime and ordinary Portland cement (OPC) have long been employed to enhance the strength of weak soils, typically through pozzolanic reactions that bind soil particles into a stronger, more cohesive matrix. However, the production of lime and cement is energy-intensive and associated with substantial carbon dioxide emissions, prompting growing interest in sustainable, low-cost alternatives derived from agricultural waste streams. Rice husk ash (RHA), obtained through the controlled combustion of rice husk, a major agricultural by-product in rice-producing regions such as Sindh, Pakistan, is one such material. RHA is rich in amorphous silica and exhibits pozzolanic characteristics, enabling it to react with clay minerals in soil in a manner similar to conventional stabilizers, thereby enhancing strength parameters such as UCS.

While the effect of RHA on the plasticity characteristics of Jamshoro shale has been previously established, its influence on the strength behavior of this soil, specifically its unconfined compressive strength, undrained shear strength, and stress-strain modulus, warrants dedicated investigation. This study aims to address this gap by experimentally evaluating the effect of RHA, at varying percentages, on the unconfined compressive strength of Jamshoro shale in a compacted state, with the objective of assessing its suitability as a sustainable strength-enhancing additive for this locally significant geomaterial.

MATERIALS AND METHODOLOGY

Soil

Jamshoro shale was collected from the vicinity of Mehran University of Engineering and Technology (MUET), Jamshoro, Sindh, Pakistan. The soil retained on the No. 40 sieve was discarded, and the remaining material was thoroughly mixed to ensure uniform testing conditions.

Table 1: Engineering Properties of Untreated Jamshoro Shale

Property	Standard	Value
Natural Moisture Content (%)	AASHTO T265	3.81
Specific Gravity	ASTM D854	2.69
Liquid Limit (%)	ASTM D4318	51
Plastic Limit (%)	ASTM D4318	29
Plasticity Index (%)	ASTM D4318	22
USCS Classification	ASTM D2487	CH (high plasticity clay)
AASHTO Classification	—	A-7-6
Group Index (GI)	—	17
Maximum Dry Density (g/cc)	ASTM D1557	1.75
Optimum Moisture Content (%)	ASTM D1557	15.0

The Group Index of 17 exceeds the maximum allowable value of 10 for highway subgrade material, classifying the untreated Jamshoro shale as a poor subgrade material and confirming the need for stabilization.

Rice Husk Ash (RHA)

Rice husk, obtained from the local market, was burnt under controlled conditions at 600°C for 2 hours to produce rice husk ash (RHA), following the same procedure and material source described in the authors' prior investigation of RHA's effect on the plasticity characteristics of Jamshoro shale, where the ash was confirmed to be silica-rich (65% SiO₂) and pozzolanic in nature.

Compaction and Specimen Preparation

The relationship between dry density and water content for the untreated Jamshoro shale was established using the modified Proctor compaction test in accordance with ASTM D1557. The maximum dry density ($\gamma_d(\max)$) was found to be 1.75 g/cc at an optimum moisture content (OMC) of 15%. RHA was blended with the shale at 0%, 2%, 4%, 6%, 8%, 10%, and 12% by dry weight, and each blend was compacted at its corresponding optimum moisture content prior to specimen preparation.

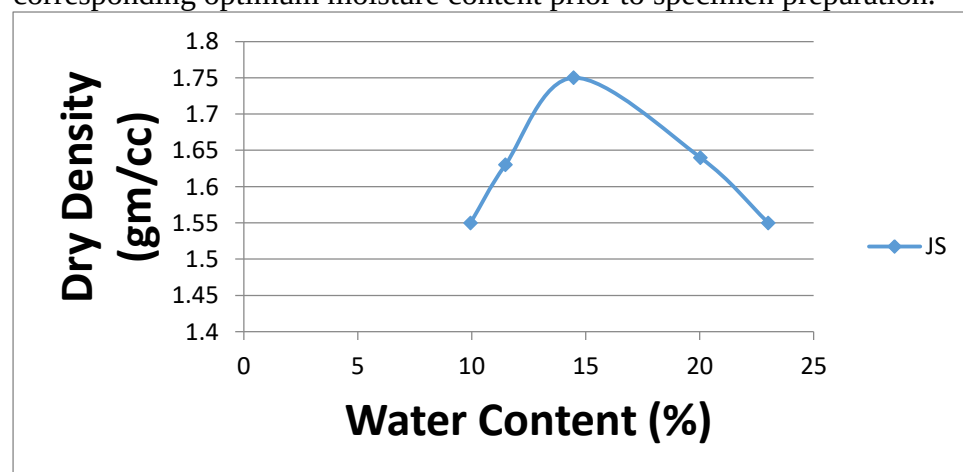


Figure 1: Compaction curve of Jamshoro Shale

Unconfined Compressive Strength Testing

Unconfined compressive strength (UCS) tests were performed on compacted cylindrical specimens for each RHA blend in accordance with ASTM D2166. From the stress-strain response, the unconfined compressive strength (q_u) was recorded as the peak axial stress. The undrained shear strength (S_u) was calculated as $S_u = q_u/2$, and the stress-strain modulus (E_s) was calculated as the secant modulus, $E_s = S_u/\epsilon_f$, where ϵ_f is the axial strain corresponding to failure. For the untreated soil, a peak stress of $q_u = 6.93 \text{ kg/cm}^2$ was recorded at a failure strain of 2.3%, giving $S_u = 3.46 \text{ kg/cm}^2$ and $E_s = 1.5 \text{ kg/cm}^2$.

RESULTS AND DISCUSSION

Stress-Strain Behavior

Figure 2 presents the stress-strain curves for Jamshoro shale specimens blended with RHA at 0%, 2%, 4%, 6%, 8%, 10%, and 12%. All blends exhibited the same general stress-strain pattern as the untreated soil, with stress increasing steadily with strain up to a peak (failure) value, beyond which the curves flattened. Specimens containing higher percentages of RHA consistently reached higher peak stress values than the untreated control, indicating a strengthening effect of RHA across the tested range.

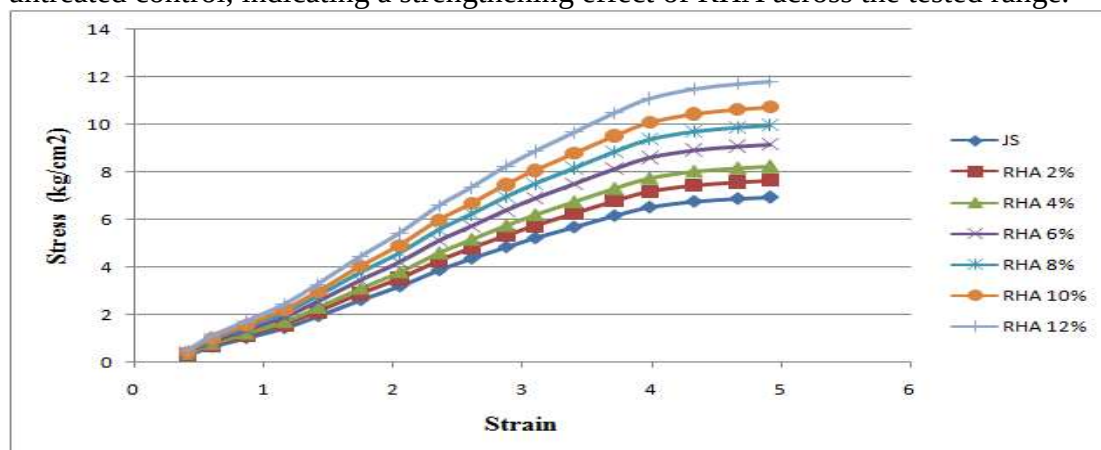


Figure 2: Stress vs. Strain for Jamshoro Shale at Varying RHA Content

Effect of RHA on Unconfined Compressive Strength (q_u)

Table 2: Effect of RHA Content on UCS Parameters

RHA (%)	q_u (kg/cm ²)	S_u (kg/cm ²)	E_s (kg/cm ²)
0	6.93	3.465	1.50
2	7.64	3.82	1.58
4	8.22	4.11	1.70
6	9.15	4.575	1.80
8	9.96	4.98	1.90
10	10.85	5.425	2.00
12	11.83	5.915	2.20

Figure 3 shows the variation of unconfined compressive strength with RHA content. The q_u of the Jamshoro shale increased progressively with increasing RHA content,

from 6.93 kg/cm² at 0% RHA to 11.83 kg/cm² at 12% RHA, representing an increase of approximately 70.7%. This increase is attributed to the pozzolanic reaction between the amorphous silica in RHA and the calcium hydroxide present in the soil-water system, producing cementitious compounds that bind soil particles together and enhance the overall strength of the soil matrix. Unlike the plasticity behavior observed in the companion study, the strength improvement showed no decline within the tested range, suggesting that further gains may be achievable beyond 12% RHA.

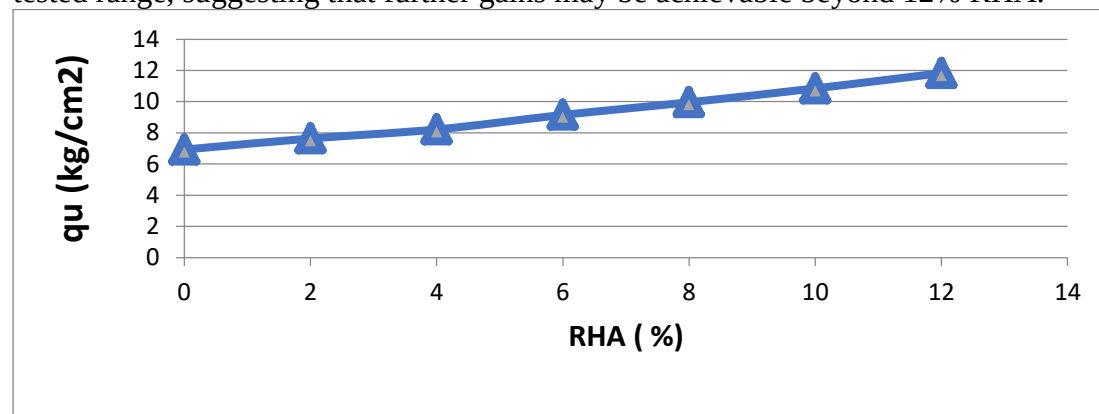


Figure 3: Unconfined Compressive Strength (q_u) vs. RHA Content (%)

Effect of RHA on Undrained Shear Strength (S_u)

Figure 4 illustrates the variation of undrained shear strength with RHA content. As S_u is directly derived from q_u ($S_u = q_u/2$), it followed an identical trend, increasing from 3.465 kg/cm² at 0% RHA to 5.915 kg/cm² at 12% RHA, an increase of approximately 70.7%. This confirms the consistent strengthening effect of RHA on the shear resistance of the soil.

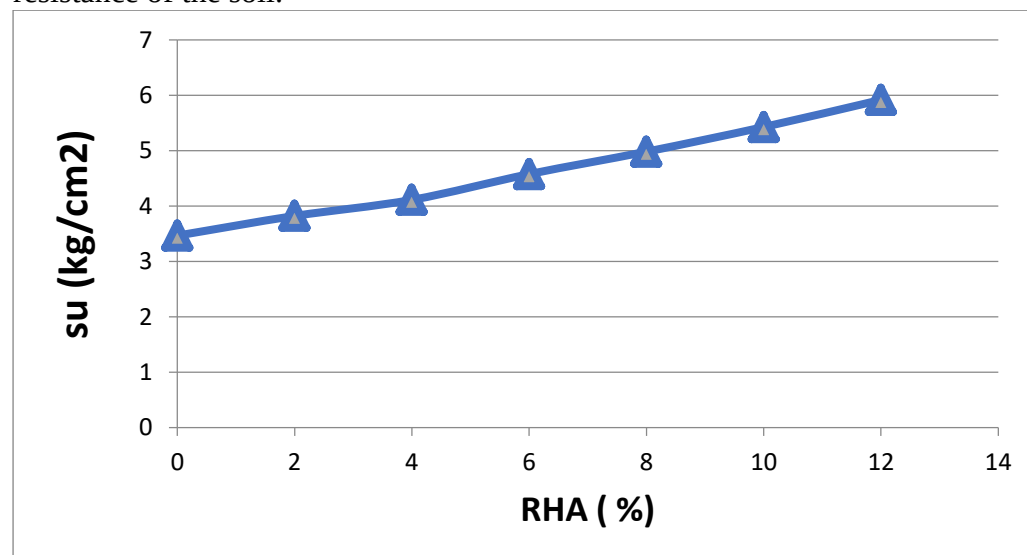


Figure 4: Undrained Shear Strength (S_u) vs. RHA Content (%)

Effect of RHA on Stress-Strain Modulus (E_s)

Figure 5 shows the variation of stress-strain modulus with RHA content. The E_s increased from 1.50 kg/cm² at 0% RHA to 2.20 kg/cm² at 12% RHA, an increase of approximately 46.7%. This increase, though less pronounced than the increase in q_u and S_u , indicates that RHA-treated soil becomes stiffer and less prone to excessive deformation under load, further supporting its suitability for use in subgrade and embankment applications.

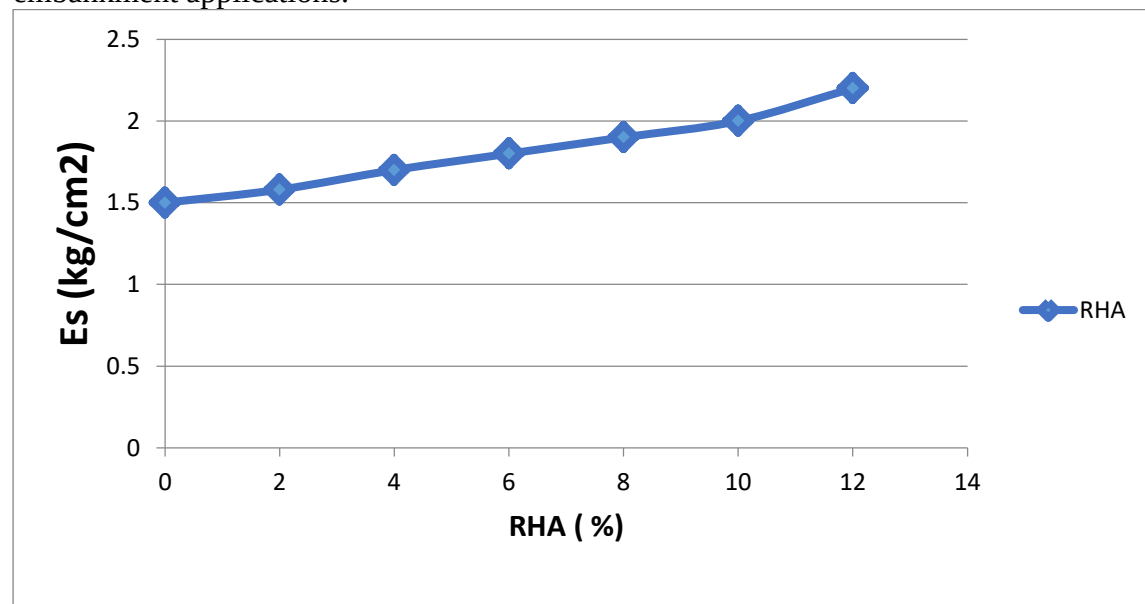


Figure 5: Stress-Strain Modulus (E_s) vs. RHA Content (%)

CONCLUSION

The untreated Jamshoro shale was classified as CH (inorganic clay of high plasticity) under the USCS and as A-7-6 under the AASHTO classification system, with a Group Index of 17, indicating a poor subgrade material.

The maximum dry density of the untreated shale was found to be 1.75 g/cc at an optimum moisture content of 15%, with a baseline unconfined compressive strength (q_u) of 6.93 kg/cm².

The unconfined compressive strength of the Jamshoro shale increased progressively with increasing RHA content, from 6.93 kg/cm² at 0% RHA to 11.83 kg/cm² at 12% RHA, an increase of approximately 70.7%.

Undrained shear strength followed an identical trend, increasing from 3.465 kg/cm² to 5.915 kg/cm² over the same range, also an increase of approximately 70.7%.

The stress-strain modulus increased from 1.50 kg/cm² to 2.20 kg/cm², an increase of approximately 46.7%, indicating improved stiffness of the RHA-treated soil.

These improvements are attributed to pozzolanic reactions between the RHA and the clay fraction of the shale, which produce cementitious compounds that bind soil particles together and enhance the strength and stiffness of the soil matrix.

Unlike the plasticity behavior of RHA-treated Jamshoro shale, which showed a progressive but potentially plateauing trend, the strength parameters examined in this

study showed no decline within the tested range (0–12%), suggesting that RHA continues to enhance the strength of Jamshoro shale up to at least 12% content.

The results demonstrate that RHA is an effective and sustainable additive for enhancing the unconfined compressive strength of Jamshoro shale, improving its suitability for use as a subgrade or embankment material in highway construction.

REFERENCES

- [1] Zaffar, S., Kumar, A., Memon, N. A., Kumar, R., and Saand, A. 2022. "Investigating Optimum Conditions for Developing Pozzolanic Ashes from Organic Wastes as Cement Replacing Materials." *Materials* 15(6): 2320.
- [2] Duong, N. T. 2022. "Effect of Rice Husk Ash on Unconfined Compressive Strength of Soil-Cement Admixture." *Suranaree Journal of Science and Technology* 29(1): 1–9.
- [3] Basha, E. A., Hashim, R., Mahmud, H. B., and Muntohar, A. S. 2005. "Stabilization of Residual Soil with Rice Husk Ash and Cement." *Construction and Building Materials* 19(6): 448–453.
- [4] Jongpradist, P., Homtragoon, W., Sukkarak, R., Kongkitkul, W., and Jamsawang, P. 2018. "Efficiency of Rice Husk Ash as Cementitious Material in High-Strength Cement-Admixed Clay." *Advances in Civil Engineering* 2018: 8346319.
- [5] Eliaslankaran, Z., Nik Daud, N. N., Md. Yusoff, Z., and Rostami, V. 2021. "Evaluation of the Effects of Cement and Lime with Rice Husk Ash as an Additive on Strength Behavior of Coastal Soil." *Materials* 14(5): 1140.
- [6] American Society for Testing and Materials. ASTM D2166 – Standard Test Method for Unconfined Compressive Strength of Cohesive Soil. ASTM International, West Conshohocken, PA.
- [7] American Society for Testing and Materials. ASTM D1557 – Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort. ASTM International, West Conshohocken, PA.
- [8] American Society for Testing and Materials. ASTM D4318 – Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International, West Conshohocken, PA.
- [9] American Society for Testing and Materials. ASTM D854 – Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. ASTM International, West Conshohocken, PA.
- [10] American Association of State Highway and Transportation Officials. AASHTO T265 – Standard Method of Test for Laboratory Determination of Moisture Content of Soils.