A COMPARATIVE STUDY ON THE STABILIZATION OF SUBGRADE SOIL USING RICE HUSK ASH

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ABSTRACT

The performance and longevity of civil engineering structures depend significantly on the strength and stability of the subgrade soil. Weak or expansive soils often require stabilization to meet the structural demands of pavements, foundations, and embankments. This study investigates the effectiveness of Rice Husk Ash (RHA)—a byproduct of agricultural waste—as a sustainable and economical soil stabilizing agent. The research aims to compare the geotechnical properties of untreated subgrade soil with those treated with varying percentages of RHA (5%, 10%, 15%, and 20% by weight).

A series of standard laboratory tests, including Atterberg limits, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), and Compaction characteristics, were conducted to assess the impact of RHA incorporation on soil behavior. The results indicate a substantial improvement in strength, bearing capacity, and plasticity characteristics with the optimal addition of RHA, particularly at the 15% mix ratio. Moreover, the pozzolanic nature of RHA contributed to long-term stabilization, making it a viable eco-friendly alternative to conventional stabilizers like lime or cement.

This comparative study confirms that RHA not only enhances subgrade soil properties but also promotes sustainable construction practices by converting agricultural waste into high-value engineering material. The findings have implications for low-cost infrastructure development, especially in rural and resource-constrained regions.

1. INTRODUCTION

1.1 General

The stability and strength of subgrade soil are critical determinants of the overall performance and durability of civil engineering structures such as roads, embankments, foundations, and retaining walls. However, many construction projects encounter weak or problematic soils with poor load-bearing capacity, high plasticity, or excessive compressibility—conditions that necessitate effective soil stabilization techniques.

Traditionally, chemical stabilizers such as lime, cement, and fly ash have been widely used to improve soil properties. While effective, these materials are often costly and energy-intensive to produce, contributing to environmental degradation through greenhouse gas emissions and resource depletion. As the construction industry shifts toward sustainable and eco-efficient practices, the use of agricultural and industrial waste products for soil stabilization has emerged as a promising alternative.

Rice Husk Ash (RHA) is a byproduct generated from the combustion of rice husks, an abundant agricultural residue in rice-producing countries. Rich in silica, RHA possesses pozzolanic properties that enable it to react with calcium hydroxide in the presence of moisture, forming cementitious compounds that enhance soil strength and durability. Moreover, utilizing RHA in soil stabilization addresses two key challenges: improving geotechnical performance and reducing environmental waste.

This study aims to evaluate the effectiveness of rice husk ash as a soil stabilizer by conducting a comparative analysis of soil samples treated with varying RHA percentages. Laboratory tests such as compaction, unconfined compressive strength (UCS), Atterberg limits, and California Bearing Ratio (CBR) are used to assess the changes in mechanical behavior and engineering properties of the soil. The objective is to determine the optimal mix ratio and to validate RHA's potential as a sustainable, low-cost, and locally available stabilizing material.

Through this research, the work contributes to the broader goal of integrating green materials in infrastructure development, particularly in rural and low-income regions where cost and material availability are major constraints.

1.2 Red soil

The weathering of metamorphic parent rock in the Deccan plateau area causes the formation of red soils. The coating's brownish-yellow hue is imparted by organic layers that bind. The dominance of yellow in the soil is caused by limonite, which is present in soils with high water content. Red soils tend to be found closer to the surface, whereas yellow soils are found more down in the soil strata. At the same time when the ground below begins to turn yellow. There is a nutrient in red soil that isn't good for certain plant species' growth. The soil is permeable, so it can't retain water near the roots. Over 3.5 lakhs sq. km. of red soil makes up the third most common kind of soil in India.

1.3 Rice husk ash

The physical and chemical properties of mineral admixtures may be met by burning rice husks into ash. Factors influencing the pozzolanic activity of rice husk ash (RHA) include (i) the concentration of silica, (ii) the phase of silica crystallisation, and (iii) the dimensions and surface area of the ash particles. Furthermore, ash can only have trace amounts of carbon. As a pozzolanic material, RHA that has been optimised by controlled burning and/or grinding has found its way into concrete and cement. There are a number of benefits to using it, including enhanced strength and durability, less carbon dioxide emissions, and less waste to landfills.

In nations that produce a lot of rice, you may find rice husk, which is a kind of agricultural waste. The paddy grain is encased in the husk. Approximately 78% of the weight of paddy grains is converted into rice, broken rice, and bran during the milling process. Hulls make up the remaining 22% of paddy's weight. The different mills utilise this husk as fuel to produce steam, which is then employed in the parboiling process. During the burning process, the remaining 25% of the weight of the husk is transformed into ash, which is referred to as rice husk ash. The husk itself comprises around 75% organic volatile matter. Amorphous silica makes up around 85% to 90% of this RHA. The rice husk is a significant agricultural waste product in many regions, particularly underdeveloped nations, where it is produced by the rice processing businesses. Worldwide, 500 million tonnes of paddy are generated each year, with only about 20% of the rice husk being converted to RHA after burning. The majority of RHA is still disposed of in landfills or into water streams, where it pollutes the air, water, and soil as it has no practical value. Utilisation of industrial and biogenic waste as supplementary cementing material has become an integral part of concrete construction, driven by increasing environmental concern and the need to conserve energy and resources. RHA, which is composed of non-crystalline silicon dioxide, has a high specific surface area and high pozzolanic reactivity. Pozzolanas increase the strength of cement by filling the spaces between the cement particles and creating a finer pore structure; they are smaller than the cement particles themselves. In the manufacturing of inexpensive building blocks, RHA acts as a Portland cement alternative; in the production of high strength concrete, it acts as an additive.

2. LITERATURE REVIEW

Rice husk is a by-product of the rice milling. About 100 million of tons of husk per year are produced worldwide [1]. The husk is not suitable as animal feed because of its abrasive character and almost negligible digestible protein content [2], its high ash and lignin contents make it unsuitable as a raw material for paper manufacturing [3].

In order to reduce such volume of waste, rice husk is burned either in open heaps or as a fuel in ovens for rice drying, power generation, etc. The burning volatilizes the organic compounds and water of the rice husk, and about 20% of the mass remains as rice husk ash (RHA) [2, 4–9]. If all rice husks had been burned, it would annually produce about 20 million of tons of RHA worldwide. To value this residue is an alternative to its final disposition with environmental benefit.

Pozzolanas are siliceous and/or aluminous materials, which in themselves possess little or no cementing properties, but chemically react with calcium hydroxide, such as lime, to form compounds possessing cementitious properties [10]. The RHA contains around 90% of silica [4, 5], which is the highest concentration of all plant residues [2]. Based upon this, RHA has been used to improve properties of soil either when added alone or when mixed with a hydraulic activator such as the cement and lime [1, 6–8, 11–16]. Soil stabilization by the addition of RHA and lime is particularly attractive for road pavements because it leads to cheaper construction and lesser disposal costs, reduces environmental damage and preserves the most highly qualified materials for priority uses [7, 8].

The effect of the addition of RHA alone on the plasticity, unconfined compression strength (UCS) and California Bearing Ratio (CBR) of a lateritic soil with 45% passing the #200 sieve (75 μm), was studied by Rahman [11]. Results showed increases of UCS and CBR in 1 day with increase in RHA up to 20 and 18%, respectively, after which they started to decrease. Similarly, Alhassan [14] observed increasing of CBR with 6-day and 1-day soaking and without soaking when a clayey soil was stabilized with RHA up to 6 and 12%, respectively.

Generally, RHA cannot be used alone in soil stabilization because of its lack of cementitious properties [7, 8]. Development of UCS has been observed when clayey, clayey sandy, silty clayey and silty sandy soils were treated with RHA and lime or cement [1, 7, 8, 12, 13]. In the case of cement, it was observed that little or insignificant increases of UCS in lateritic and clayey soils stabilized with RHA and cement with respect to its increase when they were treated with cement alone [6, 12]. 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, 7, 8]. Alhassan [15] attributes the UCS decreasing after this optimum value to the excess RHA that could not be utilized for the alkaline reactions. Also, he shows that addition of RHA in clayey soil-lime specimens further increased the UCS at specified lime content. This increment was rapid between 0 and 4% RHA content but decreased in rate from 6 to 8% RHA content at specified curing period.

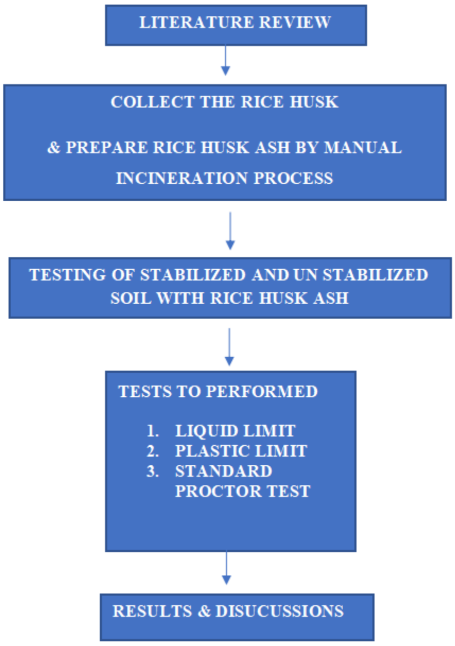
Basha et al. [8] found that a lesser amount of cement is required to achieve a given strength as compared to cement-stabilized silty sandy soil when RHA is added. Since cement is more costly than RHA, this results in lower construction cost. Ali et al. [7], evaluating the effectiveness in the improvement of a clayey sandy soil with RHA, showing that lime is a more effective stabilizing agent than cement.

3. OBJECTIVE AND METHODOLOGY

3.1 Objective of the study

1. To analyze the characteristics of Red soil for different concentrations of 0%, 10%, 20%, 30%, 40%, 50% Rice husk mixed with it.
2. To study the effect of solid wastes namely Rice husk ash in red soil on the variation of index properties and compaction characteristics.
3. To study the outcome of Rice husk in soil stabilization, in the way to decrease the waste disposal problem, environmental pollution.

3.2 Objective of the study



4.EXPERIMENTAL INVESTIGATIONS

4.1 General

The detailed experimental programme of the present study was undertaken to investigate the changed behaviour of the available red soil when mixed with easily available local stabilizing admixtures like rice husk ash in different proportions individually or in combinations. This will enable to examine not only suitability of these composite materials in the construction of sub-grade for flexible pavement, but also to decide the optimum mixing proportion for cost effective construction.

Initially the geotechnical property like Atterberg limit of the soil and stabilized soil had been determined. The necessary experiment on made to determine the compaction characteristics i.e. optimum moisture content (OMC) and maximum dry density (MDD) by conducting Standard Proctor Compaction tests of those soils. There after the effect of strength characteristics of the original soil and stabilized soils had been made by conducting California Bearing Ratio (CBR) test on the stabilized soil.

The different tests were conducted in order to determine the different characteristics and properties of the soil. The procedure of each of the tests have been explained below.

5. RESULTS AND DISCUSSIONS

5.1 Soil stabilization with adding rice husk

5.1.1 Grain size analysis

Table. 1: Grain size analysis of soil-RHA mixes.

S.No	Soil(%)	RHA (%)	GRAIN SIZE		
			SAND (%)	SILT (%)	CLAY (%)
1	100	0	7	88	5
2	90	10	7	85	8
3	80	20	8	82	10
4	70	30	7	86	7
5	60	40	7	89	4
6	50	50	7	89	4

5.1.2 Atterberg Limit (Casagrande Method)

Table. 2: Atterberg Limits of Soil - RHA Mixes

S.No	RHA(%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Group
1	0	48	29.4	18.6	MI
2	10	45	31	14	MI
3	20	42	32	10	MI
4	30	39	32.6	6.4	MI
5	40	38	33	5	MI
6	50	37.8	33.7	4.1	MI

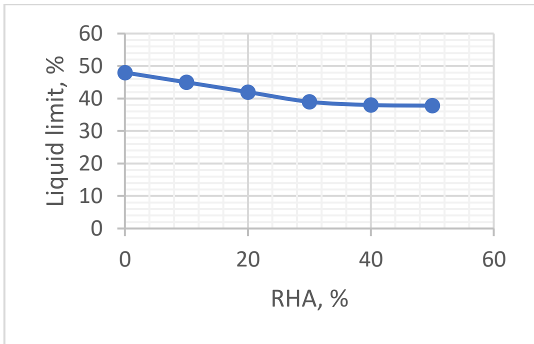


Fig. 1: Liquid limit test results.

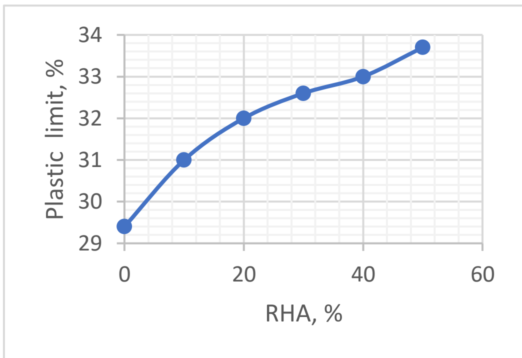


Fig. 2: Plastic limit test results.

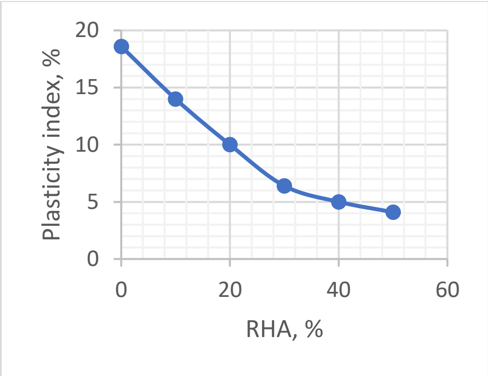


Fig. 3: Plasticity limit test results.

5.1.3 Compaction test (Standard proctor method)

Table. 3: Compaction characteristics of Soil-RHA mixes.

S. No	RHA %	Moisture content (%)	Dry density (gm/cc)
1	0	7	1.51
2		12.5	1.59
3		16	1.65
4		19	1.62
5		21.2	1.61
6	10	9.1	1.35
7		14	1.43
8		17	1.51
9		21.2	1.54
10		25	1.48
11	20	7	1.28
12		15	1.37
13		18	1.42
14		22	1.47
15		26	1.40
16		27	1.38
17	30	12.5	1.25
18		16.8	1.385
19		24.1	1.44
20		27.3	1.41
21		30.2	1.34
22	40	11.5	1.23
23		17.5	1.25
24		23	1.3
25		26	1.38
26		28	1.35
27		31	1.29
28	50	12	1.21
29		17	1.25
30		22	1.28
31		26	1.23
32		29	1.18

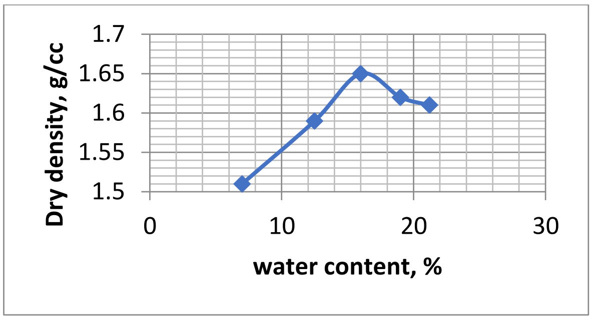


Fig. 4: Compaction curve for soil + 0% RHA.

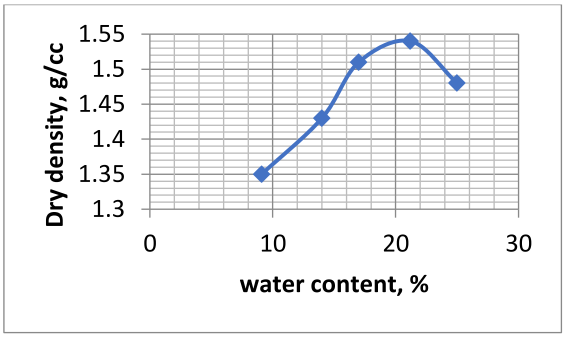


Fig. 5: Compaction curve for soil + 10% RHA.

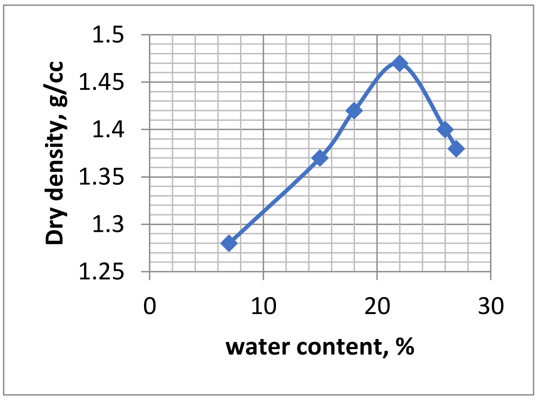


Fig. 6: Compaction Curve for Soil + 20% RHA

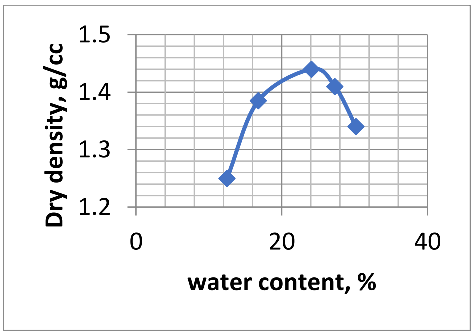


Fig. 7: Compaction curve for soil + 30% RHA.

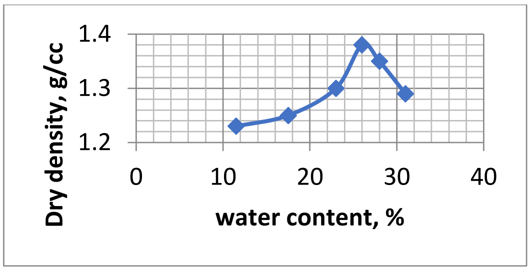


Fig. 8: Compaction curve for soil + 40% RHA.

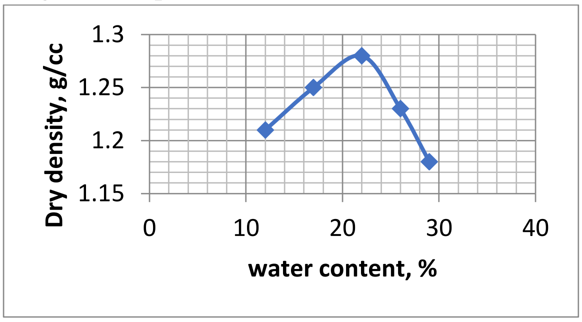


Fig. 9: Compaction curve for soil + 50% RHA.

Table. 4: OMC and MDD of soil-RHA mixes.

S.No	RHA %	OMC(%)	MDD(gm/cc)
1	0	16	1.65
2	10	21.2	1.54
3	20	22	1.47
4	30	24.1	1.44
5	40	26	1.38
6	50	22	1.28

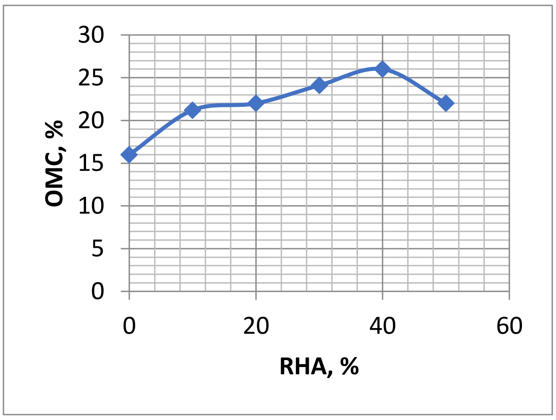


Fig. 10: OMC curve for soil + RHA.

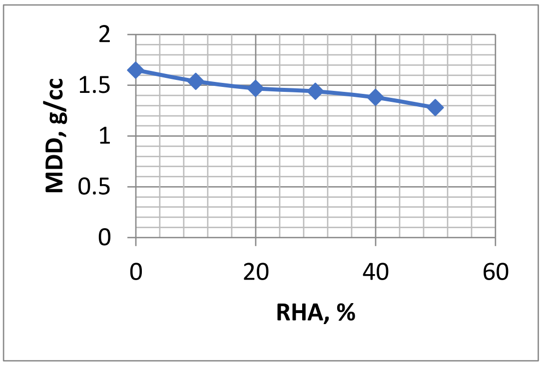


Fig. 11: MDD curve for soil + RHA.

5.2 Discussions

1. The liquid limit of the soil alone was found to be 48%. The liquid limit of the soil with addition of 50% RHA was found to be decreased by 21.25%, when compared to liquid limit of soil alone.
2. The plastic limit of the soil alone was found to be 29.4%. The plastic limit of the soil with addition of 50% RHA was found to be increases by 14.62%, when compared to plastic limit of soil alone.
3. The plasticity index of the soil alone was found to be 18.6%. The plasticity index of the soil with the addition of 50% RHA was found to be decreased by 77.95%, when compared to plasticity index of soil alone.
4. The optimum moisture content (OMC) and maximum dry density (MDD) of soil alone was found to be 16% and 1.65 g/cc respectively. The MDD of the soil with addition of 50% RHA by weight of soil is found to be decreases by 22.45% and the corresponding OMC is increased by 37.5%.

6. CONCLUSIONS

On the basis of present experimental study, the following conclusions are drawn

1. The red soil was identified As Intermediate compressible inorganic silt is designed (MI) on Indian Standard classification system. RHA was used to stabilize the soil for road construction in this study and a sufficient cementitious property was found in RHA.

2. On addition of different percentage of rice husk ash in the soil (0 to 50%), the plasticity index decreases with an increase in the proportion of rice husk ash from 0% to 50%. The percentage decreases in plasticity index value of soil from 18.6 to 4.1, rha stabilized soil respectively.
3. The compaction characteristic of stabilized soil found to be dependent on the plastic nature of the soil. For medium plastic soil, addition of stabilizer to soil reduced the maximum dry density while increasing the optimum moisture content irrespective of stabilizer type.

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