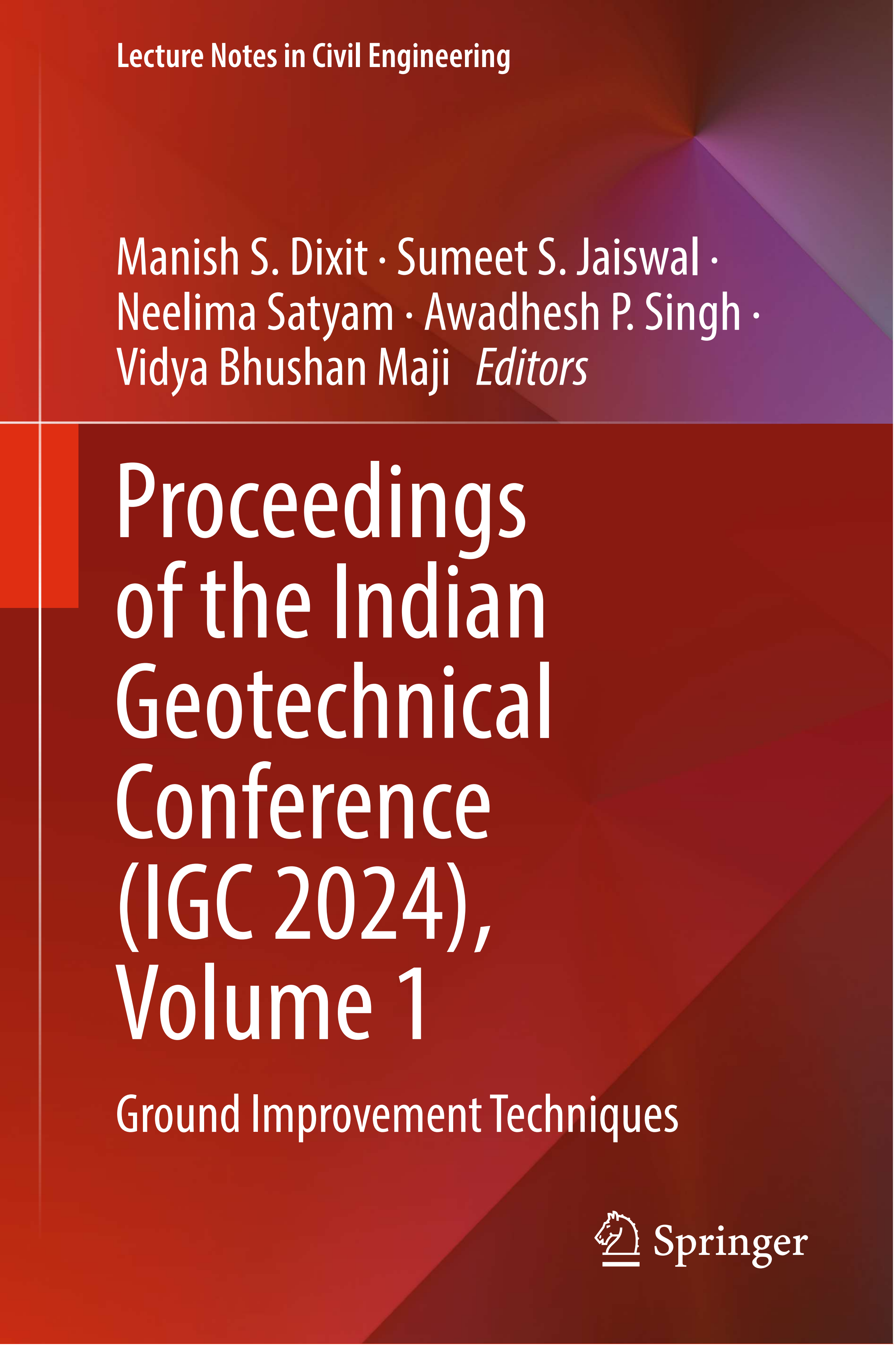

Lecture Notes in Civil Engineering

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Modification of Geotechnical Parameters of Soil by Using Agricultural Waste

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Abstract A low compressible silty-clayey soil has been stabilized by utilizing locally available agricultural waste such as Sugarcane Bagasse Ash (SCBA) and Rice Husk Ash (RHA). Bagasse is a fibrous residual material remaining after the crushing of sugarcane, and bagasse ash is produced subsequent to the burning of bagasse. Rice husk ash is similarly generated after the burning of rice husk. Improper disposal of these materials can lead to environmental damage around sugar manufacturing plants. In the present study, samples are prepared using varying proportions of bagasse ash and rice husk ash as 2.5, 5, 7.5, 10, and 12.5% of the dry mass of the soil. The Standard Proctor test and Unconfined Compressive Strength (UCS) tests have been conducted on the soil samples. The maximum dry density, optimum moisture content, and Unconfined Compressive Strength are reported for both untreated and treated samples. The outcome of the study clearly indicates that the stabilization of soil using bagasse ash and rice husk ash not only enhances strength but also facilitates to cope with environmental concerns by reducing agricultural waste material.

Keywords SCBA · RHA · Standard proctor test · Unconfined compressive strength

1 Introduction

India generates a vast amount of various waste materials as by-products from many industries, including industrial and agricultural industries. These waste products could be dangerous if they are not disposed of properly. With an increase in population occurs a rise in both the amount and type of waste produced. Because they are

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not used, these wastes stay in the environment for a longer period of time. The development of non-decaying waste materials was the root cause of the waste disposal system. Reusing waste to create valuable products is one way to tackle this problem. The study of new and innovative uses for waste materials is never-ending. Currently, studies are being conducted in India to look at the potential uses of various locally accessible wastes for soil. Thus, one of these types is agricultural waste, which is used to improve the strength and stability of soil. Rice husk is largely available in rice-producing countries like China, India, Indonesia, Bangladesh, Brazil, and South East Asia. The primary usage of rice husk as fuel in boilers for process energy requirements and power generation is in the industrial sector. A fuel with a high ash concentration is rice husk, which can contain 20–25% rice husk and 80–90% silica. Most of the husk left behind after processing rice is either burned for energy or disposed off as waste in the majority of rice-producing nations. India alone produces around 120 million tonnes of rice paddies per year, giving around 24 million tonnes of rice husk and 4.4 million tonnes of RHA every year [1]. Rice husk is agricultural by-product that is obtained when rice goes through milling. Around 20 percent of the 479 million metric tonnes of rice was produced worldwide in 2019–2020 [2]. Due to its high residual calorific value (15 MJ/kg), it was typically burned directly as a fuel to produce heat [3].

Basha et al. [4] substituted different amounts of cement and rice husk ash for the soil. The optimum value has been found to be 6–8% cement and 15–20% RHA. When rice husk ash was added to cement-stabilized soil, a notable improvement in CBR is seen. Rice husk ash remains after burning, this residue is typically disposed of as waste and dumped into rivers or landfills, causing environmental issues such as air and water pollution [5]. Rice husk ash was regarded as a green and sustainable building material because numerous researchers have shown that it has good pozzolanic activity and high levels of amorphous silica [6, 7]. RHA has been found to considerably increase the durability of concrete and chemical attack resistance when used in the proper dosage. It decreases permeability and improves chemical attack resistance. However, when used as a soil stabilizer, RHA has the ability to improve the geotechnical characteristics of weak soils [8]. This includes inceasing the shear strength of stabilized soil, elastic modulus, and California Bearing Ratio (CBR) while decreasing their compressibility and swelling. Shrivastava et al. [9] had studied the effect of lime and RHA on engineering characteristics of black cotton soil and found that the maximum dry density and optimum moisture content decreased, whereas CBR and UCS strength significantly increased.

Ganesan et al. [10] carried out experiment on the use of bagasse ash (BA) as a partial cement replacement material with respect to cement mortars. Well-burned bagasse ash can optimally replace up to 20% of ordinary Portland cement without negatively effecting the desired qualities of the concrete. Goyal et al. [11] reported that the main criterion for a pozzolanic material included high specific surface area, high amorphous silica contents, and high calcium oxide contents has been satisfied by SCBA. Cordeiro et al. [12] studied an important criterion for the growth of SCBA with pozzolanic activity. The SCBA produced by air calcination at 600 °C for hours with a heating rate of 10 °C/min includes amorphous silica, low carbon content, and high specific surface area. The sample produced with these features has significant pozzolanic activity according to both mechanical and chemical techniques of evaluation. Kiran et al. [13] studied the use of cement and sugarcane straw ash to stabilize lateritic soil. When combined with 5% cement, sugarcane straw ash proved to be an efficient stabilizer, helping to improve the geotechnical characteristics of a lateritic soil sample. Chittaranjan et al. [14] carried out experiments on the agricultural wastes for soil stabilization. Weak subgrade soil is stabilized by agricultural wastes including groundnut shell ash, rice husk ash, and sugarcane bagasse ash. Bagasse ash was categorized as a non-hazardous and inert solid waste material as per the outcomes of the solubilization and leaching experiments carried out by [15, 16].

1.1 Scope and Objectives

This study was oriented towards improving the strength of low compressible silty-clayey soil classified as per IS code 1498–1970 [17] using locally available agricultural waste materials to reduce the construction cost and agricultural wastes. The two different types of stabilizing agents are used, i.e. Rice Husk Ash (RHA) and Sugar Cane Bagasse Ash (SCBA). The main objectives of this study are as follows:

1. To investigate the physical and chemical properties of stabilizing agents and their suitability.
2. To perform the Standard Proctor Test (SPT) and Unconfined Compressive Strength (UCS) of native soil and stabilized soil by adding 2.5, 5, 7.5, 10, and 12.5% of ash in soil.
3. To compare the result of the RHA and SCBA for the stabilization of soil.

2 Methodology

In this research work, RHA and SCBA had been mixed in the proportions of 2.5, 5, 7.5, 10%, and 12.5% of the dry mass of the soil and conducted the following tests:

(i) Atterberg's Limit Test,
(ii) Standard Proctor Test,
(iii) Unconfined Compressive Strength (UCS) of native soil.

The effects of RHA and SCBA on the geotechnical parameters of the soil by using agricultural wastes were evaluated and results were compared. Figure 1 shows the methodology flow chart.

Following tests were performed on the soil samples:

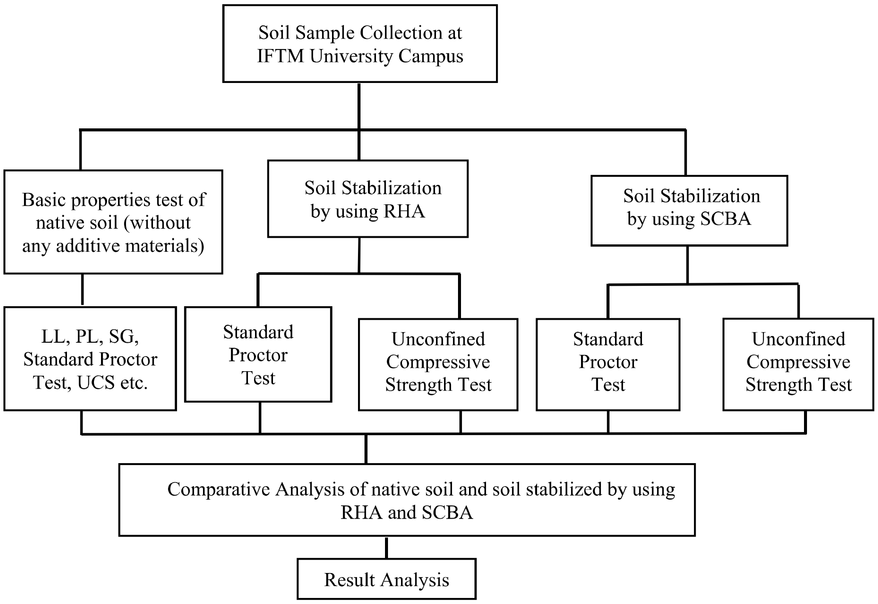

Fig. 1 Methodology flow chart

2.1 Atterberg's Limit Test

The Atterberg's limit test of the natural soil and soil mixed with two stabilizers, i.e. RHA and SCBA, was conducted as per IS: 2720 (Part-5)-1985 [18]. The residual soil was sieved through 425µ. Materials that retained on that sieve were rejected for this test. The sieved soil was oven-dried for at least 2 h before the test. The tests were carried out on the soils with different proportion of RHA and SCBA.

2.2 Standard Proctor Test

Standard Proctor Compaction test, according to IS: 2720 (Part-7) [19], was conducted to determine the maximum dry density (MDD) and the optimum moisture content (OMC) of the soils. The soil mixtures, with and without additives, were thoroughly mixed with various moisture contents and allowed to compaction. A proctor mould is filled in three layers with soil and specified water content, compacted with standard hammer by 25 blows falling through standard height. After which the dry density of the sample is determined. The test is repeated with varying water content, a graph is plotted to determine MDD and related OMC. The first series of compaction tests were aimed at determining the compaction properties of the unstabilized soils. Secondly, tests were carried out to determine the proctor compaction properties of the stabilized soil with varying amounts of RHA and SCBA.

2.3 Unconfined Compressive Strength Test

Cylindrical remoulded test specimens of diameter 38 mm with height of 76 mm were used for the test. The samples of native soil and additive mixes were cured for 7 days, 14 days, and 28 days. And at the end of each curing period, three samples each for mix were tested. The tests were conducted as per Bureau of Indian Standard—IS: 2720 (Part-10), 1991 [20]. All the samples were prepared by static compaction using split mould at optimum moisture content (OMC) and at maximum dry density (MDD).

3 Materials

The properties of native soil and soil stabilized with RHA and SCBA have been discussed in the following sections:

3.1 Soil

The native soil was taken from IFTM University campus. It was taken from the depth of 1–2 m below the top soil and was properly sealed in airtight bags. Table 1 shows the basic properties of the native soil. And particle size distribution curve of campus soil is shown in Fig. 2.

Table 1 Basic properties of soil

Parameters	Results
Clay size fraction (%)	11.96
Sand size fraction (%)	32.65
Silt size fraction (%)	55.39
Soil type as per IS: 1498–1970	CL-ML
Liquid limit (%)	22.41
Plastic limit (%)	15.89
Plasticity index (%)	6.52
Specific gravity	2.67
Maximum dry density, MDD (kN/m^3)	16.58
Optimum moisture content, OMC (%)	13.98

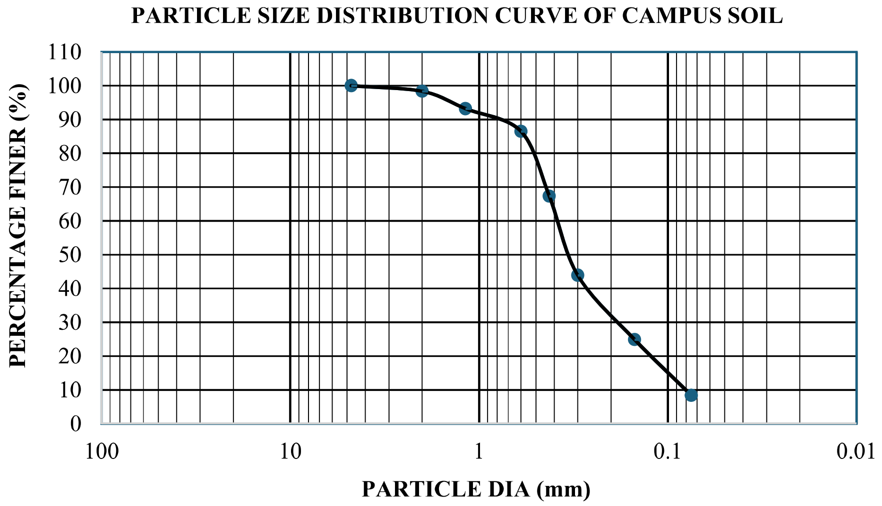

Fig. 2 Particle size distribution curve for campus soil

Table 2 Physical properties of RHA & SCBA

S. No	Component	RHA	SCBA
1	Colour	Grey	Grey
2	Specific gravity	1.89	1.91
3	Liquid limit	46.3	41.3
4	Plastic limit	Non-plastic	Non-plastic
5	MDD (KN/m^3)	11.66	11.17
6	OMC (%)	44.56	46.45

3.2 Stabilization by Using RHA

The nearest rice mill provided the rice husk, which was then burned in muffle furnace between 550 and 700 °C until it changed into amorphous silica. Rice husk ash contains silica, an element with the usual characteristics in clayey soils such as calcium generates calcium silicates that harden the mixture and allows the increase of the soil density and its resistance characteristics. Table 2 lists the physical characteristics of the stabilizers. And particle size distribution curve of RHA is shown in Fig. 3.

3.3 Stabilization by Using SCBA

Bagasse made from sugar cane in dry state was collected from jaggery mills and burned in muffle furnace between 800 and 1000 °C. SCBA contains a high percentage

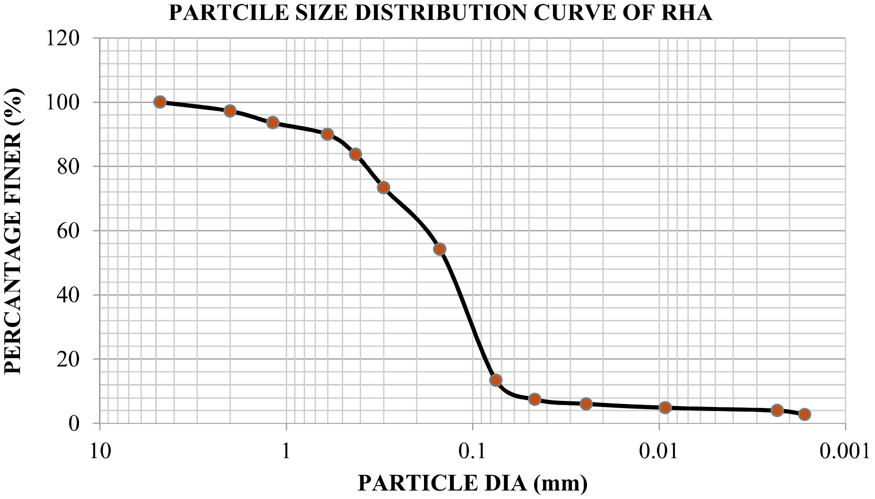

Fig. 3 Particle size distribution curve for RHA

Table 3 Chemical properties of RHA & SCBA

S. No	Property	RHA	SCBA
1	Silica (SiO_2)	93.4	71.08
2	Calcium oxide (CaO)	0.45	3.65
3	Aluminium oxide (Al_2O_3)	0.35	7.08
4	Iron oxide (Fe_2O_3)	1.65	4.65
5	Magnesia (MgO)	0.30	3.44

of silica that borders 57% of its entire composition; this contributes to its ability to be a pozzolanic material. Similarly, other compounds such as calcium oxide and ferric oxide that together with silica comprise more than 70% of SCBA are large pozzolana enhancers. Table 3 lists the chemical composition of the ashes that were investigated in the lab. And particle size distribution curve of SCBA is shown in Fig. 4.

4 Results and Discussion

Standard Proctor test and Unconfined Compressive Strength tests were performed on the native soil and soil stabilized with RHA and SCBA. Following observations were made.

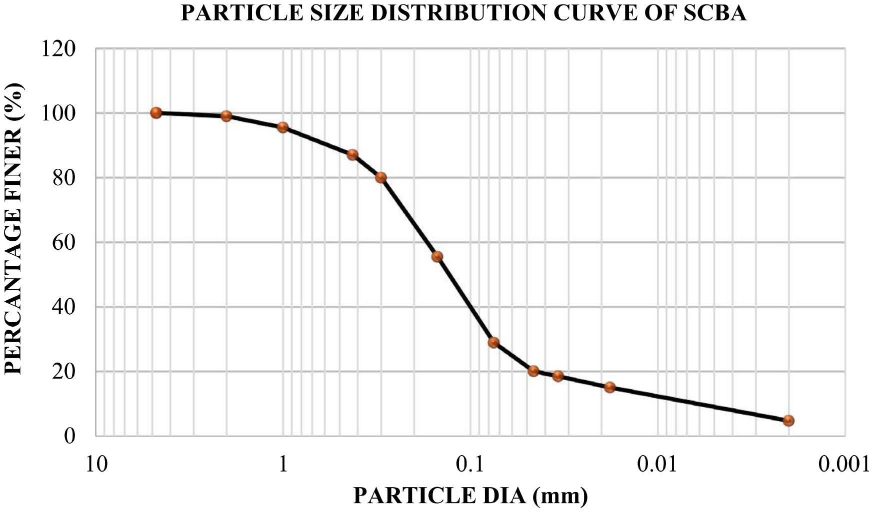

Fig. 4 Particle size distribution curve for SCBA

4.1 *Standard Proctor Test*

Determining the maximum dry density (MDD) and optimum moisture contents (OMC) of both untreated compacted and treated stabilized soil mixes was the goal of the Proctor test, also known as the moisture–density test. In order to establish the link between the optimum moisture content and the maximum dry density with various percentages of RHA, a Standard Proctor test was carried out in accordance with IS: 2720 (Part-7) [19]. Figures 5 and 6 show the relationship between maximum dry density with different percentage of RHA and SCBA, respectively. The maximum dry density variations with a percentage increase in ash are shown in Fig. 5.

Figure 5 shows the MDD with different percentage of RHA. The optimum moisture content rises as the percentage of ash in the mix increases. The MDD of treated soil was found to be 16.58 KN/m^3, 18.55 KN/m^3, 18.64 KN/m^3, 18.32 KN/m^3, 18.02 KN/m^3, and 17.88 KN/m^3 for 0%, 2.5%, 5%, 7.5%, and 12.5% of RHA, respectively. The maximum dry density was increased initially till the addition of 5% of the RHA and then it decreased gradually. When small quantities of RHA (2.5–5%) are added to soil, the MDD increases, i.e. the RHA more efficiently fills in voids and improves particle packing, generating a denser combination. However, if the RHA content increases over this desirable limit, additional voids develop and the structure of the soil is disrupted, this results in a decrease in MDD because the mixture becomes less compacted and more porous.

Figure 6 shows the maximum dry density variations as the proportion of SCBA increases. The MDD of treated soil was found to be 16.58 KN/m^3, 18.35 KN/m^3, 18.54 KN/m^3, 18.38 KN/m^3, 18.05 KN/m^3, and 17.18 KN/m^3 for 0%, 2.5%, 5%, 7.5%, and 12.5% of SCBA, respectively. When small quantities of SCBA (i.e. 2.5%

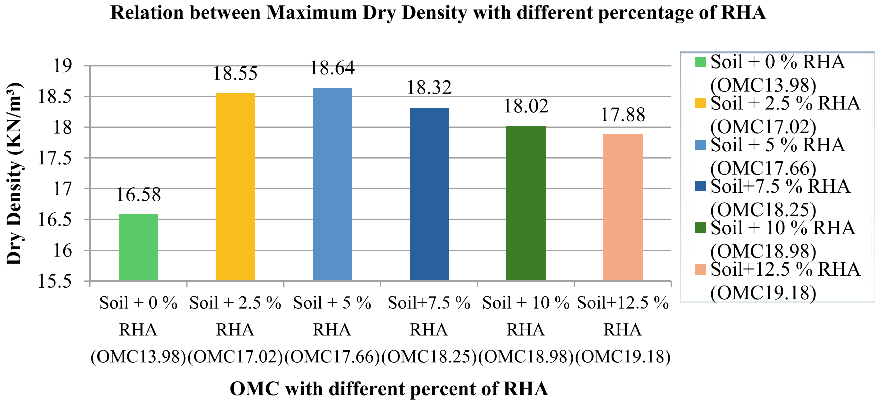

Fig. 5 Relationship between maximum dry density with different percentage of RHA

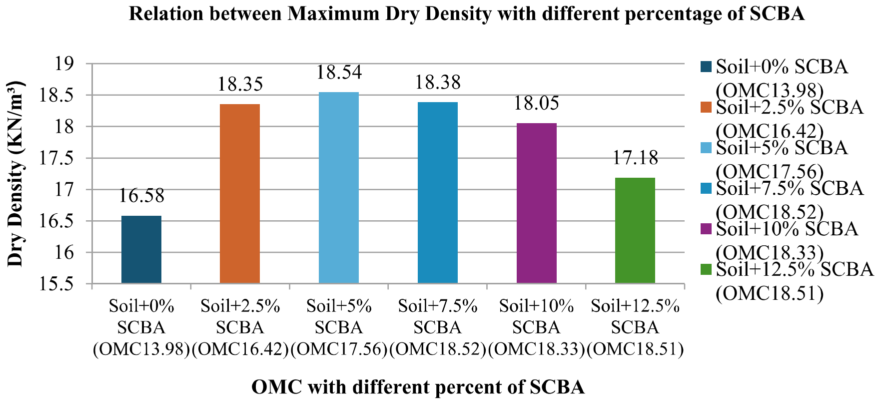

Fig. 6 Relationship between maximum dry density with different percentage of SCBA

to 5%) is added to soil, the MDD increases because the ash particles fill voids and improve particle packing, which makes the mixture denser. When SCBA is added in excess of 5%, however, more voids occur, the specific gravity of the mixture decreases, and the soil structure changes, which results in a decrease in MDD.

Figure 7 shows comparison between maximum dry density of RHA and SCBA. As shown in Fig. 7, both Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SCBA) have maximum dry density at 5% because of more effective void filling, improved particle packing, and increased compaction efficiency. An excessive amount of ash damages the soil matrix by increasing the void ratio and decreasing the mix's specific gravity, which decreases MDD. From Fig. 7, it can be observed that RHA is a better stabilizer than SCBA. The SCBA has pozzolanic properties, which react with calcium hydroxide and water to create cementitious compounds. This process slightly strengthen the bonds between soil particles at 5% SCBA, results in a denser mixture.

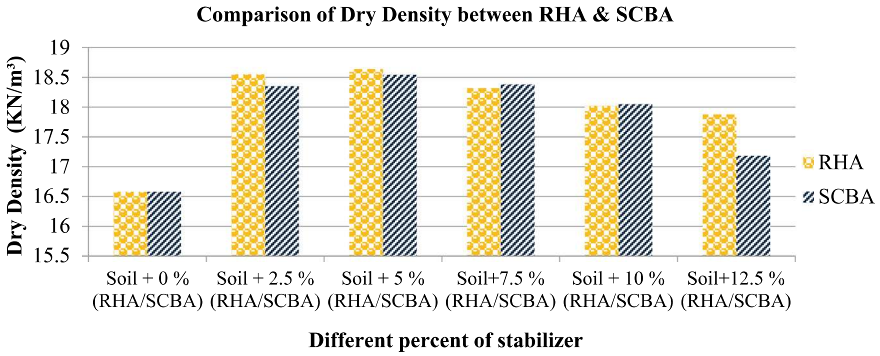

Fig. 7 Comparison of maximum dry density between RHA & SCBA

However, the effects of RHA on maximum dry density (MDD) are more pronounced. In addition to its pozzolanic activity, RHA's finer particle size and its ability to fill voids between soil particles play a more significant role in improving the density of soil. This combination of better particle packing and reactivity gives RHA an edge over SCBA in stabilizing the soil.

4.2 Unconfined Compressive Strength

The Unconfined Compressive Strength (UCS) of the native soil and the stabilized soil was evaluated using the recommendations of IS: 2720 (Part-10) [20]. It has been determined that the UCS of the native soil is 91.79 KN/m^2. When soil is replaced with a different combination of RHA and SCBA, the UCS of the soil initially increases up to the mix 92.5% soil and 7.5% RHA/SCBA and then decreases. The subsequent increase in UCS is attributed to the development of cementitious compounds between calcium hydroxide in the soil and ashes, as well as pozzolana present in the ashes. A further fall in the UCS values with the addition of 7.5% ashes may be due to the excess ashes present in the soil, resulting in inadequate bonds between the soil and the cementitious compounds developed. Tables 4 and 5 give the UCS value with different percent of RHA and SCBA for 7 days, 14 days, and 28 days. And Fig. 8 and 9 illustrate the variation in Unconfined Compressive Strength with different percent of RHA and SCBA.

Table 4 UCS value with different percentage of RHA

Unconfined compressive strength for RHA (KN/m²)						
Days	Soil + 0% RHA	Soil + 2.5% RHA	Soil + 5% RHA	Soil + 7.5% RHA	Soil + 10% RHA	Soil + 12.5% RHA
0	91.79	112.19	136.75	157.02	139.25	119.24
7	109.59	134.35	143.25	169.98	146.15	129.84
14	117.42	141.55	149.75	179.18	149.07	135.44
28	122.05	149.22	155.39	187.07	163.45	142.42

Table 5 UCS value with different percentage of SCBA

Unconfined compressive strength for SCBA (KN/m²)						
Days	Soil + 0% SCBA	Soil + 2.5% SCBA	Soil + 5% SCBA	Soil + 7.5% SCBA	Soil + 10% SCBA	Soil + 12.5% SCBA
0	91.79	107.29	127.25	151.02	129.25	111.24
7	109.59	126.25	133.05	157.28	136.35	121.24
14	117.42	128.35	141.05	161.28	139.95	126.24
28	122.05	139.08	147.13	168.29	154.35	139.14

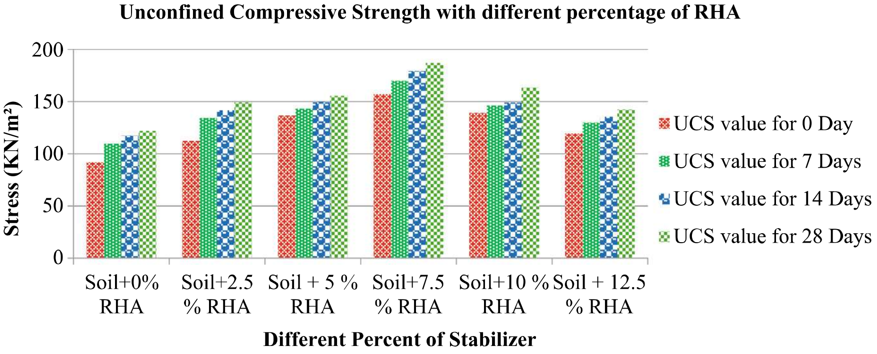

Fig. 8 Unconfined compressive strength with different percentage of RHA

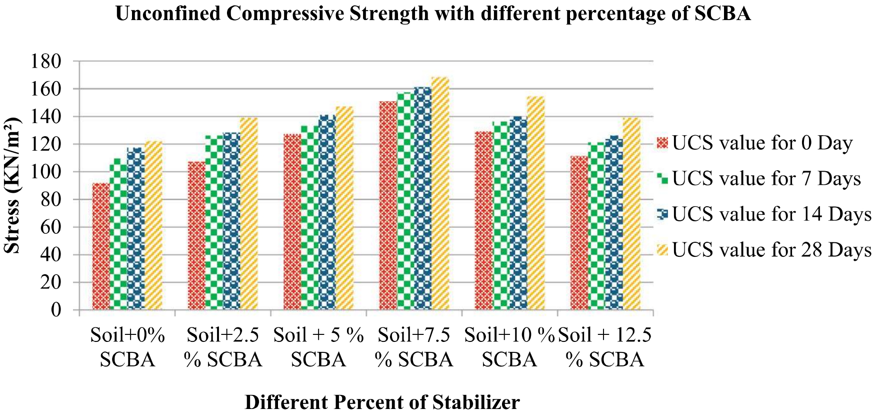

Fig. 9 Unconfined compressive strength with different percentage of SCBA

5 Conclusion

A laboratory investigation has been conducted to examine the effectiveness of agricultural waste materials like RHA and SCBA to increase the strength of soil. The RHA and SCBA-mixed soil was utilized as a stabilizer in different percentages of ash content: 2.5, 5, 7.5, 10, and 12.5%. A range of laboratory tests for obtaining the basic properties of native soil, i.e. liquid limit, plastic limit, specific gravity, Standard Proctor test, and Unconfined Compressive Strength test (UCS), were carried out. Then extensive study on the effect of RHA and SCBA stabilized soil on its UCS and MDD values has been carried out in the laboratory. The following conclusions have been drawn:

1. The optimum moisture content rises as the percentage of RHA in the mix increases. The MDD of treated soil was found to be maximum as 18.64 KN/m^3 when 5% RHA is mixed in the native soil. The maximum dry density was increased initially till the addition of 5% of the RHA and then it decreased gradually. RHA initially fills in voids more efficiently and improves particle packing, generating a denser combination. However, when the RHA content increases over the desirable limit, additional voids develop, and the structure of the soil is disrupted, this results in a decreased MDD.
2. The MDD of SCBA-treated soil was found to be maximum as 18.54 KN/m^3 when 5% of SCBA has been added to the native soil. When small quantities of SCBA (i.e. 2.5–5%) is added to soil, the MDD increases then it decreases gradually. Changes in the soil structure and specific gravity of the soil combination may be the reason for this behaviour.
3. The UCS value of the native soil was found as 91.79 KN/m^2. When soil is replaced with a different combination of RHA and SCBA, the UCS of the soil initially increases up to the mix 92.5% soil and 7.5% RHA/SCBA and then decreases. The subsequent increase in UCS is attributed to the development of cementitious

compounds between calcium hydroxide in the soil and ashes, as well as pozzolana present in the ashes. A further fall in the UCS values with the addition of 7.5% ashes may be due to the excess ashes present in the soil.

4. The maximum dry density of soil mix RHA and SCBA is observed at 5% of RHA and 5% SCBA, whereas maximum UCS of soil mix RHA and SCBA was found to be at 7.5% of RHA and 7.5% SCBA. This may be attributed to the finding that 5% RHA/SCBA optimizes the physical compaction (MDD), while 7.5% RHA/SCBA enhances the chemical stabilization (UCS) through pozzolanic activity that enhances the strength of the soil mix.
5. When 7.5% RHA is added to the soil, the UCS value increases by 53.27%, while adding SCBA increases it by 37.88%. Similarly, the MDD increases by 12.42% with 5% RHA and by 11.82% with SCBA. This demonstrates that RHA is a more effective stabilizer than SCBA. The superior performance of RHA is attributed to its higher reactive silica content and finer particle size, which promote stronger pozzolanic reactions and better void filling, resulting in improved soil compaction and stability. In contrast, SCBA's lower reactivity and higher organic impurities reduce its stabilization effectiveness.
6. RHA and SCBA are proved to be cost-effective and sustainable alternatives for soil stabilization in construction and infrastructure projects. By improving soil strength and density, the load-bearing capacity of low-quality soils can be enhanced, making them suitable for various applications like foundations, roads, and embankments.

6 Limitations and Future Scope of the Study

The limitations and future scope of the study are as follows:

1. Laboratory tests may not fully replicate field conditions. Real-world factors like moisture fluctuations, temperature changes, and traffic loads need to be examined to assess the practical effectiveness of RHA and SCBA as stabilizers.
2. The study focuses on specific soil types, and the findings may not apply universally to all soils. Different soil types could interact differently with RHA and SCBA.
3. The chemical composition of RHA and SCBA can vary depending on factors such as the type of crop, burning temperature, and processing conditions. This inconsistency can affect the results of stabilization.
4. SCBA tends to have lower reactivity compared to RHA due to its lower silica content and higher levels of organic impurities.
5. The pozzolanic reaction, especially for SCBA, can be slow, leading to a delayed strength gain in the stabilized soil.
6. Future studies should standardize the production and processing methods of RHA and SCBA to minimize variability in chemical composition.

7. Further research should explore the effectiveness of RHA and SCBA on a variety of soil types (e.g. clay, silt, loam) to determine their broader applicability in soil stabilization across different geotechnical contexts.
8. The performance of RHA and SCBA could be further enhanced by blending with other stabilizers (e.g. fly ash, lime, or cement). Research could explore how mixed stabilizers impact soil strength, durability, and environmental performance.

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