Enhancement of Engineering Properties of Black Cotton Soil Using rice husk and sawdust ash

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Abstract: The weak engineering properties of black cotton soil can cause instability and failure of structures built upon it. Thus, the improvement of its properties is of utmost importance. The present research is to investigate the effect of integrating sawdust ash and rice husk ash on the engineering features of black cotton soil. The soil samples were collected from Guntur KL University, Andhra Pradesh, at a depth of 1-2 meters. Rice husk ash was added to the soil in varied percentages of 0, 3, 6, 9, 12, and 15% by weight of black cotton soil, whereas sawdust ash was added to all mixed samples at 6% by weight of soil. To analyze the engineering properties of the soil and its mixtures, laboratory tests such as Atterberg's Limits, Specific Gravity, Particle Size Distribution, Standard Proctor test, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR) were performed. Results showed that adding a combination of 9 % Rice husk and 6 % sawdust ash to the weight of black cotton soil notably improves its engineering properties. Therefore, sawdust and rice husk ash have the potential as soil stabilizing agents, making black cotton soil a more suitable foundation material for construction.

Keywords: Engineering properties, Black cotton soils, Rice husk ash (RHA), Sawdust ash (SDA), Stabilization.

1. INTRODUCTION

Soil, is naturally occurring minerals, play vital role in construction and foundation work. The suitability of soil for a specific use depends on its engineering properties and characteristics, which can varies depending on the type of soil, its origin, and other environmental factors. However, to meet the engineering specifications for a particular project, the soil may need to be improved. Black Cotton Soil (BCS): expansive soil found in several regions, including India, Australia, South-West of the United States, South Africa, and Israel [1].This soil is also found in semi-arid tropical regions where evaporation exceeds precipitation. BCS is not suitable for building houses or roads due to its construction difficulties. Black cotton soil, commonly found in tropical and subtropical regions, is one such problematic soil that presents a challenge in construction due to its high plasticity and low strength [2].

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These characteristics make it unsuitable for use in various engineering projects, as it is prone to deformations and settlements [3].This has prompted many studies to look for ways to improve the soil's subgrade by stabilizing it and enhancing its engineering properties. The failure of some buildings in the Adamawa state of Nigeria has been attributed to the shrink-swell behavior of BCS, causing differential settlement and resulting in cracks in the walls and foundation [4].

To address this issue, researchers have investigated various ways to enhance the physical properties black cotton soil, using waste materials such as fly ash, rice husk ash, sawdust ash, etc, to ensure that it can provide adequate support for the structure being built on it. [5]. These waste materials are by-products of various industrial processes and are considered environmentally hazardous if not properly disposed of. Hence, utilizing them as soil stabilizers not only helps in improving the engineering properties of problematic soils, but also contributes to sustainable waste management practices [6]. Soil stabilization is utilized in a variety of engineering applications, although it is most commonly used in road building and pavement to improve the strength and durability of soil minerals. [7]. Soil stabilizing additives often have either cement-like or pozzolanic properties, which aid in enhancing soil quality. Although lime and cement are commonly used additives, they result in high levels of carbon dioxide emissions during production, causing significant harm to the environment [8]. As an alternative, using waste and other discarded materials, as additives can be a more cost-effective and eco-friendly solution [9].

In present work, potential use of rice husk and sawdust ash as additives to improve the properties of black cotton soil was studied. Rice Husk Ash (RHA) is a type of agricultural waste produced during paddy rice milling [10]. Annually, around 108 tons of rice husk are generated worldwide. It is predicted that 200 kg of rice husk is obtained from 1000 kg of rice, generating approximately 40 kg of RHA. As in previous research, RHA is produced by burning the rice husk for 24 hours at a temperature of nearly 600ºC. [11]. In the Philippines, rice husk is the most prevalent agricultural waste. In its raw form, it has little to no practical or nutritional value. However, when it is burned, it transforms into Rice Husk Ash (RHA) and acquires valuable properties [12]. RHA is composed of a high percentage of silica ranging from 67-90%, and aluminum, which exhibits pozzolanic properties that can enhance strength [13]. In addition to having a beneficial chemical composition, RHA is more readily available and less expensive than other chemicals commonly used in engineering applications. As a result, RHA has been commonly utilized for a variety of purposes, such as adding cement to produce concrete, reclaiming mines, and stabilizing soil. It has been discovered that RHA is an effective stabilizing additive by decreasing the swelling potential of black cotton soil [14].

Sawdust ash is a substance formed when sawdust, a waste material generated in the lumber industry during the cutting of timber into standard sizes, is burned. The ash produced from this burning process contains the residuals of sawdust, providing a compact and stabilized form of the waste material [15]. This ash produced from burning sawdust can be mixed with soil to improve its stability and reduce erosion, and this not only helps to minimize environmental degradation but also has the potential to increase the productivity of the land [16]. Soil was treated with varying percentages of rice husk ash and 6% sawdust ash, and the obtained combinations were subjected to a variety of laboratory tests, including the Atterberg limits, specific gravity, standard Proctor test, CBR test, and UCS test. The outcomes of these tests were then examined to determine the best combination of rice husk ash and sawdust ash for improving the engineering properties of black cotton soil.

The findings of present work will provide crucial insights into the possibilities of using rice husk and sawdust ash as soil binders, as well as contribute to the sustainable management of these waste products. Furthermore, the improved engineering characteristics of black cotton soil because of the incorporation of these waste materials may lead to its diverse applications in construction projects, lowering the construction industry's reliance on finite resources and its environmental impact. The present research is taken with the following objective. To investigate the effect of using rice husk and sawdust ash on the engineering properties of black cotton soil.

2. MATERIALS

In the present work, Black cotton soil, Rice husk ash and Sawdust ash were used as materials, and are shown in Fig.1.

(a) Natural black cotton soil

(b) Rice husk ash

(c) Saw dust ash

Fig. 1: (a) Black cotton soil (b) Rice husk ash and (c) Sawdust ash

2.1. Black cotton soils

This study used Black Cotton Soil material, which was obtained, from Guntur K.L University, located in the state of Andhra Pradesh. The soil was obtained from a depth of 1-2 m, packed in sacks, and then transported to the laboratory. After transportation, soil was air-dried and sieved with a 4.76 mm IS sieve (British Standard Sieve no. 4) according to the code of practice BS 1377 (1990) [17]. Table 1 illustrates the properties of the Black Cotton Soil used:

Table 1: Properties of black cotton soil at Guntur K. L University

S. No	Soil Properties		Value
1	Water content (W)		15.6%
2	Sieve analysis		Gravel =25.2% Sand =73.6% Silt and clay = 1.2%
3	Soil classification		Well-graded sand (SW)
4	Specific gravity (G)		1.8
5	Free swell index		20%
6	Liquid limit (LL)		41.02%
7	Plastic limit (PL)		20%
8	Plasticity index (PI)		21.02%
9	Maximum dry density (MDD)		1.35g/cc
10	Optimum moisture content (OMC)		18.75%
11	California bearing ratio (CBR)	Unsoaked CBR	5.058%
		Soaked CBR	5.672%
12	Unconfined compressive strength (UCS)		12.27 kpa

2.2. Rice husk ash (RHA)

Rice husk Ash is acquired from the combustion of rice husk, waste material generated during the rice milling process of paddy. The RHA, which was used in this investigation, was collected from Tenali town's local rice mill, in the Guntur district. The original soil was treated with rice husk ash in various percentages (0 %, 3 %, 6 %, 9 %, 12 %, and 15 %) by weight of black cotton soil. The basic physical and chemical properties of RHA are listed in table 2.

Table 2: The Physical and Chemical properties of Rice husk ash and Sawdust ash

S. No	Rice husk ash (RHA)		Sawdust ash (SDA)	
	Index Property	Index Value	Index property	Index value
1	Water content (W)	83.3 %	Water content (W)	11.5 %
2	Specific gravity (G)	2.0	Specific gravity (G)	1.05
3	SiO_2	81.2 %	Fineness	75 µm
4	Al_2O_3	6.01 %	Silica (SiO2)	76.3 %
5	Fe_2O_3	0.08 %	Alumina (Al2O3)	5.8 %
6	CaO	0.75 %	Lime (Cao)	4.7 %
7	MgO	0.91 %	Iron oxide (Fe2O3)	2.9 %
8	SO_3	0.42 %	SO3	1.6 %
9	Na_2O	0.13 %	MgO	1.2 %
10	K_2O	2.56 %	Other oxides	2.5 %
11	P_2O_3	6.1 %	Loss in ignition	3.9 %

2.3. Sawdust ash (SDA)

Saw Dust Ash, which was utilized, was collected from timber industry in Tenali town in Andhra Pradesh State. The sawdust was burned to ash at regulated temperature of 600°C for

4 hours using an incinerator, similar to the method employed by [4]. Sawdust ash was passed through a 0.6 mm sieve and then 6% of it was added to all mix proportions of soil and Rice husk ash. The chemical components of Sawdust Ashes (SDA) vary based on the type of wood, but it primarily comprises of silica, alumina, and lime [7]**.** The chemical composition of the sawdust used primarily consists of silica, alumina, and lime, along with other oxides present in lesser amounts. Table. 2 shows the physical and chemical properties of the SDA utilized for the present work.

3. METHODOLOGY

The research followed the British standard for testing soils when conducting its experimental procedures. The Grain size distribution test, Standard proctor test, Atterberg's limits, Specific gravity, unconfined compressive strength, and California bearing ratio were performed on both original black cotton soil and a composite of black cotton soil, Rice husk ash, and Sawdust ash. Black cotton soil was stabilized by using Sawdust ash (fixed proportion of 6 %) and Rice husk ash (varying proportions of 0 %, 3 %, 6 %, 9 %, 12 %, and 15 %).

3.1. Grain size distribution determination

This test was carried out using the procedure specified in IS 2720 Part-4 (1985) [18], and soil only was used for this test. The sample was taken from a depth of 1-2m, and it was a disturbed sample. The results of the test were plotted on a graph (Fig.4) that showed the relationship between particle size and the cumulative percentage of finer particles.

3.2. The optimum percentage of SDA and RHA

To achieve the optimum percentage of SDA and RHA, the BCS was mixed with a fixed percentage of SDA (6%) and different proportions of RHA (0 %, 3 %, 6 %, 9 %, 12 %, and 15 %) by dry weight of the soil and the samples obtained were then subjected to Atterberg's limits, standard proctor, CBR, and UCS tests. The results are shown in Table 4.

3.3. Atterberg's limits determination

The consistency limit of soil is the measure of soil's attraction to water, and it is determined by Atterberg's limits tests. These tests, which included the liquid limit, plastic limit, and shrinkage limit, were carried out in accordance with ASTM D4318 (2010) [19].

3.4. Standard Proctor Test

The process of compaction involves making the soil denser by decreasing the number of air voids within its particles. The purpose of compaction is to achieve the soil's optimum moisture content and maximum dry density. When materials have a high MDD (maximum dry density) at a low moisture content, it usually indicates that they are suitable materials for use as subgrade, subbase, or base courses, as well as filling embankments. This test was carried out according to the recommendations of ASTM D698 (2012) [20].

3.5. California Bearing Ratio (CBR)

The CBR test is a special penetration test used in highway construction to determine the shear resistance of base, subbase, and sub-grade materials. It is the most commonly used method for evaluating soils for pavement construction. CBR is determined at 2.5mm and 5.0mm penetrations, and the highest value is used as recommended by ASTM D1883-16 (2016) [21]**.** The tests were carried out at optimum moisture content and samples were tested in un-soaked conditions.

3.6. Unconfined Compressive Strength (UCS)

An unconfined compressive strength (UCS; in kilonewtons per meters squared) test is used to quickly evaluate the compressive strength of soils with sufficient cohesion to allow testing in the unconfined state. The height-to-diameter ratio of the test specimens is normally 2 to 1. During the experiment cylindrical test specimen with a diameter of 35mm and a height of 70mm made from remolded samples were used. All the samples were prepared using split molds by static compaction at Optimum moisture content and Maximum dry density. The tests were conducted as per [15].

Table 3 demonstrates the prepared seven samples. In addition, Atterberg's limits, compaction, California bearing ratio (CBR), and unconfined compressive strength (UCS) tests were performed on each soil sample. Table 4 summarizes the findings of all of these tests.

Table 3: Soil sampling

Sample number	Combination
1	Soil only (100% Soil)
2	Soil + 6% SDA + 0% RHA
3	Soil + 6% SDA + 3% RHA
4	Soil + 6% SDA + 6% RHA
5	Soil + 6% SDA + 9% RHA
6	Soil + 6% SDA + 12% RHA
7	Soil + 6% SDA + 15% RHA

4. RESULTS AND DISCUSSION

4.1. Grain size distribution determination

Figure 2 shows; particle size distribution curve for sieve analysis test of the virgin soil. It was observed that over 50% of the coarse fraction is sand and the finer particles was 1.2% only. From the analysis, it was also found that the coefficient of uniformity (Cu) and coefficient of curvature (Cc) for the original soil are 6.76 and 1.21 respectively. Thus, the soil is classified as Well graded sand (SW) because it satisfies the requirements of $Cu \geq 6$ and $1 < Cc < 3$ ASTM D6913-04 (2009) [22].

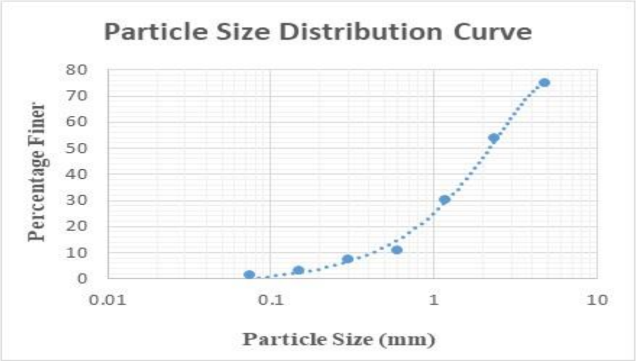

Fig. 2: Particle size distribution curve for untreated black cotton soil

The table below shows the results of all experiments. It displays the outcomes of Atterberg's limits (Liquid limit, Plastic limit, and Plasticity index), standard proctor (Maximum dry density and Optimum moisture content), CBR, and UCS tests.

Table 4: The overview of the results of all tests performed.

Sample mix	Parameter						
	LL (%)	PL (%)	PI (%)	MDD (g/cc)	OMC (%)	CBR (%)	UCS (Kpa)
Soil only	41.02	20	21.02	1.35	18.75	5.058	12.27
Soil+6%SDA+0%RHA	40	20.2	19.8	1.38	18.52	6.208	13.07
Soil+6%SDA+3%RHA	33	16.7	16.3	1.41	18.44	8.967	13.50
Soil+6%SDA+6%RHA	23	10	13	1.42	18.2	9.420	18.43
Soil+6%SDA+9%RHA	**25**	**14.8**	**10.2**	**1.56**	**17.8**	**10.346**	**24.64**
Soil+6%SDA+12%RHA	37	21.1	15.9	1.52	18.8	9.656	23.14
Soil+6%SDA+15%RHA	40	18.9	21.1	1.50	19.72	7.97	22.49

4.2 Atterberg's limit

The Atterberg's Limits are important in measuring the amount of water needed to transform the texture of soil from one form to another. Table 4 illustrates the liquid limit, plastic limit, and plasticity index values obtained before and after addition of rice husk ash and sawdust ash to black cotton soil. As shown in that table, Rice husk ash was added in varying proportions (0, 3, 6, 9, 12 and 15%) and sawdust ash was added in a fixed proportion (6%) by weight of black cotton soil. The results clearly indicated that adding 9% RHA and 6% SDA to black cotton soil resulted in the lowest plasticity index when compared to other mix proportions.

4.3. Compaction results

To evaluate the optimum moisture content (OMC) and Maximum dry density (MDD) of black cotton soil, the Standard proctor test was performed using ASTM D698 (2012) [20] protocol. Table 4 shows the variability in OMC and MDD when soil is combined with different proportions of RHA (0 %, 3 %, 6 %, 9 %, 12 %, and 15 %) and 6 % of SDA. The graph for the variations of MDD and OMC for black cotton soil treated with 6 % of SDA and different percentages of RHA is shown in Figure 3.

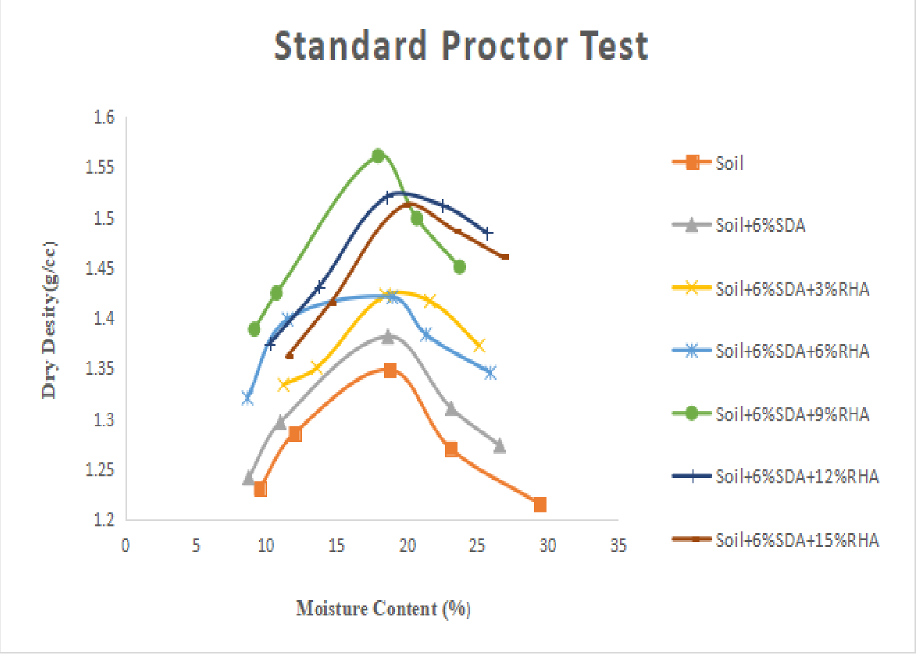

Fig. 3: MDD and OMC variations for black cotton soil treated with 6 % SDA and varying percentages of RHA

From figure 3, it is shown that the MDD of soil + 6 % SDA+ RHA mix increases from 1.35 g/cc to 1.564 g/cc as the RHA percentage increases from 0 % to 9 % respectively. It also shows that the OMC of the same mix sample decreases from 18.75 % to 17.8 % as we add more RHA from 0 to 9 %. Later the addition of more RHA from 9 % to 15 % led to the decrease of MDD from 1.564g/cc to 1.51g/cc and an increase of OMC from 17.8 % to 19.72 %.

4.4. California Bearing Ratio (CBR)

The CBR test was performed on both the original and stabilized soils to determine their carrying capacity. This test was conducted in un-soaked conditions as per the standards outlined in ASTM D1883-16 (2016) [21]. Table 4 presents the results. Figure 4 illustrates the CBR test results for black cotton soil treated with 6% SDA and varied amounts of RHA.

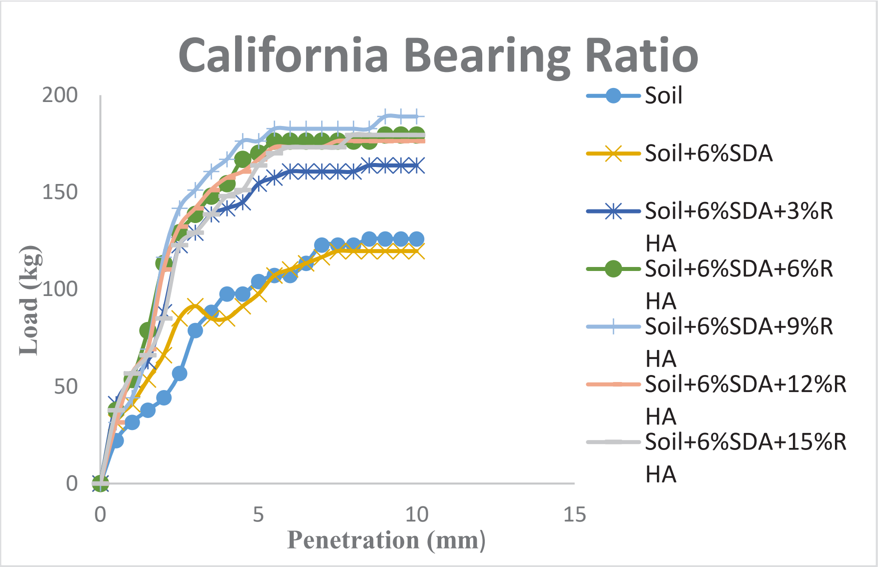

Fig. 4: CBR test results for black cotton soil treated with 6% of SDA and varying percentages of RHA

From figure 4 above, it is indicated that the addition of a fixed percentage of SDA (6%) and varying percentages of RHA (0, 3, 6, 9, 12, and 15%) to the soil had a significant impact on the California Bearing Ratio (CBR). The study revealed that the CBR of the soil increased as the percentage of RHA added to the soil increased, up to a certain level. Specifically, the CBR increased up to 9% of RHA added to the soil. However, beyond this point, the CBR started to decrease. The untreated soil had a CBR value of 5.05%, and the maximum CBR value (10.35%) was obtained when 6% SDA and 9% RHA were added to the soil, which can be considered as the optimum mixture to improve the bearing capacity of the soil.

4.5. Unconfined Compressive Strength (UCS)

Table 4 shows the results of the unconfined compressive strength test, which was performed on both natural and treated soil. As demonstrated by Figure 5, all mixes had UCS values greater than that of untreated soil.

Figure 5 indicates that adding 6% SDA and various proportions of RHA (0%, 3%, 6%, 9%, 12%, and 15%) to the soil had a significant influence on the Unconfined Compressive Strength (UCS). The study found that the UCS of the soil rose as the quantity of RHA added to the soil increased up to 9% RHA, but then began to decrease. The UCS value of untreated soil was 12.27kpa, and the highest UCS (24.64kpa) was attained when 6% SDA and 9% RHA were added to the soil, which can be considered as the optimum mixture for enhancing the soil's strength

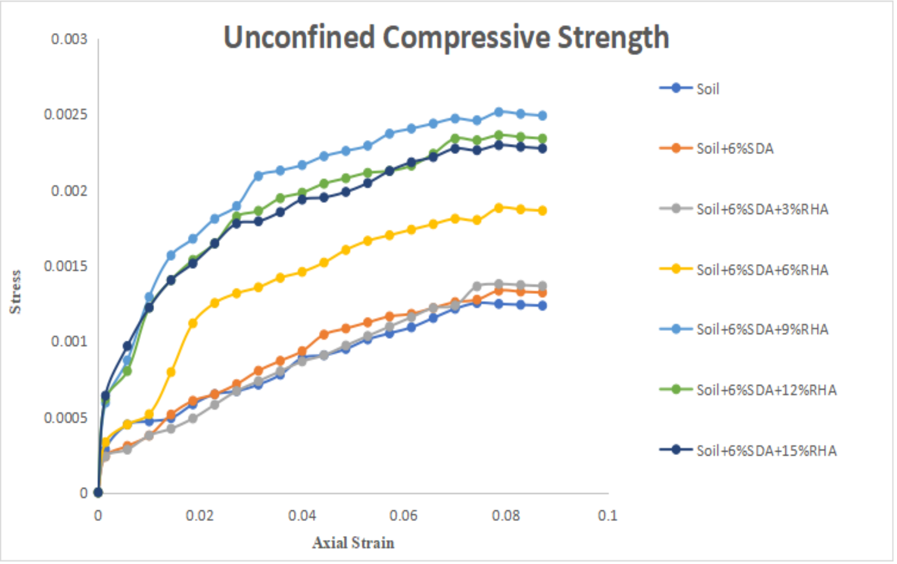

Fig. 5: Variation of UCS of black cotton soil treated with 6% of SDA and different percentages of RHA

5. CONCLUSIONS

The study performed the stabilization of black cotton soil using sawdust ash (SDA) and rice husk ash (RHA). To accomplish present work, some of the laboratory tests conducted are standard proctor test, CBR test and UCS test where these tests were carried out on both natural and treated soils. A fixed percentage of SDA (6%) and variable percentages of RHA (0%, 3%, 6%, 9%, 12%, and 15%) were added to the soil, and the following conclusions were drawn according to the results:

1. Based on the results of the compaction (standard proctor) tests, it is concluded that stabilizing black cotton soil with a fixed percentage of SDA and various proportions of RHA is effective up to a particular level of RHA. The maximum dry density (MDD) increased as the percentage of RHA increased up to 9%, which indicates an improvement in soil compaction. However, after 9% of RHA, the MDD started decreasing, indicating a reduction in the soil's strength.

2. On the other hand, when the RHA percentage increased up to 9%, the optimum moisture content (OMC) reduced, implying that the addition of RHA decreased the soil's water content necessary for maximum compaction. However, after 9% of RHA, the OMC started increasing, which indicates that the soil's workability may be affected. As a result, the best proportion of RHA for stabilizing black cotton soil using a fixed percentage (6%) of SDA is 9%, because this ratio offered maximum dry density and less optimum moisture content. Any higher percentages of RHA beyond this range may not be as effective and may even decrease the soil's strength and workability. There was an increase in the CBR and UCS values up to when 6% of SDA and 9% of RHA were added to the soil, and then they started to decrease as the percentage of RHA continued to increase. This indicates that the optimal percentages of SDA and RHA for improving the soil's bearing capacity and strength are 6% of SDA and 9% of RHA.

The addition of SDA and RHA enhanced the strength and stability of the soil, thus making it suitable for construction. The study findings are useful in determining the optimal percentage of SDA and RHA required to achieve the desired CBR and UCS values in black cotton soil. Further studies can be conducted to investigate the effect of adding other additives along with SDA and RHA on the soil's engineering properties. This study highlights the importance of using suitable additives in soil stabilization techniques to improve the soil's properties and engineering characteristics.

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