

# Strength improvement of Black Cotton Soil Stabilized with Steel Slag and Rice Husk Ash

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**Abstract**— The most difficult soil is the Black Cotton (BC) soil. Its expansive nature causes a number of issues for the foundations. This study aims to analyze numerous geotechnical characteristics of Black cotton (BC) soil - rice husk ash (RHA) mixed at varying proportions along with steel slag (SS). At various curing times, the impact of SS on compaction properties, related parameters like shear strength, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) value has been discussed. At a curing time of 28 days, it was discovered that a specimen named as 75SO10RHA15SS containing 75% BC soil, 10% RHA, and 15% SS revealed the highest UCS and CBR values.

**Keywords**—Black cotton soil, CBR, Expansive soil, Rice husk ash, Steel Slag, UCS.

## I. INTRODUCTION

Black cotton (BC) soil comes under the category of expansive soils available in many parts of the world including India. According to a report of All India Soil Survey Committee, in India BC soil covers almost 15-20% of the total land cover area. Due to the large percentages of the expansive montmorillonite mineral, BC soil is regarded as a troublesome material for foundation and pavement applications. A core octahedral sheet sandwiched between doubly tetrahedral sheets makes up the three layers of montmorillonite. According to Kumar et al., [1] BC soils lack in elemental nitrogen but are rich in minerals like magnesium and potash. These soils expand when they're moist and develop significant fissures when it's dry. These cracks occasionally have a severe limit, such as 1 1/2" broad and 12" deep. Foundations and structures built on this soil may sustain serious damage due to the change in climatic conditions. Due to all these limitations, BC soil has posed serious problems for engineers all over the world and various researches have been carried out in several parts of the world on soil stabilization. Any biological or physical or chemical, or combination of two or more processes of the above in such a way that alters the properties of natural soil to serve an engineering purpose is referred to as Soil Stabilisation. Various Soil stabilization techniques are being used like lime, cement, and Fly ash and RHA stabilization including many other additives.

The tough protective coverings on rice grains are known as rice husks and are removed from the grains during the milling process. All nations that produce rice have access to this waste product known as rice husk, which contains 30% - 50% organic carbon content. RHA is a waste product produced during controlled ignition of rice husk. Cellulose and lignin are destroyed during igniting rice husk leaving behind silica ash. Chhattisgarh is known to be the bowl of rice and it produces large quantities of rice and subsequently large quantities of Rice husk ash are produced. Previously, several studies have been done to utilize this waste product as additive to enhance the characteristics of several types of soil. Kishor et al., [2] performed a study on expansive soil using RHA and concluded that the subgrade soil strength increased up to a certain point, with an increase in the content of RHA and then declined. Along with rising RHA contents and curing time, it was also noted that the expansion parameters like Expansion Ratio (ER) and Free Swell Index (FSI) were declining. Kartai et al., [3] concluded that with a combination of RHA and lime, expansive clayey soil's CBR values were enhanced by 800%, its plasticity was reduced by about 90%, and its free swell was reduced by about 70%. According to this study's arguments, RHA successfully stabilizes expansive clayey soil. Basha et al., [4] carried out a study on residual soils and concluded that RHA may be able to stabilise the leftover soil, either by itself or in combination with cement. Hossain [5] stabilized local clayey soil and concluded that Stabilized soils display improved mechanical characteristics, including strength (tensile and compressive), elasticity modulus, CBR and enhanced durability in cases of shrinkage, water sorptivity including resilience to water also. Pushpakumara and Mendis [6] experimental results showed positive improvement in index and engineering parameters, including plasticity, shear strength, and compressive strength. Because of the RHA's pozzolanic activity, engineering qualities like shear strength and compressive strength gradually improved over time. Muntohar et al., [7] findings reveal that the addition of RHA is highly efficient in enhancing valuable engineering characteristics of clayey silty soil in regards of parameters such as compressive strength, tensile strength and shear strength by further enhancing the durability and stability of aforesaid soil. Laxmi et al., [8] performed an experimental study on clayey sand soil using RHA and lime mix and concluded that the UCS and CBR values increased 2.124 and 4.292 times respectively in comparison to unstabilized soil samples. Ashango and Patra [9] conducted research study on expansive soils stabilized with lime and RHA including steel slag (SS) and concluded that strength and CBR increased by 96% and 97.5% respectively when compared with unstabilized soil and Soil-lime-RHA mix proved to be more economical.

SS is a secondary product obtained from the production of steel and pig iron in any of the four types of furnaces mainly Blast furnace operated using coal or Basic oxygen furnace operated on natural gas or Electric arc furnace operated using electricity or Ladle furnace which also works on electricity. In India growing demand of steel has led to an exponential increase in steel production in previous years and consequently huge amount of SS is produced as a secondary product. According to a report of Ministry of Steel by the Government of India, India is currently world's second largest annual producer of crude steel with steel production of 118.1 million tonnes thereby producing around 20-30% of SS as a by-product. Proper disposal of SS is a vital problem in India with steel slag being dumped in huge landfills occupying large land area and being a major pollutant to our environment. Various research

related studies have revealed fruitful results in the past on soils stabilized with SS. Shalabi et al., [10] conducted an experiment on clayey soil which revealed that as the percentage of SS in the soil increases, the soil's maximum dry density, plasticity, swell potential, and cohesion intercept falls steeply and angle of internal friction shows an increasing trend. The Hefei expansive soil was modified using steel slag composite in a study by Wu et al., [11] which reduced the expansive soil's potential to swell and increased its strength. Mozejko and Francisca [12] tested compacted loess soil that had been stabilised with secondary steel slag, and the findings indicated that the soil resistance and stiffness increased with time. Shahbazi et al., [13] stabilized a type of expansive soil with carpet waste fibres and SS and concluded that the general qualities of expanding clayey soil can be improved effectively by adding fibres and steel slag by mechanical reinforcement, as well as chemical stabilization. Wu et al., [14] conducted a study on expansive soils stabilized by steel slag powder and cement which showed that addition of cement and SS improved the UCS of mix significantly. Wu et al., [11] modified a local expansive soil with waste steel slag and concluded that the component variation in terms of varying percentages and modification by activation enhances the cementation of the slag, which results in substantial lowering of the swell potential and better strength, according to the microstructural and mineralogical examination. The results promoted more use of steel slag due to its effectiveness, particularly in expansive soil alterations. Still there is limited study on expansive soil being stabilized with both SS and RHA together.

In the present work, study has been carried out on the use of RHA and SS together to enhance the geotechnical properties of BC soil. Additionally, laboratory tests have been done to investigate the effect of SS. The parameters such as compaction qualities, California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS) of BC soil-RHA mix at varied curing time are determined.

## II. MATERIALS AND METHODS

BC soil was gathered from a recreation area in the Raipur district of Chhattisgarh. The Bhilai Steel Plant, located in Bhilai, Chhattisgarh, provided the steel slag for this project. From a local Rice mill in the Urla Industrial Area, Raipur RHA was gathered. To ascertain the particle size distribution, Atterberg's limit, compaction properties, CBR values, and UCS values of BC soil and RHA mix specimen, several experimental investigations were carried out in the laboratory.

According to Indian standard Code IS: 2720 (part 5)-1985, the particle size distribution of BC soil and RHA was determined. According to ASTM D6913M-2017, the liquid limit (L.L) of BC soil and RHA were also calculated. According to ASTM D854-2014, the specific gravity of BC soil and RHA was calculated. BC soil and RHA compaction characteristics were evaluated in the laboratory using Standard and Heavy Proctor compaction tests in accordance with American Standards namely ASTM D698-12 and ASTM D1557-12, respectively

A. Sample Preparation

To improve the characteristics of BC soil, this study involves combining various proportions of BC soil with R HA, and SS. Further, RHA and SS were mixed in (10%, 15%, 20%, 25%) and (5%, 10%, 15%) percentages respectively. The nomenclature and individual percentages of BC soil, RHA, and SS in various mix proportions on which investigations were done are shown in (Table 1). All of the samples given in (Table 1) underwent heavy Proctor tests in the laboratory to ascertain the Maximum Dry Density test (MDD) and Optimum Moisture Content Test (OMC). UCS test and CBR test were carried out on all the samples to determine the effects on strength characteristics after the addition of SS and RHA in BC soil.

Table-1 Nomenclature of specimens containing different percentages of various materials

Specimen Name	Mixing percentages of various materials		
	Black Cotton Soil (%)	Rice Husk Ash (%)	Steel Slag (%)
90SO10RHA	90	10	0
85SO10RHA5SS	85	10	5
80SO10RHA10SS	80	10	10
75SO10RHA15SS	75	10	15
85SO15RHA	85	15	0
80SO15RHA5SS	80	15	5
75SO15RHA10SS	75	15	10
70SO15RHA15SS	70	15	15
80SO20RHA	80	20	0
75SO20RHA5SS	75	20	5
70SO20RHA10SS	70	20	10
65SO20RHA15SS	65	20	15
75SO25RHA	75	25	0
70SO25RHA5SS	70	25	5
65SO25RHA10SS	65	25	10
60SO25RHA15SS	60	25	15

**B. Unconfined Compressive Strength (UCS)**

UCS is a specific kind of triaxial test that is conducted with no cell pressure. A modified Triaxial setup is used to conduct the test in the laboratory. It is one of the most crucial tests that aids in determining the gain of strength in various composites stabilized with different materials. All of the samples listed in (Table 1) that had specimen sizes of 38 mm in diameter and 76 mm in height underwent UCS tests in accordance with the standard of ASTM D2166 M-169. Tests were conducted at a constant strain rate of 1.2 mm/min after the materials had been compacted at 97% of MDD. At an exact curing time of 7 days, 14 days and 28 days, the effects of adding different amounts of Steel Slag (5%, 10%, and 15%) to the BC soil-rice husk ash specimen were also assessed.

**C. California Bearing Ratio (CBR)**

The most frequent utilized laboratory tests for designing the pavement for highways is the CBR value. CBR tests were conducted in the laboratory under both soaked and unsoaked circumstances in accordance with ASTM D1883-16. It indicates that the specimen will be first soaked in water for a few days before being dried out and left unsoaked for the remainder of the period. To calculate the CBR value, specimens were compacted at exactly 97% of their corresponding MDD. Various cure timings mainly of 7 days (3 days wet curing + 4 days soaked), 14 days (10 days wet curing + 4 days soaked), and 28 days were also used for the soaked CBR tests (24 days wet curing + 4 days soaked). A constant uniform strain rate of magnitude 1.25 mm/min was applied to record load (in KN) and penetration (in mm).

**III. RESULTS AND DISCUSSION**

The current study aims to stabilize the BC soil by utilizing waste RHA and SS. The specific gravities of BC soil, RHA, and SS are 2.70, 1.90, and 2.35, respectively. The grain size distribution curves of RHA and BC Soil are depicted in Fig. 1 and designated as SW-SM (well graded sand with silt) and CI (intermediate clayey) respectively, according to USCS classification. The liquid limit (L.L.) for BC soil was determined to be 21.20%. It was determined that neither material was plastic as both the materials were named non-plastic. The geotechnical characteristics of BC soil and RHA are summarized below in Table 2.

Table 2: Geotechnical characteristics of RHA and BC Soil

<b>Properties</b>	<b>Rice Husk Ash (RHA)</b>	<b>Black cotton Soil (BC soil)</b>
Specific Gravity (S.G.)	1.90	2.70
Sand-size particle (in %)	92	10.80
Silt-size particle (in %)	8	20.50

Clay-size particle (in %)	0	69.70
Soil Classification	SW-SM	CI
Liquid limit (L.L.) (in %)	–	21.20
Plastic limit (P.L.)	Not-plastic	Not-plastic
MDD (in $\text{kN/m}^3$ ), (under standard compaction test)	11.70	19.50
OMC (in %), (under standard compaction test)	38.11	17.20
MDD (in $\text{kN/m}^3$ ), (Under heavy compaction test)	14.60	21.41
OMC (in %), (Under heavy compaction test)	31.20	14.70

#### A. Compaction Characteristics

In Fig. 1 and 2, the standard and heavy Proctor compaction curves for both BC soil and RHA, respectively are shown. Under both levels of compaction, the MDD and OMC of BC soil and RHA are shown in Table 2. According to observations from Fig. 1 and 2, RHA has a lower dry density than BC soil because of its lower specific gravity and complex pore structure. In contrast to BC Soil, more OMC is seen in RHA. Additionally, the Heavy Proctor compaction tests were performed on specimens with varying percentages of BC soil, RHA, and SS as shown in Table 1, and the compaction curve for each ratio is shown in Fig. 3a–d. Table 3 displays the MDD and OMC curves for each specimen. Table 3 shows that as the amount of RHA in BC soil increases, MDD decreases and OMC increases. The reduced specific gravity of RHA can be attributed cause of the decrease in MDD in the BC soil-RHA mixture. Phanikumar and Nagaraju [15] showed similar results in their previous study. Further, with an increase of SS content in RHA-BC soil, the MDD increases and OMC decreases. Study conducted by Ambedkar and Shahane [16] on expansive soil stabilization with Steel slag showed similar nature of MDD and OMC parameters in study.

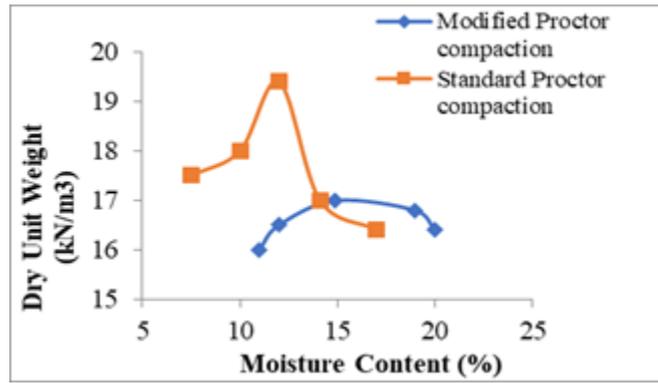


Fig 1: Heavy proctor and standard compaction Curve of BC Soil

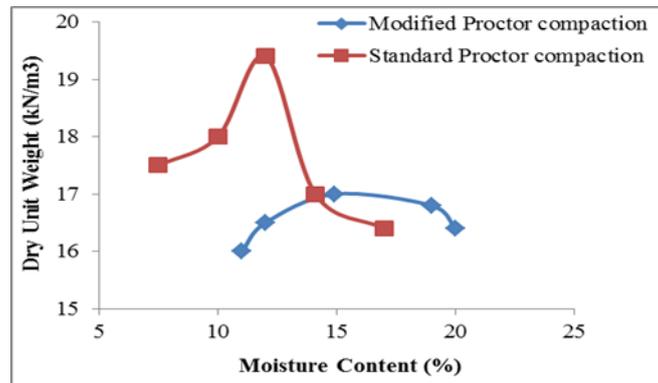
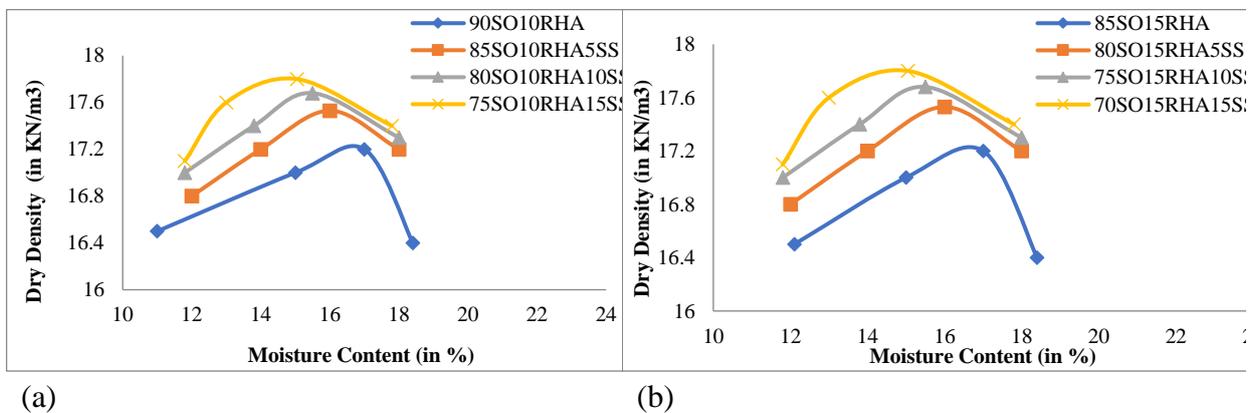
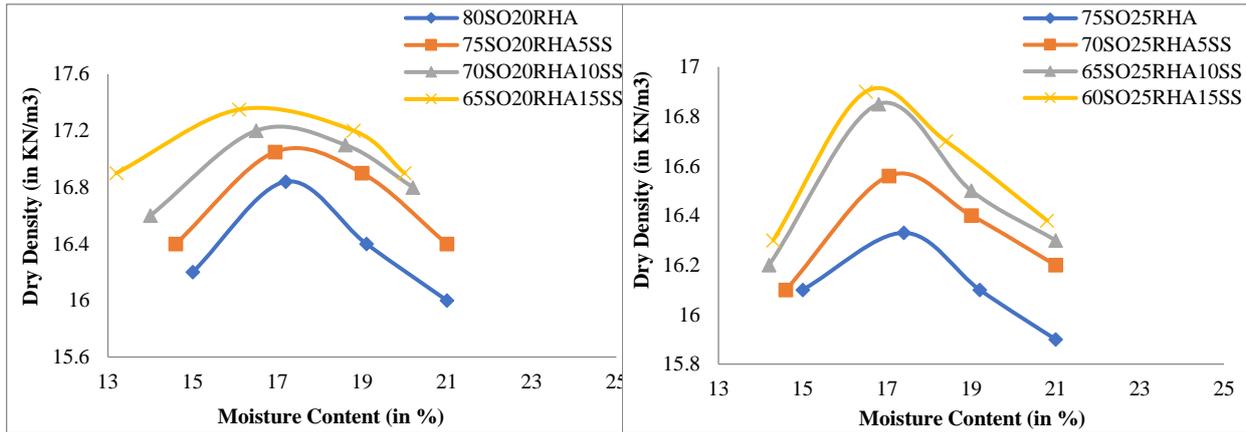


Fig 2: Heavy proctor and standard compaction Curve of RHA

B. Unconfined Compressive Strength (UCS) Test

UCS results are used to quantify the increase in strength brought on by soil stabilization. All of the mix proportions underwent UCS tests presented in Table 1. Table 4 shows the UCS value for a BC soil-RHA mix at various amounts and curing times. The UCS value was found to decrease as rice husk ash percentage in the mix proportions increased, and slightly increase as the curing period increased. Rice husk ash's lower UCS value and non-cohesiveness may be to blame for the decline in value.





(c)

(d)

Fig 3: Compaction curve of specimens containing varying percentages of BC Soil, SS, and RHA a) 10% RHA, b) 15% RHA, c) 20% RHA, d) 25% RHA

Table 3: MDD and OMC values of all specimens with varying percentages of SS and RHA

Specimen	MDD (in kN/m <sup>3</sup> )	OMC (in %)	Specimen	MDD (in kN/m <sup>3</sup> )	OMC (in %)
90SO10RHA	18.80	15.86	80SO20RHA	17.95	19.40
85SO10RHA5SS	19.16	15.61	75SO20RHA5SS	18.26	18.96
80SO10RHA10SS	20.28	15.41	70SO20RHA10SS	18.47	18.81
75SO10RHA15SS	19.46	14.98	65SO20RHA15SS	18.56	18.31
85SO15RHA	18.59	18.65	75SO25RHA	17.59	19.61
80SO15RHA5SS	18.74	18.15	70SO25RHA5SS	17.77	19.26
75SO15RHA10SS	18.87	17.81	65SO25RHA10SS	17.95	19.96
70SO15RHA15SS	18.92	19.35	60SO25RHA15SS	17.99	19.72

Also shown in Fig. 4a–d is the UCS value of SS mixed with BC soil-RHA mix during various curing times and was discovered that a noticeable increase in UCS is seen with an increase in SS content. Additionally, the UCS value of the steel slag combined BC soil-RHA specimen mix increases with longer curing times. It might be because the cementitious compound's strength increases with longer curing times. The Maximum UCS value was found to be 0.78 MPa at 7 days , 0.84 MPa at 14 days and 1.21 MPa at 28 days of curing for specimen named as 75S010RHA15SS containing 75% BC Soil, 10% RHA, and 15% SS.

C. California Bearing Ratio (CBR) Test

CBR is a parameter used in design that is applied to pavement construction and is also used in pavement layer thickness design. The CBR values of mix specimens of BC soil and RHA is shown in Table 5 for both moist and soaked conditions. The outcome indicated that both the moist and soaked CBR values rise with an increase in RHA percentage. But compared to other

BC soil-RHA mix proportions, the one with 90% BC Soil and 10% RHA seem to have a higher CBR value. Also, the effect of varying SS percentages and curing time on CBR values of BC Soil-RHA specimens are shown in Fig. 5a–d. The CBR test result states that the maximum CBR value is obtained for specimen named as 75SO10RHA10SS containing 75% BC soil, 10% RHA, and 15% SS at exactly 28 days curing time which is 69.40%.

Table 4: UCS values of different specimens of BC soil-RHA at various curing time

Specimen	Immediate	Curing time of 7 days	Cutting time of 14 days	Curing time of 28 days
100SO	0.60	0.64	0.69	0.72
90SO10RHA	0.58	0.62	0.66	0.69
85SO15RHA	0.54	0.57	0.60	0.59
80SO20RHA	0.52	0.55	0.58	0.56
75SO25RHA	0.32	0.35	0.38	0.37

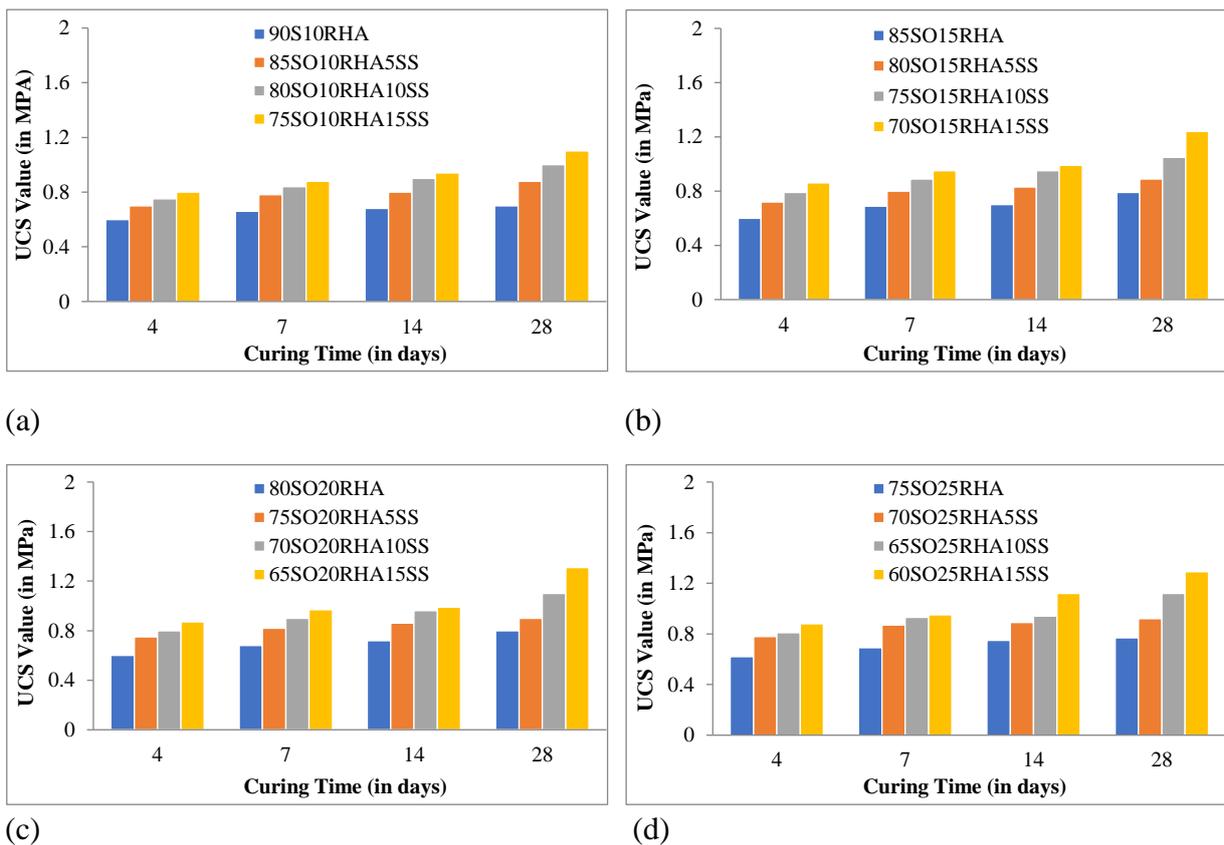


Fig 4: Consequence of SS on UCS value of RHA-BC Soil mix specimen at different Curing time a) 10% RHA, b) 15% RHA, c) 20% RHA, d) 25% RHA.

Table 5: Moist and soaked CBR of various mix specimens of BC Soil- RHA

Specimen	CBR value in moist condition (in %)	CBR value in soaked condition of 4 days curing time, in %)
100SO	35.70	5.20
100RHA	41.78	6.93
90SO10RHA	40.61	6.61
85SO15RHA	38.61	6.31
80SO20RHA	37.91	5.91
75SO25RHA	36.11	5.61

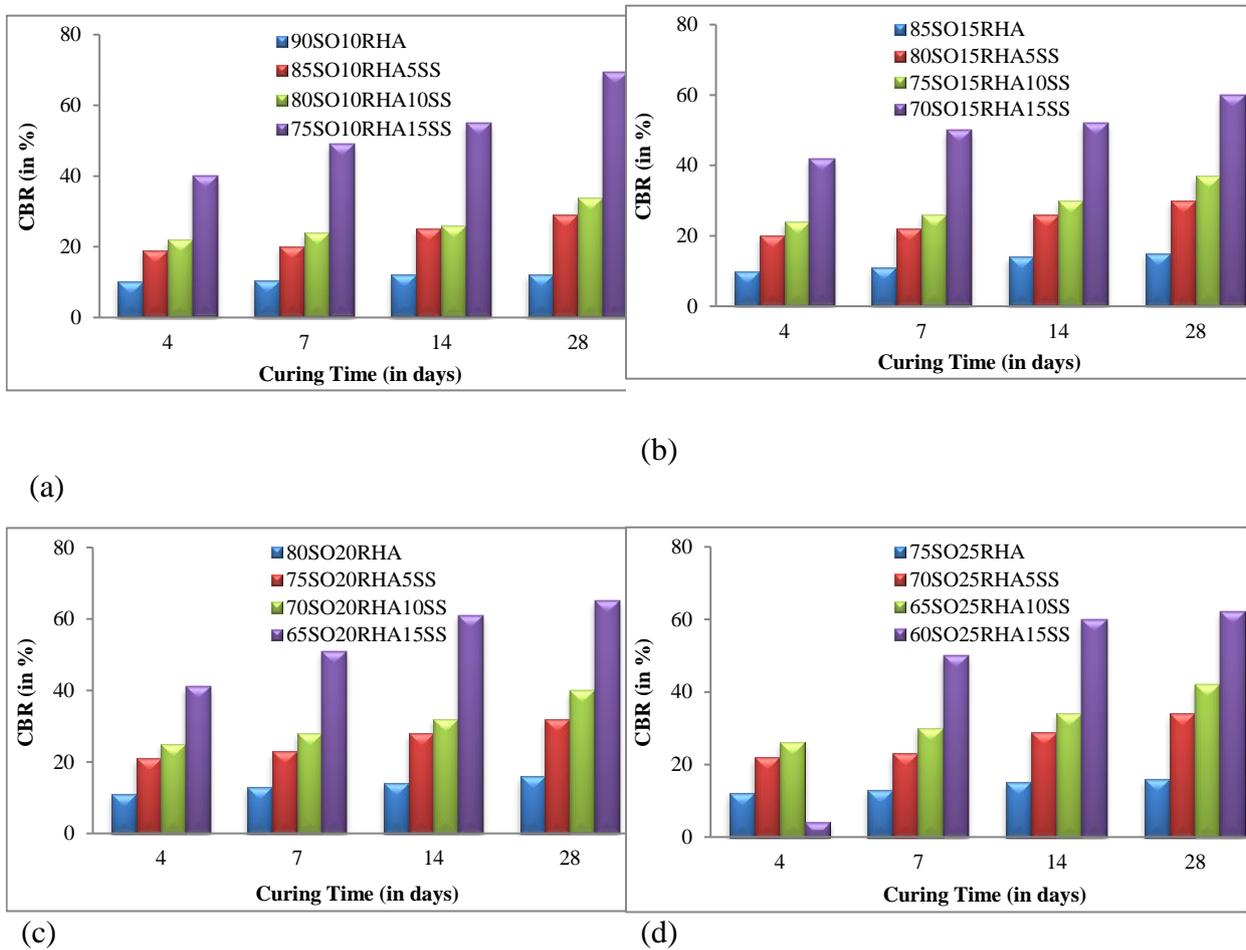


Fig 5: Consequence of SS on CBR value of BC soil- RHA mix specimen at different Curing time a) 10% RHA, b) 15% RHA, c) 20% RHA, d) 25% RHA.

#### IV. CONCLUSIONS

The conclusions and arguments that can be made based on the above experimental study are as follows:

1. With increase in percentages of RHA in the BC soil-RHA mix specimen, the MDD falls and the OMC rises. Additionally, MDD rises but OMC falls when the percentage of SS in the BC soil-RHA mixture increases. Further with an increase in steel slag from 0 to 5% MDD first decreases and OMC also decrease, but then further addition of SS beyond 5% leads to rise in MDD but OMC continues to fall in the BC soil-RHA mix.
2. An increase in the percentage of RHA in the BC soil-RHA mix specimen leads to a drop in UCS values. With an Increase in SS percentage and curing time, SS-RHA mix proportions are associated with improvements in UCS value. A specimen named as 75SO10RHA15SS containing 75% BC soil, 10% RHA, and 15% , the maximum UCS value is 0.78 MPa at 7 days, 0.84 MPa at 14 days and 1.21 MPa at 28 days of curing.
3. In one and the other of wet and soaked conditions, the CBR value increases as the percentages of RHA in the BC soil-RHA mix specimen are increased. However, a BC soil-RHA mix Specimen made up of 90% BC Soil and 10% RHA exhibits the highest CBR value. The CBR value significantly improves with further addition of more SS and a longer curing period. The mix proportions comprising 75% Black cotton soil, 10% rice husk ash, and 15% steel slag at a 28-day curing time yield the highest CBR value of 69.40%.

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