Stabilization of Black Cotton Soil with Copper Slag and Rice Husk Ash – An Environmental Approach

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Abstract: ***Stabilization of Black Cotton (BC) soils have been in recently attracted many researchers. The stabilization of Black Cotton Soils by Copper slag (CS) and Rice husk ash (RHA) were tried in the past separately. The authors tried to use both of them together in stabilization of BC soils. Present study was undertaken to evaluate the effectiveness of different percentages of rice husk ash and copper slag as soil stabilizers. The tests performed on the mixed proportion of BC soils, Copper Slag and Rice Husk Ash are Vane shear, California Bearing Ratio (CBR), Atterberg limits, free swell index (FSI), and compaction tests. Limited studies have been reported for the combination of copper slag and rice husk ash in soil stabilization. The optimum mix was found to be in the proportion of 64%BC+30%CS+6%RHA. FSI of soil treated with RHA+CS decreased steeply from 100% to 20.4%. There was a slight change in maximum dry density of the treated soil. The unsoaked CBR test shows that strength of optimum mix was 12.7%. The stabilized soil mixtures have shown satisfactory strength characteristics and can be used for low-cost constructions to build houses and road infrastructure.Laboratory vane shear tests have been carried out under undrained conditions to study the shear strength parameters of the stabilized soil.***

Keywords: Black Cotton soil,Rice husk ash, Copper slag, Free swell index, California bearing ratio

1. Introduction

Foundations in civil engineering are land-based structures requires a strong base provided by soil or rocks. Weak soil including soft clays, expansive soil, organic deposits, and loose sand are often unsuitable for construction due to their poor engineering properties [1]. Black cotton soil is one of the major deposits of India, exhibiting high swelling and shrinkage properties in the presence and absence of moisture content respectively, resulting in deformation of the road surface and reduction of soil-bearing strength [2].Montimorillonite is a clay mineral, which is mainly responsible for expansive characteristics of the soil. The kaolinite group is generally non-expansive. The mica-like group that includes illites and vermiculites, can be expansive, but generally does not pose notable problems [4]. The chief properties of a soil with which the construction engineer is concerned are volume, strength, permeability and durability.A basic decision by a Civil Engineer among the following must, be made whether to:

1) Accept the site material as it is and design to standards, sufficient to meet the restrictions imposed by its existing quality,
2) Remove the site material and replace with a superior material and
3) Alter the properties of existing soil.

The soil stabilization process enhances the physical properties of expansive soils with respect to strength, durability, or other geotechnical properties. Soils can be stabilized by mixing the correct proportion of sandy and clay soil or by mechanical compaction of natural soil, which increases the strength and cohesion [5]. This is an important factor for road construction, and other problems related to the building and maintenance of infrastructure. Blending a binder into the soil to increase its strength and stiffness through chemical reactions is referred to as chemical stabilization [7].Waste &industrial byproducts utilization in the soil stabilization for road and civil constructions has become common research idea. This idea has been generated, as the industrial waste disposal is highly concerned with transportation cost disposal site problems as per the stringent environmental rules and regulations [8]. Waste materials such as rice husk ash, blast furnace slag, fly ash, bottom ash and cement kiln are pozzolanic in nature, reduce the water absorption, and bind the clay particles [5]. The degree of effectiveness varies from one stabilizing agent to another [9]. Chemical analyses have shown that many modern industrial waste sludge is rich in main oxides such as CaO (lime), Al_2O_3 (alumina), SiO_2 and Fe_2O_3 (ferrite) [12]. Hence, we can built wealth out of waste.

2. Materials and Methods

2.1 Soil

Basaltic rocks are dark black colored rocks solidified from lava and on weathering form black cotton soils. Hence, they are very dark in colour. They develop cracks during the dry period and swell during the wet period hence [1] [6] [8]; they are self-tilling in nature, fertile and can hold water for a long time. This capacity is used for cotton cultivation. Hence, they are also called as Regur or Black Cotton Soil. The Black cotton soil is poorly graded soil. Montimorillonite is the clay mineral responsible for expansive properties of black cotton soil. The black colour in the black cotton soil is due to the presence of titanium oxide in small concentration. These are inorganic clays of medium to high compressibility. The soil sample was collected from a site in local village (korremula), Hyderabad at 1.5m depth from the ground level. About 40kg of soil was used for conducting the experiments.

2.2 Copper Slag

Copper slag is a by-product formed during the copper smelting process. Sulphuric acid recovered from the copper smelting process provides a cost-effective by-product and appreciably reduces the air pollution caused by the furnace exhaust. Copper slag was collected from Srinivasa metallizers, Cherlapalli, Hyderabad. 10 kg of copper slag was used for conducting the experiments, which is passed through 600microns IS sieve was used in mix proportions of black cotton soil in the range of 0%, 10%, 20% and 30%. It has been estimated that the production of one ton of blister copper generates 2.2 tons of slag [13] [14]. Birla Copper Industries at Dahej, Gujarat, produces roughly 0.5 million tons of copper slag per year and its captive thermal power plants produce 18,000 tons of fly ash per year [16]. In addition, by mixing it with fly ash, it becomes suitable for embankment fill material. Slag, when mixed with fly ash and lime, develops pozzolanic reactions [17]. The maximum California bearing ratio (CBR) value of 32% was observed for a mix of 80% slag and 20% fly ash when copper slag mixed with different percentages of fly ash [18].

Table 1: Chemical composition of copper slag [1]

Chemical Composition Copper slag	*Percentage of content*
Silica (SiO2)	32%
Alumina (Al2O3)	4%
Iron oxide (Fe2O3)	41%
Calcium oxide(CaO)	1.5%
Magnesium oxide(MgO)	1.35%

2.3 Rice husk ash

RHA was collected from the Lalitha rice mill industries private limited, chowdariguda, near Ghatkesar, Telangana. Rice husk ash is used in the range of 2%, 4% and 6% mix proportions.Rice mill industry generates a huge amount of rice husk during milling of paddy that comes from the fields [19]. Rice husk is used as fuel in the boilers for power generation and processing of paddy. Rice Husk Ash is about 25% by weight of rice husk when burnt in boilers. This RHA is a considerable environmental threat causing damage to the land and surrounding area on which it is discarded. During paddy milling 78% by weight is received as rice, broken rice and rice bran and 22% by weight of paddy is received as husk. Rice mills use this husk as fuel to generate steam for the parboiling processes, which contains about 75% of organic volatile matter, and the remaining by 25% of the weight of this husk is converted into ash during the firing process, which is known as Rice Husk Ash. This RHA sequentially contains around 60% to 90% Silica [20]. It is estimated that 1,000 kg of rice grain produces 200 kg of rice husk. On burning the rice husk, about 20% or 40 kg would become rice husk ash [19].

Table 2: Chemical composition of rice husk ash [5]

Chemical composition	*Percentage (%)*
Iron oxide (Fe_2O_3)	0.6
Silica (SiO_2)	91.3
Alumina (Al_2O_3)	1.4
Calcium oxide (CaO)	2.4
Magnesium oxide (MgO)	2.1
Sodium oxide (Na_2O)	0.3
Potassium oxide (K_2O)	1.9

3. Methodology

Tests viz., Atterberg limits (liquid limit and Plastic limit tests),Vane shear test, free swell index test, California bearing ratio test and compaction tests were performed as described by the standard protocols IS 2720 (Part 5)-1970, IS 2720 (Part 7)-1980, IS 2720 (Part XL) – 1977, IS 2720 (Part 16)-1987 and IS 2720 (Part 30)-1980. These tests were first conducted on untreated soil (100%) and compared with that of treated soil (with different percentages of BC+CS+RHA).

Table 3: Different proportions of mix used in each tests

Test number	*Soil (% by weight)*	*Copper slag (% by weight)*	*Rice husk ash (% by weight)*
1	100	-	-
2	88	10	2
3	76	20	4
4	64	30	6

3.1 Consistency limits

Out of 120gm sample required for conducting the experiment, 88% of soil by weight (105.6gm), 10% CS (12gm) and 2% RHA (2.4gm) was taken that is passed through 425 microns IS sieve and mixed. Distilled water is added to form a uniform paste and a portion of this mix is placed in Casagrande's liquid limit device and spread with the help of a spatula. The mix is trimmed at 1cm depth at the point of maximum thickness and blows are given at two revolutions per second until two halves of the mix come in contact with each other for a length of about 1cm. The number of blows is recorded and a portion of the mix was taken to determine water content and the same procedure is repeated for different moisture contents. Liquid limit value is obtained from the graph plotted between no. of blows and water content. The same procedure is followed for varying percentages of soil (88%, 76% and 64%), RHA (2%, 4% and 6%) and CS (10%, 20% and 30%).

Plastic limit test was conducted as described by the standard protocol IS 2720 part - 5 (1985).
Plasticity index = L.L-P.L = 0.73*(L.L-20)

3.2 Compaction test

Tests were performed as per Indian standard specifications for standard proctor test (IS 2720 part 7-1980). The sample was mixed thoroughly with soil, CS and RHA. Water content is added from 8, 10, 12 and 14% by weight of the sample. Then mix is placed in the mould and compacted in three layers and each layer was compacted using 2.6 kg rammer under a free fall of 310cm. A portion of this compacted mix is taken in a mixing tray and placed in an oven for moisture content determination. The procedure is repeated for the increment of water added and a graph is plotted between dry density and moisture content. Moisture content corresponding to maximum dry density gives the optimum moisture content of the mix.

$$\text{Dry density } \frac{\text{weight of compacted soil}}{\text{volume of mould} * (1+w)}$$

Where w = moisture content of the mix.

3.3 California bearing ratio test

CBR test is a penetration test for evaluating the strength of subgrades. The unsoaked sample is prepared and compacted as described by IS 2720 part- 16 (1987) with optimum moisture content obtained from compaction tests. The mould is placed on Cbr apparatus and load is applied on the piston so that the penetration rate is about 1.25 mm/min. The load readings at each penetration is noted and the mould is detached from the loading equipment. About 20 to 50 g of this mix from the top 3 cm layer is taken for moisture content determination.

$$Cbr = \frac{\text{test load}}{\text{standard load}} * 100$$

3.4 Vane shear test

CBR test is a penetration test for evaluating the strength of subgrades. The unsoaked sample is prepared and compacted as described by IS 2720 part- 16 (1987) with optimum moisture content obtained from compaction tests. The mould is placed on CBR apparatus and the load is applied on the piston so that the penetration rate is about 1.25 mm/min. The load readings at each penetration are noted and the mould is detached from the loading equipment. About 20 to 50 g of this mix from the top 3 cm layer is taken for moisture content determination.

3.5 Free swell index test

FSI test helps in identifying the potential of a soil to swell. Two 10gm sample mixes were taken mentioned as per in table 3. These two samples were poured into 100ml measuring jar. One jar is filled with distilled water, the other with kerosene up to 100ml. Initial volume is noted down, and sample is kept undisturbed for not less than 24 hours. Final volume of the mix is noted and the FSI is calculated using the formula

$$FSI = \frac{Vd - Vk}{Vk} * 100$$

Where
Vd = the volume of soil specimen read from the graduated cylinder containing distilled water and
Vk = the volume of soil specimen read from the graduated cylinder containing kerosene.

4. Results and Discussions

The optimum mix for the stabilized soil with CS and RHA was determined based on the maximum shear strength and CBR value, the optimum mix for soil stabilized was at 64%S + 30%CS + 6%RHA.

4.1 Liquid limit and Plastic Limit

Liquid limit is used in the classification of soil and to correlate the engineering behavior such as compressibility, permeability, compatibility and shear strength [23]. The liquid limit and plastic limit value decreases with increase in the percentage of CS+RHA. The plasticity index of the optimum mix is 28.47%, which is about 59% lower than that of clay soil. Generally, reduction in liquid limit means reduction in the compressibility and swelling characteristics, which is beneficiary for sub grade soil. These limits are also used to calculate the activity of clay, toughness index and flow index. A decrease in the plasticity index generally corresponds to an increase in the shear strength of soil. A steady decrease in the plasticity index in BC+CS+RHA combination is attributed to the fact that RHA and CS reaction forms compounds possessing cementitious properties [2]. The variation in the liquid limit, plastic limit and plasticity index values are shown in the table 4.

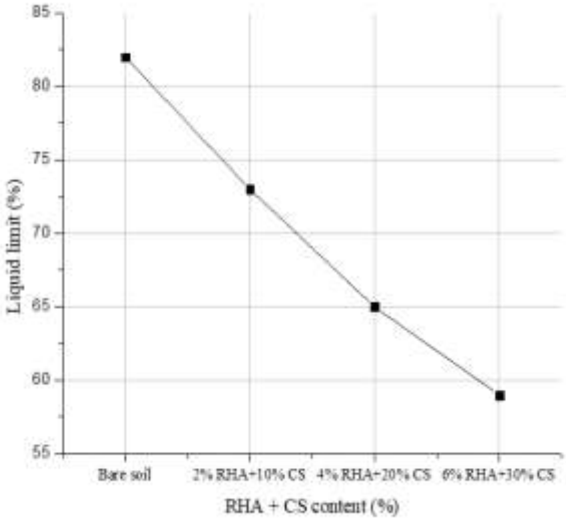

Figure 1: Variation of liquid limit of soil with rice husk ash and copper slag

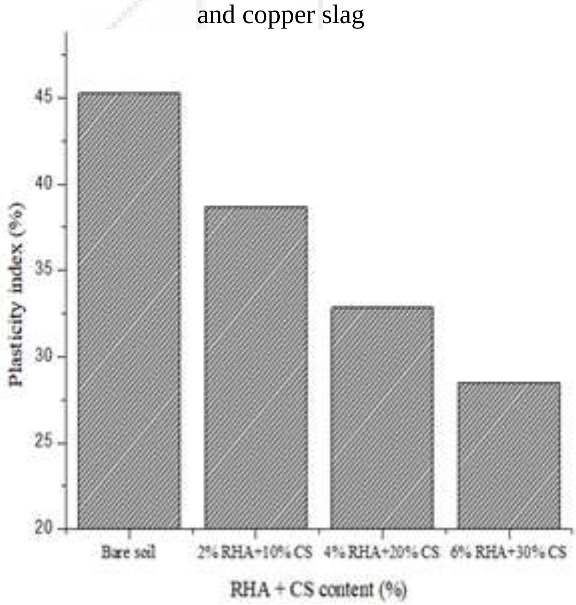

Figure 2: Variation of plasticity index of the clay soil RHA+CS content

Table 4: Variation in Atterberg limits

Description	*Liquid Limit (%)*	*Plastic Limit (%)*	*Plasticity Index (%)*
Bare soil	82	66.6	45.26
88%BC+10%CS+2%RHA	73	52	38.69
76%BC+20%CS+4%RHA	65	33.33	32.85
64%BC+30%CS+6%RHA	59	25.04	28.47

4.2 Effect of compaction test

The addition of CS and RHA content to the soil in the standard compaction tests increases the maximum dry density of the treated soil and decreases the optimum moisture content (OMC). The clay soil has maximum dry density of 1.38gm/cc and the optimum moisture content of 10%. The maximum dry density (MDD) and optimum moisture content of the optimum mix are 1.40gm/cc and 8%, respectively. The maximum dry density of the optimum mix (64%BC+20%CS+4%RHA) increased from 1.38 gm/cc to 1.45 gm/cc and the optimum moisture content decreased from 10% to 8% compared to clay soil. Voids of Coarser particles are filled by the finer particles and the unit weight increases as a result causing an increase in the maximum dry density and decrease in the optimum moisture content [13] [14]. The MDD is high at 4%RHA+20%CS and after decreases to 1.40gm/cc which is considerably more than the MDD of the clay soil. The variation of maximum dry density values are tabulated in table 5.

Table 5: Variation of maximum dry density values

Description	*Maximum dry density (gm/cc)*
Bare soil	1.38
88%BC+10%CS+2%RHA	1.42
76%BC+20%CS+4%RHA	1.45
64%BC+30%CS+6%RHA	1.40

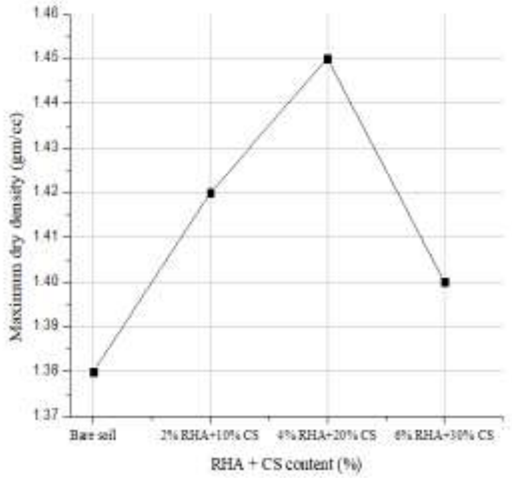

Figure 3: Variation of MDD of sub grade material with RHA+CS content

4.3 Effect of CBR test

From the compaction tests, it is evident that MDD of soil increases consistently with percentage of RHA+CS and OMC decreasing with the same, which implies that strength of such soil also, would be increasing. The unsoaked CBR value for clay soil and the optimum mix are 11.37% and 12.7% respectively. The CBR of treated soil at the optimum mix increases about 11% to that of original strength of clay soil for the zero curing period. Increase in CBR may be due to the pozzolanic and cementing properties of copper slag and rice husk ash. The graphical relationship between CBR and different mix proportions show that up to 30%CS+6%RHAthey are directly proportional to each other. Higher the CBR value, lesser would be the thickness of the pavement. The variation in CBR values are shown in table 6.

Table 6: Variation in CBR values

Description	*Unsoaked CBR values (%)*
Bare soil	11.37
88%BC+10%CS+2%RHA	11.85
76%BC+20%CS+4%RHA	12.33
64%BC+30%CS+6%RHA	12.7

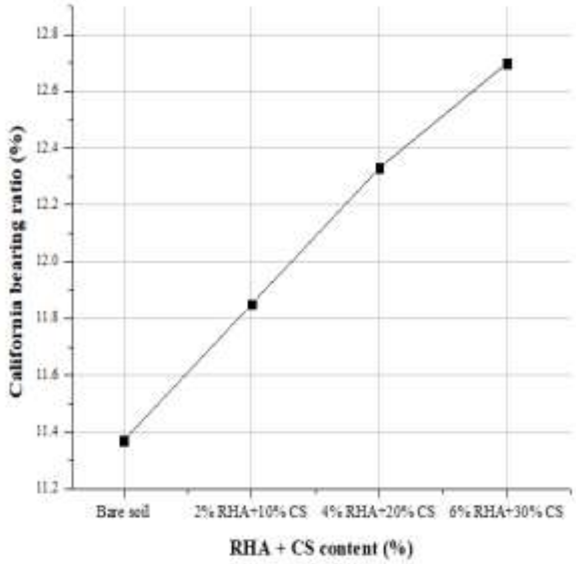

Figure 4: Variation of bearing capacity of expansive clay soil with RHA+CS content

4.4 Effect of vane shear test

Vane shear test is a quick test used to determine the undrained shear strength of cohesive soils. In soils, shear strength is contributed by cohesion and angle of internal friction. In pure clays, the shear resistance due to internal friction is negligible. Hence, the complete shear strength in clays is due to cohesion. The shear strength of 64%BC+30%CS+6%RHA was 5.33x10^{-5}kg/sq.cm, which is 74% more than the shear strength of the untreated soil. The sudden increase in the shear strength value can be seen clearly after adding 10% copper slag and 2% rice husk ash. Figure 5 represents the changes in shear strength values with the increase in RHA and copper slag content.

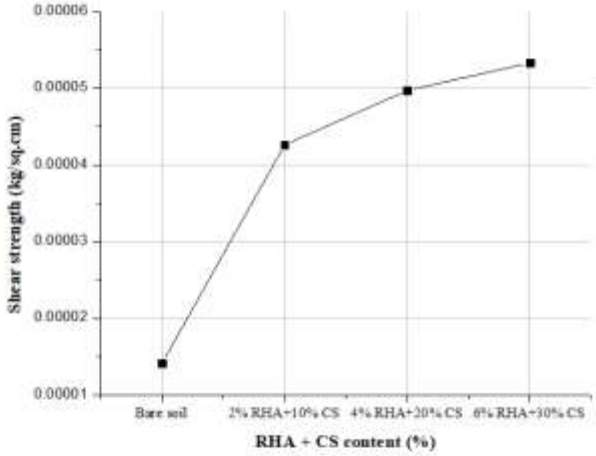

Figure 5: Variation of shear strength with RHA+CS content

Table 7: Variation of shear strength values

Description	*Shear strength (kg/sq.cm)*
Bare soil	1.41×10^{-5}
88%BC+10%CS+2%RHA	4.26×10^{-5}
76%BC+20%CS+4%RHA	4.97×10^{-5}
64%BC+30%CS+6%RHA	5.33×10^{-5}

4.5 Effect of free swell index

Free swell index of soil is used to determine the potential of a soil to swell, which in turn require additional detailed investigation, with reference to swelling and swelling pressures under various field conditions [22]. The free swell index decreases from 100% to 20.4% for 64%BC+30%CS+6%RHA.The decrease is attributed to the presence of freeCaOin RHA, which react with clay properties and addition of non-clay copper slag due to which physical forces generated between the particles decreases the swelling [23].

Table 8: Free swell index values

Description	*Free swell index (%)*
Bare soil	100
88%BC+10%CS+2%RHA	61.33
76%BC+20%CS+4%RHA	45.1
64%BC+30%CS+6%RHA	20.4

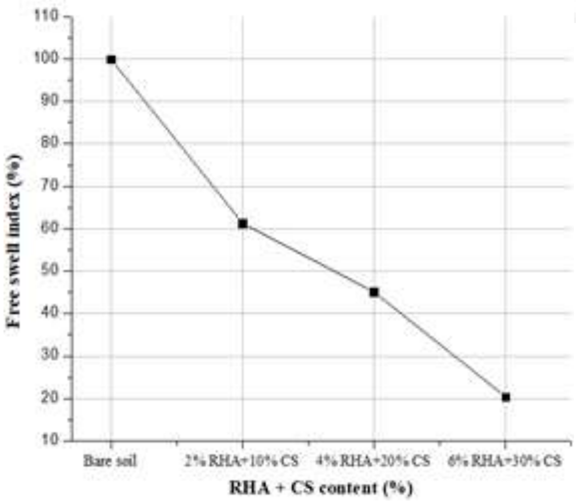

Figure 6: Variation of free swell index with RHA+CS content

Comprehensive results are tabulated in the following table

Table 9: Comprehensive test results

Type of tests	100% Soil	88% BC+10% CS +2% RHA	76%BC+ 20%CS+4 %RHA	64%BC+ 30%CS+ 6%RHA	Result
L.L. (%)	82	73	65	59	Decreases
P.L. (%)	66.6	52	33.3	25.04	Decreases
P.I. (%)	45.26	38.69	32.85	28.47	Decreases
MDD (gm/cc)	1.38	1.42	1.45	1.40	Increase up to 4%RHA
Shear strength (kg/sq.cm)	1.41×10^{-5}	4.26×10^{-5}	4.97×10^{-5}	5.33×10^{-5}	Increases
CBR (%)	11.37	11.85	12.33	12.7	Increases
FSI (%)	100	61.33	45.1	20.4	Decreases

The above table clearly shows that the Liquid limit, plastic limit and plasticity index desirably decreases up to final mix 64%BC+30%CS+ 6%RHA. The MDD increases up to the mix 76%BC+20%CS+ 4%RHA. Shear Strength and CBR strength increases up to 64%BC+30%CS+ 6%RHA.

5. Conclusions

The Black Cotton soil collected from a local village Korremula, Telangana, India, has been stabilized with copper slag and rice husk ash. Based on the results obtained from the study, the following conclusions are drawn:

1) Based on the maximum CBR and shear strength value, the percentage of the optimum mix of S, CS and RHA are 64, 30 and 6%, respectively (64%S + 30%CS + 6%RHA).
2) The plasticity of the optimum mix decreases to 59%.
3) Shear strength of the optimum mix (64%BC+30%CS+ 6%RHA) increases to 74% compared to the unstabilised black cotton soil.
4) The CBR of the optimum mix is 12.7%.
5) High value of MDD is 1.45×10^{-5} kg/sq.cm in combination of 76%BC+20%CS+4%RHA and further it tends to decrease.
6) The shear strength of optimum was 5.33×10^{-5}kg/sq.cm, which is 74% more than the shear strength of the clay soil.
7) The free swell index reduced from 100% to 20.4% by the addition of RHA and CS.
8) The soil-CS-RHA mix gives better savings cost than conventional stabilization systems. Million tons of waste materials are disposed ofevery year.
9) Use of waste materials as stabilizers gives economic and ecological solutions for stabilization of subgrade of road embankment.

The combination of Copper Slag and Rice Husk Ash is proved advantageous in stabilizing the black cotton soils and the method adopted is cost effective. In the process, we will be helping the industries to dispense with this waste generated and saving the space occupied by the waste.

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Notations

The following symbols are used in this paper:

BC = Black Cotton Soil;
CS = Copper Slag;
RHA = Rice Husk Ash;
L.L. = Liquid limit;
P.L. = Plastic limit;
P.I. = Plasticity index;
CBR = California Bearing Ratio;
MDD = Maximum Dry Density;
FSI = Free Swell Index;
OMC = Optimum Moisture Content;
BC-CS-RHA = Mix of Black Cotton Soil–Copper Slag–Rice Husk Ash;

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