STABILIZATION OF BLACK COTTON SOIL BY USING CALCIUM CARBIDE RESIDUE AND BAGASSE ASH

Abstract

The development of road alignment over expansive clayey soil is becoming challenging in India. Smectite minerals are seen in black cotton soil. it exhibits strong swelling and shrinking characteristics. The construction of pavement structures on Black Cotton Soil is becoming irksome, because of its propensity to exhibit volume change behaviour and cause uplift pressure to light structures and pavement layers. In the process of stabilising the soil, its physical characteristics are changed for long-term tensile strength. Soil is stabilizing with addition of chemical additives. Calcium Carbide Residue (CCR) & Bagasse ash are two additives which are using for stabilization of Black cotton soil.

Keywords: Smectite, Black Cotton Soil, Calcium Carbide residue, Bagasse Ash.

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I. INTRODUCTION

1. **General:** The most significant layer on the surface of the Earth is the soil. Rocks undergo weathering, which creates this layer. There are numerous different soil kinds in India as well. The main varieties of soil found in India are alluvial, black, arid, lateritic, red, and yellow soil. Around 20% of Indian land is covered with black dirt, which comes from these sorts of soil. Central states including Maharashtra, Gujarat, Madhya Pradesh, Andhra Pradesh, and sections of Tamil Nadu have black soil. The majority of the particles in this soil are clay, which helps it retain moisture. The nature of Black Cotton soil with moisture content is quite fragile. Black cotton soil changes volume and has a very expansive nature. When in touch with moisture, this soil expands and contracts in dry conditions. Cracks emerge in the natural world as a result of such swelling and shrinkage. The primary cause of structural damage is those soil surface fissures. Black Cotton soil possesses very low bearing capacity to withstand against heavy structural load. The industry that produces acetylene gas produces calcium carbide residue, or CCR. Calcium Carbide reacts with water to form Calcium Hydroxide and Acetylene gas. Calcium carbide and water undergo a reaction to create CCR. Around 500,000 tonnes of calcium carbide are used globally to produce acetylene gas, which produces 1.4 million tonnes of CCR. CCR is typically deposited in a dump yard because it is viewed as a waste product. Due to its alkaline nature, it has an impact on the amount of landfills and contributes to environmental issues there. The biodegradation of other wastes is likewise slowed down by CCR.

   The by-product of the sugarcane industry is bagasse. After the sugarcane juice is extracted, bagasse is produced. It is a dry, fibrous, pulpy substance. Additionally, bagasse has various applications.

   The purpose of this work is to investigate the combined effects of Bagasse ash and Calcium Carbide residue with Black Cotton soil. How the rising amount of CCR affects the engineering qualities of Black Cotton soil by maintaining a constant bagasse ash percentage. The Soaked and Unsoaked condition CBR test, Direct Shear test, and Unconfined compression test are three major engineering property determining tests that have an impact on pavement design. The needed pavement thickness for the relevant test values is derived from the results of the soaked CBR testing. The findings of this study can help engineers make decisions on how much soil, CCR, and bagasse ash to mix with water will effective for designing a subbase.

2. **Objectives**

   - To evaluate engineering properties of Black cotton soil before & after stabilization with CCR & Bagasse ash.
   - To design flexible pavement by utilizing various proportions of CCR and Bagasse ash.
   - To perform cost analysis for blended soil.

3. Combinations to be Used

- Virgin soil (100% BCS).
- 92% BCS + 4% Bagasse ash + 4% CCR.
- 88% BCS + 4% Bagasse ash + 8% CCR.
- 84% BCS + 4% Bagasse ash + 12% CCR.

II. MATERIALS

1. **Black Cotton Soil:** Black cotton soil required for this investigation is collected from Yavat in Pune district. This soil is primarily used for cultivation purpose. Most of the soil is in Greyish Black colour. Majorly Sugarcane, Wheat, Soyabean crops are cultivated in this Black soil. Soil used for this study is air dried by using Sunlight. From Grain size analysis test, most of the soil contains sandy particles.

Table 1: Physical Properties of Soil

Sr. No	Physical Properties	Obtained Values
1.	Colour	Greyish Black
2.	Specific Gravity	2.50
3.	Grain Size Analysis (in %) Gravel Sand Silt Clay	 6% 59% 15% 19.8%
4.	Free Swell Index	24.40%
5.	Plasticity Index	18.86%

2. **Calcium Carbide Residue:** Calcium Carbide residue is a waste by product formed during production of Acetylene gas. When Calcium Carbide stones are added in water an exothermic reaction takes place and produces acetylene gas and Calcium Carbide waste. Calcium Carbide residue is also known as Lime sludge or Carbide Lime which is primarily considered as waste product. It can be beneficially uses for soil stabilization due to presence of chemical component in it. During chemical composition test on Calcium Carbide residue, it is observed that it contains primarily high percentage of Calcium Oxide (CaO), which is a key ingredient in soil stabilization. This Calcium Oxide reacts with water and forms Calcium Hydroxide which helps in to improve engineering property of Soil. Calcium Carbide residue contains pozzolanic properties which helps in to bind the soil particles together. The hydraulic behaviour of Calcium Carbide residue helps in to set and harden the soil particles in presence of water. This property is beneficial for stabilizing soil, as it helps to create a solid matrix and improves soil strength and durability. Calcium Carbide residue also helps in to fill the voids in soil particles. Calcium Carbide residue is examined for chemical composition test and obtained test results are as follows.

Table 2 Chemical Properties of CCR

Sr. No	Chemical Composition	Observed Value (in %)
1.	CaO	87.7
2.	SiO_2	8.3
3.	Al_2O_3	1.36
4.	Fe_2O_3	0.25
5.	Na_2O	1.35

3. **Bagasse Ash:** Bagasse ash is the residual product obtained after burning sugarcane bagasse in boilers during the process of sugar production. Sugarcane bagasse is the fibrous material left over after the juice has been extracted from the sugarcane stalks. It is commonly used as a fuel source in sugar mills to generate steam and electricity for the sugar production process.

   In Maharashtra state, there are many Sugarcane Industries are available for Bagasse. Bagasse ash contains reactive silica, which, when mixed with soil, forms a cementitious gel. This gel binds the soil particles together, resulting in increased soil strength and stability. Bagasse ash can help reduce the permeability of the soil, making it less susceptible to water infiltration and erosion. The pozzolanic reactions of bagasse ash with soil minerals create stable compounds that contribute to the long-term durability of the soil structure.

III. RESEARCH METHODOLOGY

Basic Physical and Chemical Composition test on testing materials is done and tested results are mentioned earlier.

To examine engineering properties of Virgin soil as well as blended soil combination following tests are carried out.

Table 3: Laboratory Testing on Soil Specimen

Laboratory Testing	
Index properties of soil Grain Size analysis. Consistency Indices.	Engineering Property of Soil Specific Gravity test. Free Swell Index. Permeability. Compaction test. Direct Shear test. Unconfined compression test. California Bearing ratio.

IV. RESULTS AND DISCUSSIONS

1. **Grain Size Analysis:** For dry sieve analysis, 10 sunlight dried soil samples are collected and sieved using motorized sieve shaker. On the basis of results obtained during sieve analysis Black cotton soil will be classified.

Table 4: Grain Size Analysis Result

Sieve Sizes	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
6.3mm	100	100	100	100	100	100	100	100	100	100
4.75mm	78.4	92.4	87.8	88.8	81	95	91	87.8	87.2	83.45
2.36mm	55.95	73.15	67.8	70.6	57.5	80	71	70.95	68.2	61.05
1.18mm	32.65	48.25	38.4	43.9	33	51.5	43.5	44.95	43	34.8
600	19.05	31.7	19.8	24.95	18	31	25.5	24.9	25.95	19.1
300	8.65	15.65	7.65	10.9	7.8	14.5	11	9.65	10.65	8.4
150	3.95	6.95	3.65	5.3	3.8	7	5	4.3	4.4	4.4
75	2	3	1.85	2.7	1.97	3.35	2	2.1	2.1	2.3
Pan	0	0	0	0	0	0	0	0	0	0

With referring to above particle size table, Particle size distribution curve is represented in following chart.

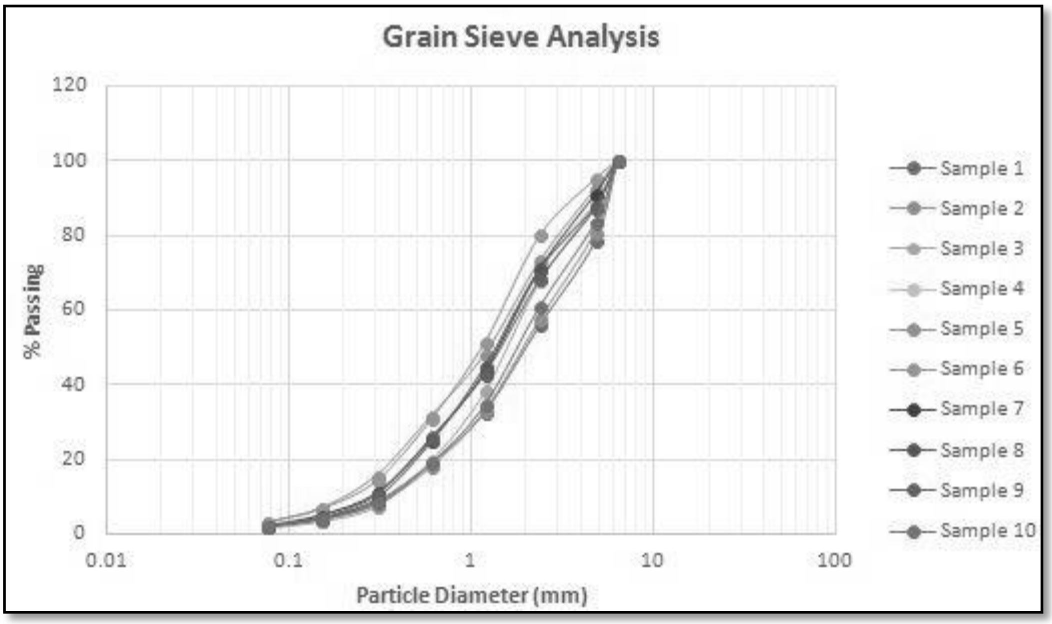

Figure 1: Grain size analysis chart

2. **Consistency Indices:** Consistency indices of virgin soil and combination of samples is determined. Plastic limit, liquid limit and shrinkage limit are derived from obtained results. These 3 limits are represented in following table.

Table 5: Consistency Indices Result

	Virgin BCS Soil	92% BCS +4% CCR+4% B.A	88% BCS +8% CCR+ 4% B.A	84% BCS +12% CCR + 4% B.A
Liquid Limit	45.84	54.47	56.336	58.11
Plastic Limit	32.91	46.93	48.67	49.91
Shrinkage Limit	18.47	19.89	21.62	23.46

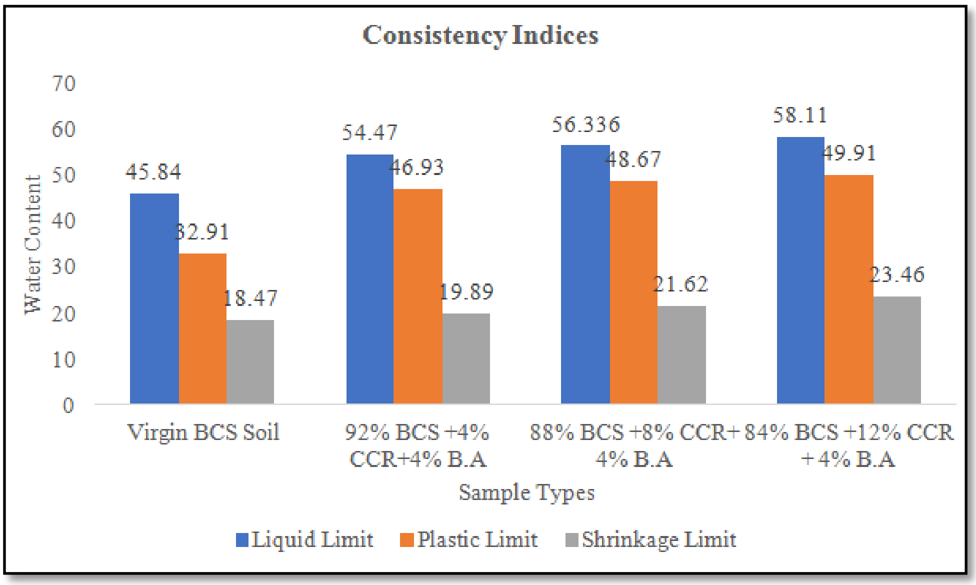

Figure 2: Consistency Indices Graph

It is clearly signifying that on addition of CCR and bagasse ash, Liquid limit value of BCS is increasing. Same trend is observed with plastic limit and shrinkage limit.

3. **Specific Gravity Test:** To examine the Density of soil and combined specimen, Specific Gravity test is carried by using Pycnometer method. The void ratio present in between soil particles can be calculated by using this density value.

Table 6: Specific Gravity value

Sr. no	Soil Specimens	Specific Gravity value
1	Virgin BCS Soil	2.5
2	92% BCS +4% CCR+4% B.A	2.25
3	88% BCS +8% CCR+ 4% B.A	2.36
4	84% BCS +12% CCR + 4% B.A	2.39

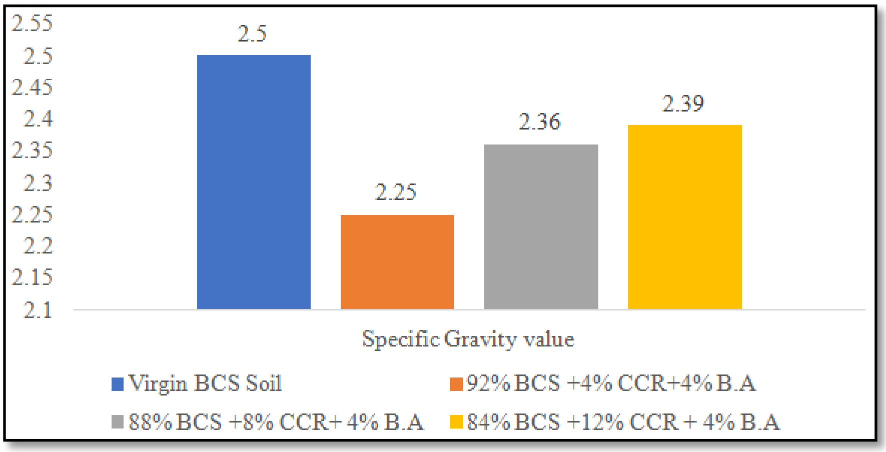

Figure 3: Specific Gravity Value

Sudden drop is observed in specific gravity of soil blended with 4%CCR and 4% Bagasse ash. With increasing percentage of CCR in soil specimen slowly increases specific gravity value.

4. **Free Swell Index:** Swelling potential of soil samples in presence of water is examined using this test. By keeping soil samples in distilled water and kerosene for 24 hrs Free swell index of soil specimens can be calculated.

Table 7: Free Swell Index Value

Sr. No	Soil Specimens	Free Swell Index
1	Virgin BCS Soil	24.4
2	92% BCS +4% CCR+4% B.A	19.6
3	88% BCS +8% CCR+ 4% B.A	18.23
4	84% BCS +12% CCR + 4% B.A	16.94

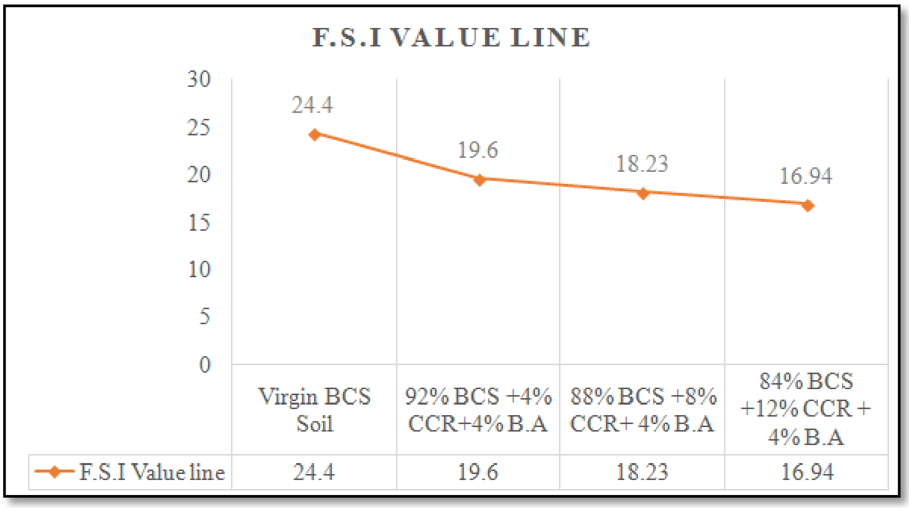

Figure 4: F.S.I Value Line

Free swell index value of virgin soil is higher than F.S.I value of other blends. The decreasing trend observed on addition of CCR and Bagasse ash will definitely help in to reduce crack formation.

5. **Permeability:** Permeability of soil specimens aids in evaluation of behaviour of soil to barrier ground water flow. This test also helps to determine the hydraulic conductivity of soil specimens. This test helps in understanding the flow of water through soil particles.

Table 8: Permeability values

Sr. No	Soil Specimens	Coefficient of permeability values (in Cm/s)
1.	Virgin BCS Soil	0.0000249
2.	92% BCS +4% CCR+4% B.A	0.0000193
3.	88% BCS +8% CCR+ 4% B.A	0.0000167
4.	84% BCS +12% CCR + 4% B.A	0.0000151

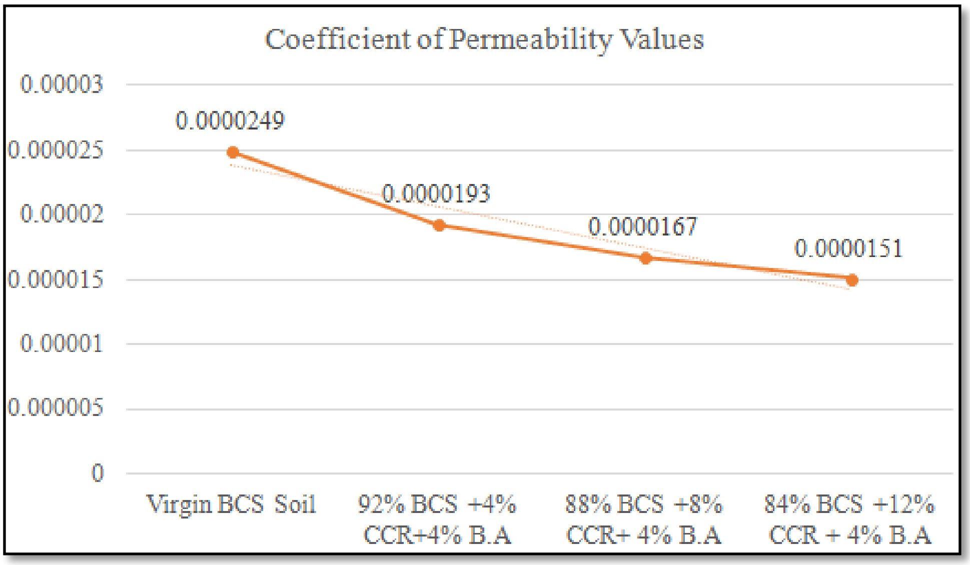

Figure 5: Coefficient of Permeability Value

From above line chart, clears addition of CCR and Bagasse ash in virgin soil is reducing the permeability of soil which will helps in to reduce uplift hydraulic pressure.

6. **Compaction Test:** For the evaluation of Virgin soil and Blended soil, next most important test performed is compaction test. This test helps to achieve maximum density of soil under standard loading condition with certain increase in water content. To understand the maximum dry density can be achievable from virgin soil and blended soil, standard proctor test was performed.

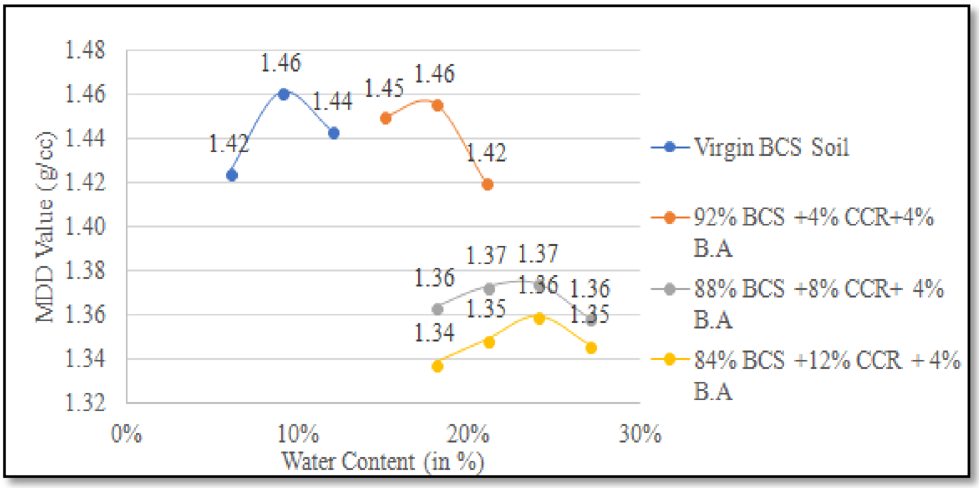

Figure 6: MDD vs OMC Curve

Table 9: Compaction Test Result

Sr. No	**Soil Specimens**	**MDD value (in gm/cc)**	**OMC value (in %)**
1.	Virgin BCS Soil	1.46	9%
2.	92% BCS +4% CCR+4% B.A	1.46	21%
3.	88% BCS +8% CCR+ 4% B.A	1.37	24%
4.	84% BCS +12% CCR + 4% B.A	1.36	24%

7. **Direct Shear Test:** This test is performed to determine shear strength parameters of soil specimens. Cohesion value and angle of friction of soil specimens is determined using this test. These values are helpful to analyse the slope stability of embankment. Test is performed in consolidated undrained condition. Test results obtained during test are as follows.

Table 10: Shear Stress Value

Normal stress (N/Cm^2)	**Shear Stress (N/Cm^2)**			
	Virgin BCS Soil	**92% BCS + 4% B.A + 4% CCR**	**88% BCS + 4% B.A + 8% CCR**	**84% BCS +4% B.A+12% CCR**
4.9	3.86	5.12	6.58	8.44
9.8	4.32	7.26	8.37	10.16
14.7	5.94	8.05	9.51	12

From above Normal Stress and shear stress values, a graph is plotted in following chart. The values plotted in graph and by using that values, trendline equations are formed. With Comparing trendline equations with Mohr- Coulomb failure theory euation, value of cohesion angle and angle of internal friction is calculated.

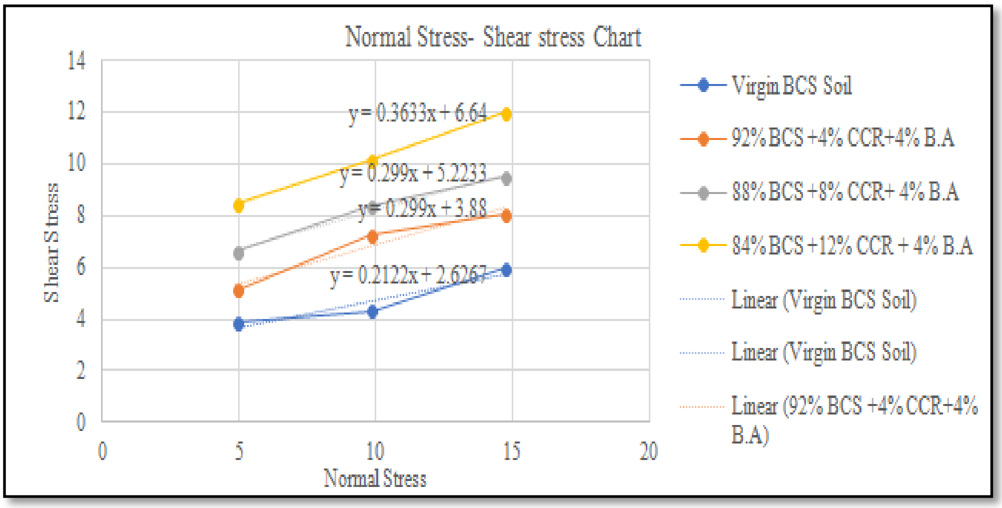

Figure 7: Normal Stress- Shear Stress Line Diagram

Table 11: Shear Stress Value

Sr. No	Soil Specimen	Cohesion (c)	Angle of Internal Friction
1.	Virgin BCS Soil	2.62	11.86
2.	92% BCS +4% CCR+4% B.A	3.88	16.17
3.	88% BCS +8% CCR+ 4% B.A	5.22	16.17
4.	84% BCS +12% CCR + 4% B.A	6.64	19.8

Above table signifies, there is increase in cohesion value observed with respect to angle of Internal friction. Cohesion value of Virgin soil was observed to be 2.62 with angle of internal friction 11.86. Later on, this cohesion value is increased with angle of Internal friction 16.17. On addition of 4% CCR and 4% Bagasse ash cohesion value resulted 3.88. For next blend, 4% increase in CCR resulted cohesion value 5.22 with same angle on internal friction i.e 16.17. For last blend 84%BCS +12% CCR + 4% Bagasse ash, cohesion value resulted 6.64 with 19.8 angle on internal friction.

8. **Unconfined Compression Test:** The primary purpose of this test is to determine the shear strength parameter of a soil specimen under a uniaxial vertical loading condition. The results obtained for unconfined compression test are as follows.

Table 12: UCS value

Sr. No	Soil Specimen	Strain	Strain in %	UCS test Value (in KPa)
1.	Virgin BCS Soil	0.0197	2	104.97
2.	92% BCS +4% CCR+4% B.A	0.0263	2.6	187.69
3.	88% BCS +8% CCR+ 4% B.A	0.0328	3.3	314.842
4.	84% BCS +12% CCR + 4% B.A	0.0394	3.9	417.906

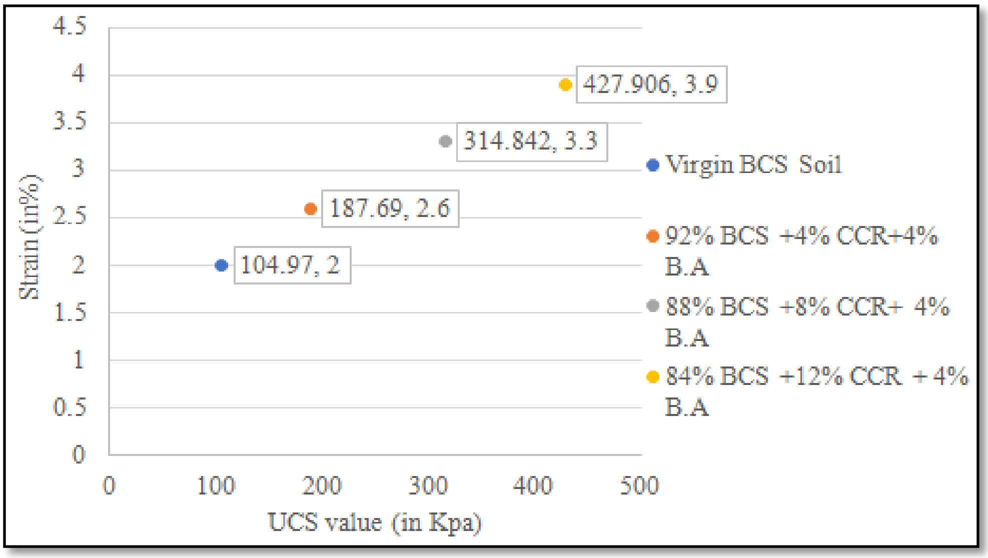

Figure 8: UCS Value

Unconfined compression strength value showing increasing trend with respective strain. For Virgin soil 2% strain is observed with UCS value 104.97Kpa. For specimen 1 obtained strain value is 2.6. Compression strength for specimen 1 in increased by 45% and resulted as 187.69Kpa. For specimen 2 and specimen 3 obtained strain values are3.3 and 3.9 with Compressive strength of 314.84 and 427.906 Kpa respectively

9. **California Bearing Ratio Test:** A California Bearing ration test is conducted on soil specimen for pavement design. This test is executed in soaked as well as unsoaked condition. For Soaked condition, Soil specimen was kept in water tank for 4 days with surcharge weight 2.5 Kg. Soil Specimens are compacted to its MDD value with its OMC in mould by using Standard Rammer. The Soaked and Unsoaked results are mentioned in following table.

Table 13 CBR Value for Soaked Condition

Sr. No	Soil Specimens	CBR value for Soaked Condition (in %)
1	Virgin BCS Soil	3.01
2.	92% BCS +4% CCR+4% B.A	4.87
3.	88% BCS +8% CCR+ 4% B.A	6.1
4.	84% BCS +12% CCR + 4% B.A	7.23

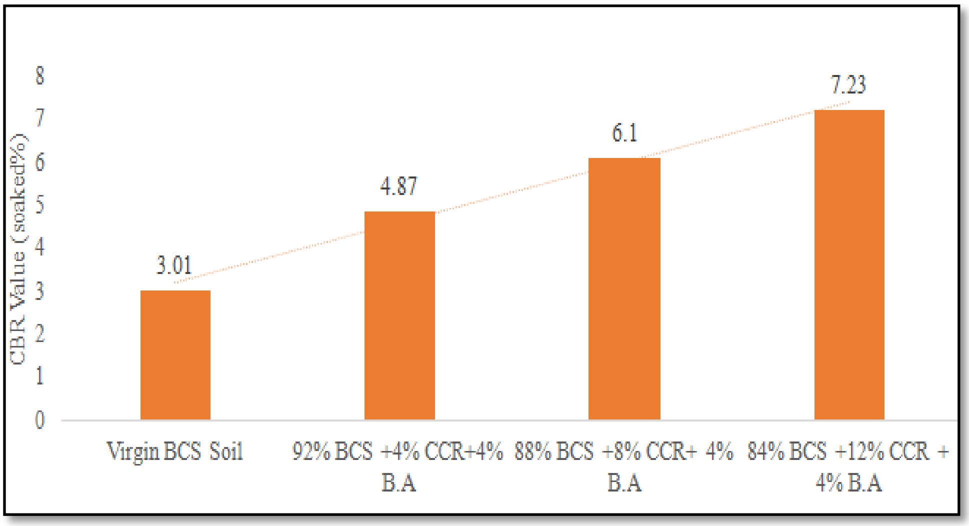

Figure 9: CBR Value for Soaked Condition

CBR value of soil specimen in soaked condition seems to be less. CBR values of soil specimens in soaked condition shown increasing trend. The values of CBR in unsoaked condition are represented in following table.

Table 14: CBR value for Unsoaked Condition

Sr. No	Soil Specimens	CBR Value for Unsoaked Condition (in %)
1.	Virgin BCS Soil	2.59
2.	92% BCS +4% CCR+4% B.A	5.67
3.	88% BCS +8% CCR+ 4% B.A	8.48
4.	84% BCS +12% CCR + 4% B.A	12.18

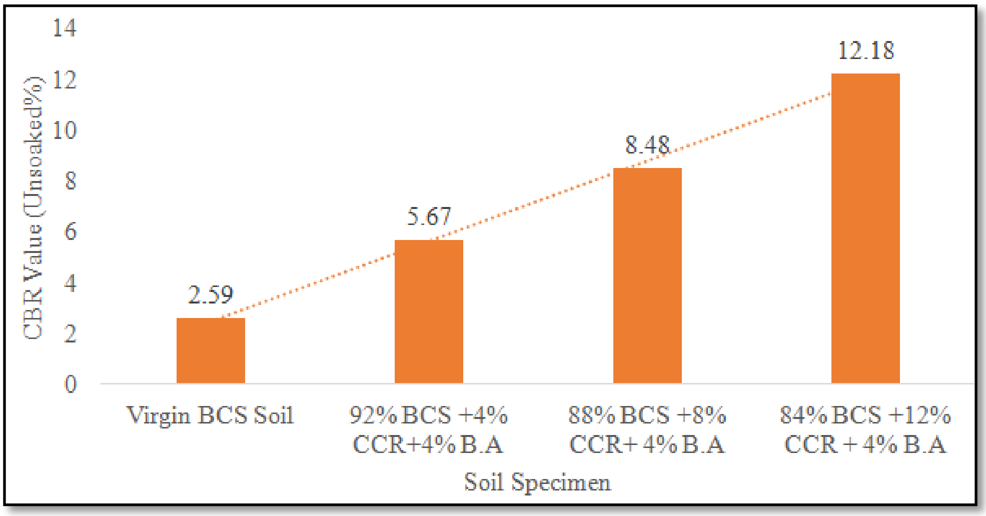

Figure 10: CBR value for Unsoaked Condition

In case of soaked CBR values for soil specimens same increasing trend is observed like unsoaked test conditions. But in soaked condition CBR value of blended specimen is hiked in good way as compared unsoaked condition.

10. Cost Analysis: Cost analysis is concluded for following data

- Road type = Four lane Dual Carriageway (National Highway).
- Initial traffic in the year of completion of Construction = 1450 CVPD (Sum of both directions).
- Traffic Growth rate = 7%
- Design life = 15 years
- Vehicle Damage Factor based on axle load survey = 4.5 Standard axle load per commercial vehicle.
- Lane Distribution factor = 0.45

By using CBR values in soaked condition for respective soil specimens, pavement structure is designed. Following cost analysis is done based on the calculated thickness for each pavement layer.

Table 15: Cost Analysis

Sr. No	Soil Specimens	CBR Value (in %)	Costing (in Rs)
1.	Virgin BCS Soil	5%	3,83,44,180
2.	92% BCS +4% CCR+4% B.A	5%	3,81,33,840
3.	88% BCS +8% CCR+ 4% B.A	6%	3,80,44,580
4.	84% BCS +12% CCR + 4% B.A	7%	3,79,26,980

V. CONCLUSIONS

1. With referring to results observed during grain sieve analysis of 10 samples. Maximum soil is resulted in fine grained fractions. Soil used for research is categorized as Clayey silt on the basis of particle size distribution table.
2. Atterberg’s limits of soil specimens showed increasing trend in liquid limit, plastic limit and shrinkage limit values. For specimen 1 sudden drop observed in plasticity index. However, for next specimens, plasticity index value is increasing gradually. Around 41% plasticity value is dropped for specimen 1. But for specimen 2 and 3 this value is increasing in the range of about 3%. Which means plasticity property is developing with increasing percentage of CCR.
3. As specific gravity of Bagasse ash is less than that of Black cotton soil, which results in decreases the specific gravity of soil specimens. On comparing specific gravity of Virgin soil and soil specimen1 it drops 10%. However specific gravity is increased with increasing percentage of CCR.
4. On Comparing F.S.I values of virgin soil and soil specimens; a decreasing trend is observed throughout the testing. Which means CCR and bagasse ash was impacting on swelling nature of virgin soil.

5. A decreasing trend was observed in values of coefficient of permeability of virgin soil and soil specimens. On performing permeability test on virgin soil and soil specimen's values of coefficient of permeability was decreased 40%.
6. Standard compaction test was performed on virgin soil as well as soil specimens to determine the maximum dry density value and OMC value. With reference to table no. 4.7, this shows that MDD value of virgin soil and specimen 1is resulted same 1.46gm/cc. But Difference was showed in OMC values. OMC value virgin soil was 9% and OMC value soil specimen 1 was increased by 2.33 times than virgin soil which comes 21%. Which clearly signifies that on addition CCR and Bagasse ash, required water content will be more to obtain maximum density.
7. From the results that obtained from direct shear test, value of cohesion and angle of internal friction values are increased with increasing percentage of CCR and Bagasse ash. Cohesion values of 3rd specimen was increased by 2.53 times than cohesion value of virgin soil.
8. Unconfined Compression test showed increasing trend in strain and shear strength values.
9. CBR values of Specimen 1, Specimen 2, Specimen3 is higher than CBR value of virgin soil in both soaked and unsoaked condition. Which is beneficial in perspective of thickness of pavement required to construct pavement structure.
10. Based on the CBR value and traffic count, the estimated cost for constructing a pavement with the addition of 12% CCR and 4% Bagasse ash with 84% virgin soil is going to be competitive in terms of economically and load bearing capacity for pavement structure.

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