A Review on Study on Effect of Various Admixtures on Geotechnical Properties of Expansive Soils

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Abstract

Objectives: Waste materials can be used as geotechnical admixtures to improve geotechnical properties of black cotton soils as well as curb environmental degradation. Methods: The aim of this paper is to provide a clear understanding of the effect of geotechnical admixtures on the properties of expansive soils through selective reference to some of the literature. Experimental observations such as maximum dry density, optimum moisture content, California bearing ratio and unconfined compressive strength are reviewed. A comparative study is based on the proposed optimum combinations of admixtures and the geotechnical properties of expansive soil. Findings: Addition of geotechnical admixtures alters the physical and compaction characteristics of cohesive soils. Through thorough comparative studies of the existing researches it can be inferred that the combinations of admixtures and expansive soil improve the CBR value, UCS and decrease swelling index of soft soils to an acceptable range and aid in achieving economic design of pavement. Applications:

• Stabilization of black cotton soil.
• Optimum use of admixtures to enhance the geotechnical properties of black cotton soil.
• Construction of pavements over black cotton soil.
• Slope stability of embankment construction over black cotton soil.

Keywords: Admixtures, Black Cotton Soil, California Bearing Ratio, Unconfined Compressive Strength

1. Introduction

Expansive soils have evidently major deposits in arid and semi-arid regions of world. Black cotton soils have substantial deposits in Deccan trap of India mainly consisting Gujarat, Madhya Pradesh, Karnataka, Andhra Pradesh and some other districts which amounts of approximately 20% land area of India. Major construction done on these weak or soft soils results in immense settlement of structures. Reason behind the excessive settlement is the presence of clay minerals namely montmorillonite, and vermiculite in the black cotton soils. Due to presence of these minerals the soil swells when in contact with water and undergoes excessive shrinkage upon subjection to dry conditions. They are generally black due to presence of TiO$_2$, humus, organic iron and aluminium compounds. To overcome the swelling nature of black cotton soils some admixtures are used. Every year there is tremendous increase in production of industrial waste and the disposal of such waste in huge quantities results in environmental degradation. In order to curb their adverse effect these materials can be used as geotechnical admixtures. The admixtures used in this current study are fly ash, coconut fiber, lime, crushed glass and stone dust. Thus utilization of the above mentioned waste products could

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be an ecofriendly alternative for soil stabilization. Figure 1 shows the distribution of Black Cotton Soil in India. Table 1, shows the properties of black cotton soil.

![Distribution of Black Cotton Soils in India.](image)

### Table 1. Properties of Black Cotton Soil

| Properties                               | Results |
|------------------------------------------|---------|
| Specific Gravity                         | 2.5     |
| IS Classification soil                   | CI      |
| Maximum Dry Density (gm/cc)              | 1.2     |
| OMC (%)                                  | 18      |
| CBR (%)                                  | 1.48    |
| Liquid Limit (%)                         | 57      |
| Plastic Limit (%)                        | 36      |
| Direct Shear Test                        | 19      |
| Swelling Pressure Test                   | 35      |
| Unconfined compressive strength (Kg/cm²) | 5.847   |

### 2. Materials Considered

#### 2.1 Coir Fiber

Fibers can be categorized in three types as natural, animal and mineral origin. Coir is a natural fiber, which is extracted from coconut. Substantially, coir as a fibrous material is found between the outer, hard coat and the inner shell of coconut. Affordability, easily availability and eco-friendly nature are the prominent virtue of using natural coir fibre.

#### 2.2 Crushed Glass

Glass is a non-crystalline and amorphous material, which is brittle and transparent in nature. Glass material is soda lime glass composed of 75% silica, Na₂O, CaO and several additives. Crushed glass has also been used as an aggregate for sub-base. Glass is totally inert and therefore non-biodegradable. Addition of glass powder to soil improves its engineering properties.

#### 2.3 Fibers

Polypropylene fibers can be used to evaluate a methodology for preventing cracks development in clay due to desiccation by the use of short polymeric fibers. The inclusion of randomly distributed fibers; discrete tensile reinforcement offers a potential solution to the problem of sloughing instability of levees.

#### 2.4 Fly Ash

Fine fraction of ash collected through Electrostatic Precipitators (ESP) located inside Chimneys. Collectively the production of fly ash is 170 million tons from different coal thermal power plants. It has high amount of alumina and silica. Table 2, shows the properties of fly ash. Table 3, shows the chemical composition of fly ash.

### Table 2. Properties of Fly Ash

| Properties                               | Results |
|------------------------------------------|---------|
| Specific Gravity                         | 2.0     |
| Maximum Dry Density(g/cc)                | 1.4     |
| OMC (%)                                  | 20.0    |
| CBR (%)                                  | 3.48    |

### Table 3. Chemical Composition of Fly Ash

| Compound | Weight (%) |
|----------|------------|
| SiO₂     | 59         |
| Al₂O₃    | 21         |
| Fe₂O₃    | 3.7        |
| CaO      | 6.9        |
| MgO      | 1.4        |
| SO₃      | 1.0        |
| K₂O      | 0.9        |
| LoI      | 4.62       |
2.5 Lime
Lime could be used in the form of hydrated lime (Ca(OH)₂) and quicklime (CaO); lime can be used either alone or in combination with other materials to explore diversity of soil types.

2.6 Moorum
The weathered rock fragments, which are gravelly and non-plastic in nature, are locally called as moorum.

2.7 RBI Grade 81
RBI Grade 81 is a synthetically fabricated soil stabilizer and pavement material. It is non-toxic, non-inflammable, grey colour, cementitious powder.

2.8 Rice Husk Ash
Bursting of rice husk in encompassing air leaves a store called rice husk ash. Rice husk is a stand out amongst the most generally accessible rural wastes in numerous rice producing nations around the globe.

2.9 Stone Dust
Pulverized stones, which can be used in construction of, walk ways and other stable surfaces. The dust is mixed with soil and used with gravel to fill spaces between irregular soil particles. Stone dust is a byproduct of stone crushing operations.

3. Expansive Soil Stabilized with Admixture
Several researchers has studied on fly ash mixed with use admixtures viz. coir fiber, lime and various waste products to determine their impact on Black Cotton Soil in its engineering properties.

3.1 Coir Fiber
In formulated the importance of local subgrade soil for road construction by the use of coconut coir fiber. They represented the study in which locally available subgrade soil i.e. clayey soil, which is stabilized with, varied amounts of coir fiber. Coir fiber is biodegradable in nature and prevents disposal problem in environment. Soil samples are prepared at their attained OMC to get MDD for California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) in the CBR mould with and without reinforcement. The amount of coir fiber is taken from 0.25% to 1% by dry weight of soil and soaked and un-soaked CBR and UCS tests is performed corresponding to each fiber content. In concluded that the unsoaked CBR value rose from 8.72% to 13.55% and soaked CBR value rose from 4.75% to 9.22% of soil reinforced with 1% coir fiber. It was also formulated that the UCS values rises from 2.75 kg/cm² to 6.33 kg/cm² upon insertion of 1% randomly distributed coconut fiber. The thickness of pavement decreases by introducing coconut coir fiber which upshots the increase of CBR of mix and curtails the cost of construction which results in economic construction of highway.

In determined the applications of coconut coir and fly ash in subgrade strengthening. A series of California Bearing Ratio and Unconfined Compressive Tests were performed with the different amounts of fly ash i.e., 0% to 20% at any increment order of 5% and with varying percentages of coir fibers i.e., 0% to 1% at an increment order of 0.25%. The tests mentioned above on black cotton soils showed that on inclusion of fly ash (20%) with Black Cotton Soil the CBR value gets significantly improved by 83%. With the inclusion of combination coconut coir fiber (1%) and fly ash (20%) the CBR value gets improved by 285%. On inclusion of 20% of fly ash with Black Cotton Soil the UCS value improves by 66%. With the inclusion of 1% coconut coir fiber and 20% of fly ash the UCS value gets improved by 120%. Figure 2 shows CBR values at varied combinations of fly ash and coir fiber.

Figure 2. CBR Values at Varied Combinations of Fly Ash and Coir Fibers.
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3.2 Crushed Glass

In experimental study on stabilization of Black Cotton Soil by fly ash, coconut coir fiber and crushed glass. They focused their attention on the impact of coconut fiber, fly ash, and crushed glass with different percentages on index properties and engineering properties of Black Cotton Soil such as limits, compaction, swelling pressure, California Bearing Ratio, direct shear test, permeability, utilization of superfluous products as an alternative to conventional materials like cement, etc., various combinations of materials used and how to improve the economy. To attain this objective 48 trial samples were prepared and experimental tests were conducted mainly in two phases i.e. in first phase of research, the physical properties of soil were analyzed such as limits, specific gravity, grain size distribution, moisture content, permeability test, CBR, MDD-OMC, swelling pressure, Direct Shear Test Values. In second phase of research, with varying additions of fly ash (FA) from 10% to 25% at an increment order of 5%, Coconut Coir Fiber (CCF) from 0.25% to 1% at an increment order of 0.25% and Crushed Glass (CG) at odd percentages till 7% in Black Cotton Soil and their unique combinations with Black Cotton Soil numerous investigations were conducted. Figure 4 shows the variation of CBR % with combinations.

3.3 Fibers

In underwent an experimental study on stabilization of Black Cotton Soil with stone dust and fibers. Unsystematically distributed fibers render the limited potential plane of weakness that generates in parallel to aligned reinforcement and strength isotropy. Several tests such as compaction, unconfined compressive strength, and California Bearing Ratio tests were executed on Black Cotton Soil with modifications in amounts of fibers and stone dust. It was found that with increase in percentage of stone dust the dry density increases significantly. The increase of the MDD is from 1.465, 1.475, 1.482, 1.531, 1.537, and 1.536 to the stone dust of 0%, 1%, 2%, 3%, 4%, and 5%, respectively. The CBR and UCS optimum value was also found to be 2.91 and 9.36 at 3% of stone dust respectively. There is increase of CBR value upto 0.9% of fibers. And the combination of 3% stone dust and 0.6% fibers with Black Cotton Soil yielded max value of CBR i.e. 4.16, which is 2.25 times the soil alone.

In experimental study on stabilization of Black Cotton Soil using High-Density Polyethylene (HDPE) waste fibers, stone dust and lime. They introduced the varying percentages of HDPE fibers (0.5%, 1%, 1.5%), stone dust (5%, 10%, 15%) and lime (3%, 6%, 9%) and tests were performed such as compaction, California Bearing Ratio, Unconfined Compressive Strength, Atterberg’s limits, Free Swell Index, Direct Shear Test, and Permeability. It was observed that liquid limit reduces from 55 to 46 and plastic limit reduces from 32 to 29. OMC remains the same and MDD decreases from 1.71 to 1.58 gm/cc. It was also observed that California bearing ratio in un-soaked and soaked conditions rises 3 to 5.99 and 1.53 to 12 respectively. And unconfined compressive strength value rises 1.41 to 5.82 kg/cm².

3.4 Fly Ash

In studied soil stabilization by using fly ash. They premeditated the action of fly ash in stabilization of soft fine-grained expansive soils, attained from thermo genesis of sub-bituminous coal at electric power plants. Fly Ash has low cementitious value but when in direct contact with moisture, retaliates chemically which outcomes in creation of cementitious products and development of compressibility and strength char-
acteristics of soils. Unconfined compressive strength, California Bearing Ratio, compaction, Specific gravity, Atterberg’s limits tests were conducted upon soil reinforced with fly ash produced at optimum moisture content of 9% and unreinforced soils. In found that red soil when used with 6% of fly ash, there was an increment in bearing capacity of 25 kg/mm² compared to unreinforced red soil. CBR value of reinforced soil improves by 35%. Thus the pavement thickness corresponding to the mentioned CBR value is 8.5 inches i.e., 215.9 mm.

In studied stabilization of Black Cotton Soil by fly ash. Fly ash is introduced in Black Cotton Soil in various proportions i.e. at 0, 10, 20, 30, 40 and 50. CBR and compaction tests were performed and it was observed that the dry density and un-soaked CBR values were higher with fly ash (20%) than other mixes of different percentages of fly ash. They also concluded that the comparatively low density of fly ash makes it suitable to be placed over soft soils or soils having less bearing strength. Its insensitiveness to variation in moisture content, competent frictional properties, simplicity of compaction, freely draining nature, low specific gravity, etc. enables us to use it in various constructions of such as embankments, roads, fill behind retaining structures, etc. Figure 5 shows the relationship between CBR values and soil-fly ash mix. Figure 6 shows the dry density - water content relationship for soil fly ash mixes.

3.5 Lime

In studied the soil stabilization using lime. They utilized hydrated lime for stabilization of Black Cotton Soil where they concluded that hydrated lime reduces the water holding capacity of soil and increases its stability. When the lime and water is inn adequate quantities the pH scale increases in order of 10.5 and breaking the clay particles. Thus this leads to the formation of calcium-aluminate-hydrates (CAH) and calcium-silicate-hydrates (CSH). Portland cement contains these cementitious products i.e. CSA and CAH and matrix formation takes place that imparts strength to the lime-stabilized soil layers. CBR and compaction tests were performed to decide the most favorable concentration of the quicklime. At 6% CaO, it was observed that the CBR value increased 4 to 10 times than that of untreated soil.

In studied the effect of lime and stone dust in the geotechnical properties of black cotton soil. Initially an optimum value of lime was determined by Standard Proctor’s Test and stone dust was added 25% by weight with the increment of 5% and morphology of soil along with the admixture was studied under the Scanning Electron Microscope (SEM), while the mineralogical composition was studied by X-Ray Diffraction (XRD). It was perceived that the maximum dry density of soil stabilized with lime (9%) increases up to the addition of stone dust 20% and further increases of the content of stone dust results a decreases in MDD. The results from SEM pictures as shown in mentioned paper that coarser bonded particles of stone dust, lime and Black Cotton Soil whereas from XRD test, it is clear that there is great presence of montmorillonite, vermiculite and whewellite and quartz in stone dust. Figure 7 shows Scanning electron micrographs of (a) Black Cotton Soil (b) Lime (c) Stone Dust (d) Black Cotton Soil + 9 % Lime (e) Black Cotton Soil + 9 % Lime + 25% Stone Dust. Figure 8 shows the variation of MDD with percentage of lime.

Figure 5. Relationship between CBR Values and Soil Fly Ash Mix.

Figure 6. Water Content Density Relationship for Soil Fly Ash Mixes.
Figure 7. Scanning Electron Micrographs of (a) BLACK COTTON SOIL, (b) Lime, (c) Stone Dust, (d) Black Cotton Soil + Lime (9%) and (e) Black Cotton Soil + Lime (9%) + Stone Dust (25%)\textsuperscript{18}.
3.6 Moorum

In studied the improvement in properties of subgrade soil by using moorum and RBI Grade 81. With an increase of cost, RBI grade 81 proved to be an economical method where as moorum are weathered rock fragments which are gravely and non-plastic in nature. The standard proctor’s test was done on untreated soil with a value of MDD was 1.43 g/cc and OMC was 25.80% and also for various mixes of soil with RBI Grade 81 at varying proportions. The maximum value of soil to RBI Grade 81 obtained with a ratio of 96:4 with a value of MDD 1.45 g/cc and OMC 26.16% and in case of soil to moorum the maximum value of MDD 1.53 g/cc with an optimum content 24.85%. According to IRC, the pavement thickness is 2 MSA having CBR value of subgrade soil 2.56% is 660 mm and if same soil is treated with 2% RBI Grade 81, CBR value increased upto 4.89% and ultimately the total pavement thickness reduced up to 520 mm. It can be concluded that with raising the amount of moorum, the OMC of soil reduces and MDD increases. Figure 9 shows the effect of RBI Grade 81 and moorum on soaked CBR, MDD and OMC values of soil. Figure 10 shows the impact of moorum and RBI Grade 81 on CBR value of soil.

In studied the stabilization of Black Cotton Soil using Envirobase and sodium silicate with lime. This was one of the chemical methods used for stabilization of soil. Index properties, compaction and CBR were conducted on Black Cotton Soil with addition of Envirobase as 1%, 2% and 3% and proportions of lime in soil were 2%, 4%, 6% and sodium silicate taken as half lime. In Compaction test maximum reduction in optimum moisture content observed at 3% Envirobase where OMC is reduced by 12% and in CBR tests the value of CBR value increases by 250% with an addition of 3% Envirobase. With addition of sodium silicate with lime, the liquid limit decreases and when the addition of 1% Envirobase liquid limit becomes constant. Sodium silicate reduced the plasticity index. When Envirobase added to the soil, the OMC reduces and CBR value increases to great extent.

In represented the study of stabilization of Black Cotton Soil using lime. The work has been carried out with 0, 4 and 6% of lime content. Swelling index, compaction, California Bearing Ratio, plastic limit and liquid limit tests were carried out. And it was found that an addition of 4% lime decreases liquid limit by 12.1% while addition of 6% showed a decrease of 17.7%. MDD was found to decrease by 2.4% and 5.6% at 4% and 6% lime content respectively. OMC shows a reduction of 14.3% at 6% lime content. CBR value at 4% and 6% lime content shows an increment of six folds and eight folds respectively. Also it was observed that at 4% and 6% lime addition swelling pressure decreased by 40% and 80% respectively. So lime stabilization helps in increasing the strength, durability and also minimizes the moisture variations in the soil.

Figure 8. Variation of MDD with Percentage of Lime.

Figure 9. Action of RBI Grade 81 and Moorum on Soaked CBR Value, MDD and OMC of Soil.
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3.7 RBI Grade 81

In\textsuperscript{22} researched on comparative study of Black Cotton Soil stabilization with RBI Grade 81 and sodium silicate. Atterberg’s limit, compaction, CBR test, UCS tests were conducted on the samples of soil with different amounts of RBI Grade 81 i.e., 2\% to 6\% and sodium silicate of varying percentage 3\% to 6\%. three specimens were prepared with different percentages of RBI Grade 81 and Sodium silicate. As amount of RBI Grade 81 increases the liquid and plastic limit decreases on the other hand the amount of sodium silicate increases the liquid and plastic limit. Swelling potential of Black Cotton Soil decreases by 83\% with RBI Grade 81 and with a percentage of 6\% sodium silicate the swelling index increases up to 166\%. While using both stabilizers the UCS value increases if the soil is treated with RBI Grade 81 its strength in day-by-day increases and in case of sodium silicate decreases. Also, CBR value decreases as the amount of sodium silicate increases.

3.8 Rice Husk Ash

In\textsuperscript{22} introduced the effect of lime and rice husk ash on engineering properties of black cotton soil. They varied the concentration of RHA from 0\% to 20\% and added lime up to 5\% in the mix. Tests conducted mainly compaction test, CBR, UCS and differential swell index. As content of RHA is increased, the MDD reduces from 1.68 g/cc to 1.51 g/cc. OMC increased from 18.5 \% to 20\% and CBR also increased from 1.94 \% to 7.52\%. Similarly unconfined compressive strength increased from 1.10 Kg/ cm\(^2\) to 1.43 kg/cm\(^2\) and differential swelling index decreases from 54.30 \% to 7.10\% (Soil + 5\% lime + 20\% RHA).

In\textsuperscript{24} studied the stabilization of soil with fly ash and rice husk ash. He introduced the fly ash and rice husk ash in the soil with different proportions varying from 0 to 25\% and 0 to 12\% respectively and California bearing ratio, unconfined compressive strength and swelling tests were conducted. It was observed that Unconfined Compressive Strength improves by 97\% when Rice Husk Ash amount rises from 0 to 12\%. It was also observed that California bearing ratio is increased by 47\% when the Rice Husk Ash amount rises from 0 to 12\%. It was also found that the swelling potential of the soil reduces with developing of high swell reduction layer thickness ratio. The most favorable rice husk ash amount was observed at 12\% for both CBR and UCS.

In\textsuperscript{25} conducted an experimental study on Black Cotton Soil stabilized with rice husk ash, fly ash and lime. They carried out laboratory tests on virgin soil and stabilized soil such as particle size distribution, compaction test (standard proctor test), California Bearing Ratio, Atterberg’s limits, unconfined compressive strength, direct shear test, selling pressure, permeability etc. at different proportions of 0 to 8 \% lime, 0 to 25 \% fly ash and 0 to 20 \% rice husk ash. It was observed that plastic limit and liquid limit of Black Cotton Soil reduces with further addition of Lime. But plastic limit and liquid limit of Black Cotton Soil rises with further addition of rice husk ash and fly ash. It was also observed that CBR value rises with increase in addition of rice husk ash, lime and fly ash and their respective optimum contents are 20\%, 8\% and 20\%. Unconfined compressive strength value of Black Cotton Soil also rises with change in amount of RHA, Fly ash and lime. Swelling pressure is found to be minimum at 20\% of Rice husk ash and Permeability of Black Cotton Soil is reduced with change in addition of fly ash and Lime. Designing the road treated with the mixture of RHA (20\%), fly ash (20\%) and Lime (8\%) is found to be improved by 73\%.

3.9 Stone Dust

In\textsuperscript{24} studied the effect of stone dust on the strength characteristics of Black Cotton Soil stabilized with rice husk ash. The optimum value of Rice Husk Ash (RHA) was observed to be 10\% of total soil. The plasticity index reduced from 26.18\% to 18.24\% on varying concentrations of stone dust with optimum value of RHA. The CBR value was found to be maximum at 15\% of stone dust for both soaked and un-soaked conditions, i.e.
340% increment of CBR value in unsoaked condition and 302% increase of CBR value in soaking condition on comparison with virgin soil. Unconfined compressive strength was found to be improved by about 103% of the untreated soil after adding 15% stone dust. It was also observed that any increment in stone dust concentrations resulted in decrease in UCS values. Figure 11 shows variation of CBR values for RHA stabilized Black Cotton Soil with varying percentages of stone dust. Figure 12 shows the variation of UCS curves with varied ratio of Rice Husk Ash (RHA).

In [26] studied the effect of stone dust on some geotechnical properties of soil. California Bearing Ratio, Specific gravity and compaction tests were conducted on soil mixed with stone dust. The amount of stone dust was considered as 10%, 20%, 30%, 40% and 50% of dry weight of soil. The first stage consists of CBR, specific gravity and compaction tests were carried out on the soil and the same tests were carried out in the second stage on soil samples mixed with stone dust. The maximum dry density of soil was observed to be improved from 1.764 g/cm³ to 1.891 g/cm³ with the rise in amount of Stone Dust. On the other hand, OMC of soil reduces to 13.25% from 16.5% with the rise in amount of Stone Dust. The specific gravity of soil first rises to 2.96 from 2.4 with the addition in amount of stone dust from 0% to 30% and afterwards it reduces to 2.82 on further addition of stone dust content to 50%. The CBR of soil first rises to 2.91 from 1.95 with the addition in amount of stone dust from 0% to 30% and afterwards it reduces to 1.94 on further addition of stone dust content to 50%.

In [27] analyzed the performance of expansive soil treated with stone dust and fly ash. The investigation was undertaken to observe the impact of fly ash and stone dust mixed at different amounts on expansive soil, the tests such as unconfined compression strength, swelling, proctors compaction and index properties were carried out on expansive soil with the equivalent percentage of fly ash and stone dust along with the soil in the study are 10%, 20%, 30%, 40% and 50% respectively. It was found that as the amount of admixture rises, there is a marked decrease in plastic limit and liquid limit of soil tested. The liquid limit at inclusion of 50% fly ash and stone dust results in the liquid limit value as 52. It was also found that the soil sample with addition of 30% of admixture results in maximum dry density of 18.45 kN/m³ at OMC of 16%. The unconfined compressive strength values at 50% inclusion of fly ash and stone dust admixture to the soil is 148 kPa and compared to the untreated soil, the amount of rise in unconfined compressive strength value 15%. It was found that the free swell index values of the expansive soil have reduced with the addition in amount of fly ash and stone dust admixture. It was also found that as the addition of admixture such as stone dust and fly ash rises the CBR value rises from 2% to 3.9% at optimum value of 30%.

In [28] studied the stability of clay using rice husk ash and stone dust. They introduced the rice husk ash and stone dust at different proportions of 0%, 5%, 10%, 20% and 0%, 10%, 20% respectively and standard proctor test and unconfined compressive strength
test were performed on various combinations of soil, rice husk ash and stone dust. It was observed that maximum dry density rises from 1.74 to 1.79 gm/cm$^3$ and OMC reduces from 26 to 23, which is achieved at combination of stone dust (20%) and rice husk ash (20%). It was also observed that unconfined compressive strength is maximum (1.612 kg/mm$^2$) at mixture of stone dust (20%) and rice husk ash (20%). Figure 13 shows the variation of Dry density at varied percentages of stone dust and rice husk ash. Figure 14 shows graphical presentation of comparison between stress and strain at varied percentages of stone dust and rice husk ash.

4. Comparisons of Outcomes of the Studies:

| Work done by | Admixtures Used                                                                 | MDD (gm/cc) | OMC (%) | CBR    | UCS (kN/m$^2$) |
|--------------|--------------------------------------------------------------------------------|-------------|---------|--------|----------------|
| 12           | Coir fiber (1%)                                                                 | -           | -       | Soaked-9.22 Unsoaked-13.55 | 620.7 |
| 13           | Coir Fibre (1%) and Flyash (20%)                                               | -           | 11.6    | 669    |
| 2            | Crushed glass (5%), Fly Ash (20%), and Coconut coir fibre (1%)                 | -           | -       | 5.2    | -              |
| 5            | Fibers (0.6%) and Stone dust (3%)                                              | 1.53        | 23      | Soaked-4.16 | 918    |
| 14           | Fibers (1%), stone dust (10%), and lime (6%)                                   | 1.63        | 18      | Soaked-12 Unsoaked-5 | 570.75 |
| 15           | Fly Ash (6%)                                                                   | 2.35        | 10.20   | 4.82   | 88.8           |
| 17           | Fly ash (20%)                                                                  | 1.52        | 22.19   | Soaked – 2 Unsoaked-13.55 | - |
| 18           | Lime (9%) and Stone dust (20%)                                                 | 1.77        | 21      | Soaked - 21 | 182  |
| 19           | Lime (6%) and Sodium silicate (3%)                                             | 1.44        | 26      | 2.01   | -              |
| 20           | Lime (6%)                                                                      | 1.68        | 12      | 15.2   | -              |
| 9            | Moorum (20 %), and RBI Grade 81(4%)                                           | 1.49        | 24.76   | Soaked-14.76 | - |
| 21           | Moorum (7.5%) and Fly ash (5%)                                                 | 4.92        | 16.14   | -      | 26.47          |
| 22           | RBI grade 81 (6%)                                                              | 2.4         | 26.4    | 32.63  | 589.58         |
| 23           | Rice husk ash (20%) and Lime (5%)                                              | 1.51        | 22      | 7.52   | 140.2          |
| 24           | Rice husk ash (12%), and Fly ash(25%)                                          | 1.58        | 15      | 10     | 1250           |
| 14           | Rice husk ash (20%), Fly ash (20%), and Lime (8%)                              | 1.65        | 18      | 12.7   | 350.217        |
dust rose to 19.08%, whereas the OMC of kaolinite clay was 33%. With the addition of quarry dust OMC decreased considerably to 19% with addition of quarry dust but considering the economy suitable combination for pavement stabilization was 40% quarry dust along with 2% coir fiber.

In studies, the improvement of kaolinite clay sub-grade using coir fiber waste. Generally weak sub-grade has low value of CBR and can be improved by introducing the coir. Proctor compaction and CBR tests were carried out. From the test conducted, it was found that the CBR value of kaolin clay was 1.91, which was not useful to construct the flexible pavement. There was no considerable change in optimum moisture content and dry density values of clay on encompassing 1% and 2% fiber. In concluded that the quarry dust can be used as a good supplement to the clayey soils. Hence, quarry dust is also mixed along with the fiber waste to point-out the effective use of coir fiber waste in highway constructions. The MDD of the kaolinite sample was 11.16 kN/m³. It was observed in that by increasing the quantity of quarry dust in kaolinite clay, dry density improved appreciably and for a sample containing 50% quarry dust.

### 5. Conclusions

Intense comparative studies of the existing researches indicate that using various admixtures can enhance the geotechnical properties of Black Cotton Soils. There are various combinations of admixtures with which the nature of these soft soils can be controlled. As it can be seen, usage of lime as reinforcement in expansive soils results in 86.84% increase of CBR value on comparison with unreinforced soft soils. Addition of lime results in initiation of a pozzolanic reaction leads...
to creation of cemented combinations, which aids in higher shear strength and lower volumetric changes. Several researchers such showed that lime can be used along with various waste products as a combination to further refine the geotechnical properties of soft soils; used stone dust (15%) and RHA (10%) to gain moderate CBR value of 10.43. The conducted studies confirmed that, various waste products such as fly ash, rice husk ash, stone dust and crushed glass can also be used as a geotechnical admixture. Addition of these admixtures alters the physical and compaction characteristics of cohesive soils. Thus, it can be concluded that the combinations of admixtures and expansive soil improve the CBR value, UCS and decrease swelling index of soft soils to an acceptable range.

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