



Experimentation of Black Cotton Soil Using Flyash And Crumb Rubber for Subgrade Application In Pavement Construction

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Abstract

Black cotton soil is known to possess the properties of high plasticity and significant swelling-shrinkage action. It consequently results in low bearing capacity and poor roadway performance of pavements. This research involves the stabilization of black cotton soil utilizing fly ash and crumb rubber so as to enhance its engineering properties for road construction. Different percentages of crumb rubber were incorporated in the soil, namely 7.5% 10% 12.5% and 15%, while the percentage of fly ash was kept constant at 20% based on the dry weight of soil. Experimentation was conducted following relevant Indian Standards in testing the materials to check the effect of these stabilizers on the geotechnical properties of soil. The various tests which were conducted as part of this study include Atterberg limits, California bearing ratio (CBR), standard Proctor compaction and unconfined compressive strength (UCS). The conclusions illustrated that the flexibility characteristics and swelling capacity of the untreated soil were significantly affected by fly ash. The ideal quantity of crumb rubber confirmed enhancement in the load-bearing capacity of stabilized soil, consequently enhancing its flexibility and deformation properties. But the compressive strength decreased when crumb rubber exceeded the optimum amount, which was due to the decrease in interparticle forces. To summarize, the combined use of fly ash and crumb rubber was an efficient and sustainable soil stabilization method for improving the geotechnical characteristics of expansive black cotton soil, thus opening perspectives for its application in construction of pavements and embankments while promoting waste and industrial resources utilization.

Keywords: Sub grade, Geotechnical characteristics, black cotton soils, pavements, stabilized soils, crumb rubber, flyash.

Introduction

Expansive soils are recognized as some of the most difficult geotechnical material to deal with within civil engineering, particularly when paving and constructing foundations. Because of the seasonal changes in moisture contents, these soils often lead to differential settlement, cracking in pavement, low bearing capacity and premature failure of structure. (Randhawa 2024) Black cotton soil is one of (Raghuwanshi and Kaur 2016) the types of expansive soil which is known for a significant amount of montmorillonite clay which leads to its high plasticity, dramatic changes in volume and inadequate engineering properties. Expansive soils are mostly found in semi-arid and tropical regions where they serve as natural subgrade for highways and other transport structures. Nevertheless, they must be properly stabilized to ensure their efficient engineering use. (Altaf, Sharma, and Singh 2024)

Black cotton soils:

The existence of expansive clay minerals gives black cotton soil the highest liquid limit, the highest plasticity index, and a high level of swelling potential. While the soil swells and gains much water during the wet season, it shrinks and loses moisture during the dry season, which results in the formation of deep cracks. The periodic swelling and shrinkage of this clay soil plays a negative role in ensuring the stability and serviceability of pavements, embankments, and shallow foundations. Hence, the improvement of the geotechnical properties of black cotton soil has become a topical issue in geotechnical and transportation engineering. (Goutham and Krishnaiah 2020)

Crumb Rubber as stabilizer:

Increasing environmental issues connected with waste tire disposal push researchers to seek ways for the effective application of tires in civil engineering. Crumb rubber, brought about by mechanical grinding of used tires into tiny particles, is becoming a good ecologically friendly additive used in soil stabilization. (USE OF FLY ASH AS ECO-FRIENDLY FILLER IN SYNTHETIC RUBBER FOR TIRE APPLICATIONS n.d.) Due to its low density, great elasticity, flexibility, and good energy-absorbing ability, crumb rubber enhances deformation characteristics, ductility, and resilience of stabilized soil. These features improve subgrade resistance in pavements against repeated loading, and lower the chances of brittle failure. At the same time, too much crumb rubber can have a negative impact on the interlocking of soil particles and on the

compaction process, which leads to the decrease in strength. (Aouf, Alhakim, and Jaber 2024)

Flyash As a stabilizer:

(Kumar 2014) The method of soil stabilization has long been used to improve the engineering properties of poor-quality soils. One of the most used chemical stabilizers is fly ash, which is known for its pozzolanic properties as well as its good environmental properties. Fly ash is a fine powder that comes from burning coal in thermal power plants. Fly ash contains reactive silica and alumina that can react with calcium when water is present, forming building materials such as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). (Julphunthong et al. 2024) These hydration processes result in the better bonding of soil particles leading to reduced plasticity, decreased swelling capacity, increased dry density and improved strength and durability of stabilized soils. What is more, using fly ash for geotechnical purposes leads to sustainable environmental results because it helps to get rid of industrial waste and limits the use of traditional stabilization agents. (Kumar, Christy, and Chauhan 2023)

Soil stabilization:

Soil stabilization (Afrin 2017) is a process used to improve the engineering performance of weak soils by increasing their strength, bearing capacity, and durability while decreasing their plasticity, permeability, and swelling-shrinkage behavior. Out of the many soil stabilization options available, the use of industrial by-products such as fly ash and recycled materials such as crumb rubber (Li et al. 2017) has started gaining popularity due to their environmental and technical advantages. Fly ash improves soil strength through pozzolanic reactions, which produce cementitious compounds while crumb rubber helps improve soil flexibility and resistance to deformation. The combined use of these materials offers a sustainable and could be a cheap method to improve black cotton soil. (Mallikarjuna and Mani n.d.)

Objectives of the Current Investigation:

- To assess the impact of the fly ash and crumb rubber used in the research on the geotechnical characteristics of black cotton soil such as the properties of plasticity, swelling characteristics, and compaction parameters.
- To examine how different proportions of the crumb rubber (7.5%, 10%, 12.5%, and 15%) along with the same percentage of 20% fly ash affects the UCS and CBR of the treated soil.
- To find out the right percentage of crumb rubber that can be used along with the same 20% fly ash which will result in good quality soil with desired strength, flexibility and bearing capacity for the subgrade of pavement.

Literature Review

(Zada et al. 2023) Expansive soil is a widely discussed topic in the field of geotechnical engineering due to its swelling and shrinkage properties, which have negative impacts on pavements, foundations, and earth structures. Expansive clay soils usually have high plasticity index values, low shear strength, lower bearing capacity, and wholesale volume changes based on seasonal moisture fluctuations. As a result, various types of soil stabilization methods have been researched that comprise cement/lime stabilization, fly ash stabilization, industrial by-products, and recycled waste materials.

Among the many industrial by-products available for the stabilization of expansive soils, fly ash has especially been the focus of many researchers. The reactivity of fly ash is shown in the way it combines with the moisture and calcium present in the soil to produce compounds with cement-like properties (e.g., calcium silicate hydrate and calcium aluminate hydrate). Products of the fly ash hydration process led to better particle bonding, lower porosity, and lower liquid limit and plasticity index. (Park et al. 2016) Studies have shown that use of fly ash leads to improvement in maximum dry density, UCS, and CBR values, confirming its effectiveness as a stabilizing material.

In recent times, waste tire crumb rubber has received significant traction as a type of eco-friendly material for use in geotechnical functions. Crumb rubber is characterized by its low density, high elasticity, and energy absorption ability. (Peter et al. 2016) This leads to the rubber improving ductility, decreasing brittleness, and maximizing the strength of the pavement subgrades in relation to cyclic loading and cracking. Despite this, past studies show that when too much rubber is used the dry density decreases, there is less particle interlocking and the compressive strength decreases too because rubber is not as stiff as mineral soil particles. This makes it important to determine the right amount of crumb rubber in order to maximize flexibility while maintaining strength. (Barman and Singh 2024)

A variety of scholars have also examined the usage of fly ash and rubber crumb in the same project to improve soil. Existing literature shows that fly ash plays a major role in increasing the strength of the product using pozzolanic cementation, while at the same time, rubber crumb facilitates a flexible inclusion into the soil, providing it with higher deformability and impact resistance. Thus, the combination technique opens new perspectives in improving soil properties, while also bringing a positive impact on the use of industrial waste and discarded tires in construction. (Ravichandran et al. 2016)

Despite meaningful developments, there are very few studies concerning the interaction between fly ash

and crumb rubber in black cotton soil that could be employed in pavement subgrade applications. Almost all previous works are focused either on fly ash or crumb rubber; thus, little has been written about the interplay of fly ash and crumb rubber with different contents of rubber at constant level of fly ash. Besides, works that examine the dynamics of index properties, compaction characteristics, shrinkage behavior, permeability, UCS, and CBR are also few and far apart. (Ramaji n.d.)

For this reason, this research aims to establish the stabilization of black cotton soil which is done using a fixed percentage of fly ash (20%) and variable percentages of crumb rubber (7.5%, 10%, 12.5%, and 15%). The objective of the research is to determine the optimum crumb rubber content which would be effective in improving the properties of expansive soils and at the same time be ecological and sustainable too with respect to the use of waste and raw materials for construction of pavement subgrade. (Verma, Prasad, and Bonal 2024)

Research Gap

Numerous studies have explored the impacts of fly ash and crumb rubber independently on the stabilization of expansive soils. Fly ash has been shown to enhance soil strength and diminish plasticity through pozzolanic reactions, while crumb rubber contributes to the increase of flexibility and energy absorption properties. However, there is little research on the consequences of applied fly ash and crumb rubber in the process of modifying the behavior of black cotton soil when used for pavement subgrade. A synergistic effect of these two recycled products can lead to an improvement of strength, durability, ductility, and sustainability at the same time, which can be helpful in finding the solution for efficient stabilization of expansive soil and realization of the principles of circular economy through the use of waste and industrial by-products.

Methodology

This study was carried out with the purpose of determining the efficiency of stabilizing expansive black cotton soil using the mix of fly ash and crumb rubber for use as a sustainable pavement subgrade. It has been considered how these industrial materials and waste products can affect the physical, mechanical, and hydraulic properties of black cotton soil. In this view, the technique of soil stabilization is aimed at improving its engineering properties as well as contributing positively to the environmental aspect of construction through the recycling of industrial waste and tires.

A comprehensive experimental program was designed based on established geotechnical laboratory techniques and executed in compliance with the requirements of the Indian Standard Code (IS 2720). Analytical procedures included systematic testing in the laboratory under controlled environmental conditions to achieve repeatability and reliability of the data. All phases of preparation of the specimens were done using established protocols to ensure that the proportions of the materials, the moisture content, the compaction energy and the curing process remained uniform during the experiment.

The black cotton soil samples were taken from the Vijayawada district of Andhra Pradesh, India, a prominent region known for its expansive clay deposits. First, the soil was air-dried, crushed, and sieved through a 4.75 mm IS sieve to ensure that the large particles were removed and the material was ready for laboratory examination. The physical and engineering characteristics of the untreated soil were first examined to provide baseline information for effective evaluation of stabilization. For this experiment, Class F fly ash from a thermal power plant was chosen to serve as the main stabilizing agent because of its great pozzolanic properties. Based on earlier studies, the amount of fly ash was kept constant at 20% by dry weight. To enable good deformation characteristics of the stabilized soil material, crumb rubber obtained from discarded car tires was used as a secondary stabilizer, and four amounts of crumb rubber, namely 7.5%, 10%, 12.5%, and 15% by dry weight were used to study their impact on stabilized soil material.

Accurate measurements were taken using a digital balance for the amounts of soil, fly ash, and crumb rubber that were to be combined. First, the dry soil and fly ash were blended to ensure a uniform distribution of the pozzolanic material in the soil mix. After that, crumb rubber was introduced gradually into the mixture followed by the addition of water in controlled quantities in line with the moisture requirement of each test. The mixing was done manually until the mixture had a uniform and homogenous nature with no visible segregation of soil and fly ash and rubber particles. The resulting mixtures were put in air-tight containers and allowed to equilibrate before specimen preparation to achieve even moisture distribution and activated interaction between the stabilizers.

Thereafter, an extensive program of laboratory testing was conducted to determine the effect of stabilization on the engineering properties of black cotton soil. To determine the index properties, Atterberg limit tests, which included liquid limit, plastic limit, and plasticity index were employed to study the soil changes in terms of consistency and swelling characteristics. In addition, the Standard Proctor test was used to find the values for Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for the stabilized mixture. The mechanical behavior of the stabilized soil was analyzed with the use of the Unconfined Compressive Strength (UCS) test and the California Bearing Ratio (CBR) test both under the soaked and unsoaked conditions was carried out to determine how suitable the stabilized soil can be to be

used as subgrade material in pavements.

The findings of each experiment were evaluated systematically and compared with the outcomes of black cotton soil in its natural state. Evaluation of stabilization was done on the basis of changes in liquid limit, plasticity index, swelling potential, permeability, and an improvement to the general behavior of the soil in terms of compaction characteristics, compressive strength, shrinkage resistance, and California Bearing Ratio. An effort was made specifically to determine the optimum amount of crumb rubber which would give a good balance between the strength, flexibility, durability, and load bearing capacity of the soil while keeping the compaction characteristics of the treated soil intact.

Mix Ratios

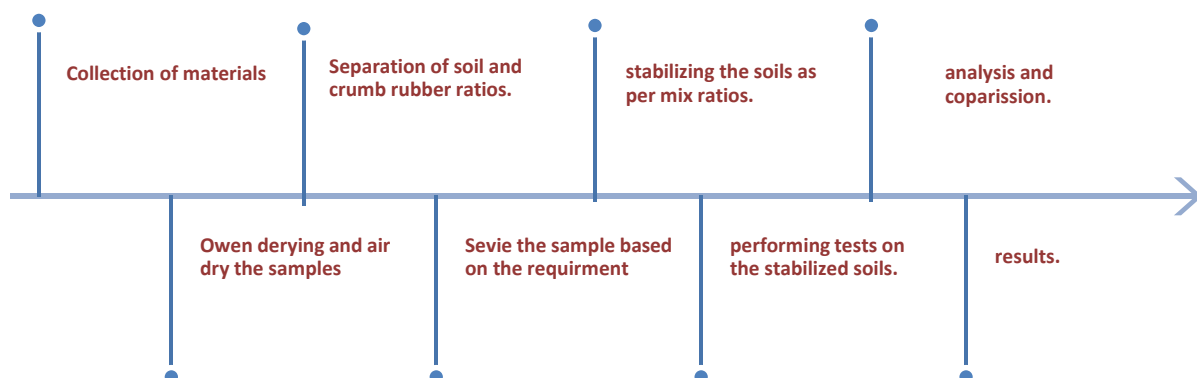
S.no	Type of soils	Condition of soils	Percentage of soils.	Percentage of crumb rubber	Percentage of flyash
1	Black cotton soils.	Normal Soils	100%	0%	0%
2		Stabilized soils.	72.5%	7.5%	20%
3			70%	10%	20%
4			67.5%	12.5%	20%
5			65%	15%	20%

Table no.1. Mix Proportions of the soil for stabilization

Preparation of Specimens:

The appropriate amounts of soil, fly ash, and crumb rubber were obtained by weighing through a digital scale having precision of ± 0.01 g. The soil and the fly ash were dry mixed to obtain a uniform colour. The crumb rubber was now added to the mixture so that the consistency of all the particles in the soil matrix could be achieved. Water as required by each experiment was added very slowly and mixed thoroughly at the same time so that moisture distribution was equal. Finally, the prepared mixtures were stored in sealed polyethylene bags without allowing moisture loss for a period of 24 hours before conducting the experiments to allow complete water absorption and better interaction of fly ash and soil.

Flow chart:



Experimental work

The aim of this experimental study was to explore the effectiveness of stabilization with a fixed fly ash content of 20%, while changing the contents of crumb rubber to 7.5%, 10%, 12.5%, and 15% on dry soil weight, to improve black cotton soil's engineering characteristics. To check how far the type of additives influences the physical and mechanical characteristics of the soil, the laboratory tests were planned on the premise that all tests were carried out according to IS 2720 standards.

The first step was to make characterization of untreated black cotton soil for understanding its original properties. The soil demonstrated its liquid limit of 68%, plastic limit of 27%, and plasticity index of 41%, which indicates that it is highly plastic and expansive. Such properties are typical for montmorillonite, a clay mineral with a significant water absorption capacity, as well as swelling and shrinking reaction to the wetness variation during the seasons. The mentioned features of untreated black cotton soil make it impossible to be used directly for subgrade road construction due to insufficient strength and stability.

After determining the properties of the untreated soil, stabilization was carried out using 20% fly ash and various amounts of crumb rubber (7.5, 10, 12.5, and 15%). Fly ash was chosen because it is a pozzolana and rubber was used to add pliability and ductility and resistance to repeated traffic loads. The mixtures were dry mixed first and water was added gradually into the mixture.

- Atterberg's limit.
- Liquid limit.

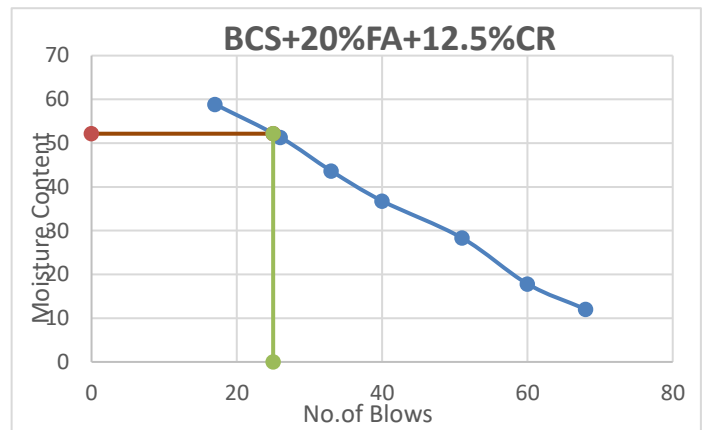
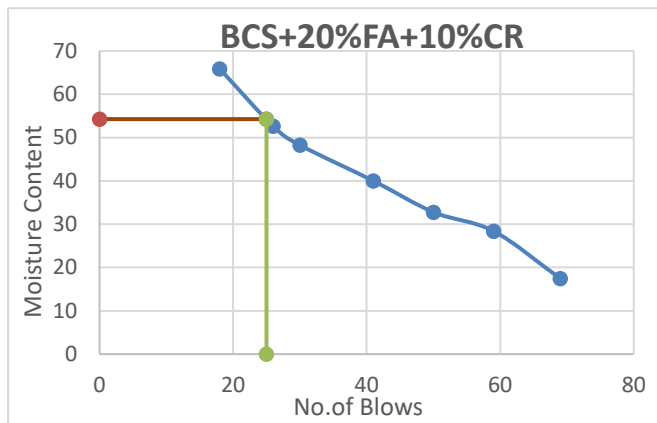
- Plastic limit.
- Shrinkage limit.
- Compaction Characters.
- Permeability.
- Unconfined compressive strength (UCS).
- California bearing ratio (CBR)

These tests were conducted according to IS 2720 (Part 5). The liquid limit test was conducted using the Casagrande apparatus, and the water content was found from the flow curve for 25 blows. The plastic limit test was conducted by rolling the soil threads until they crumbled to a 3mm diameter

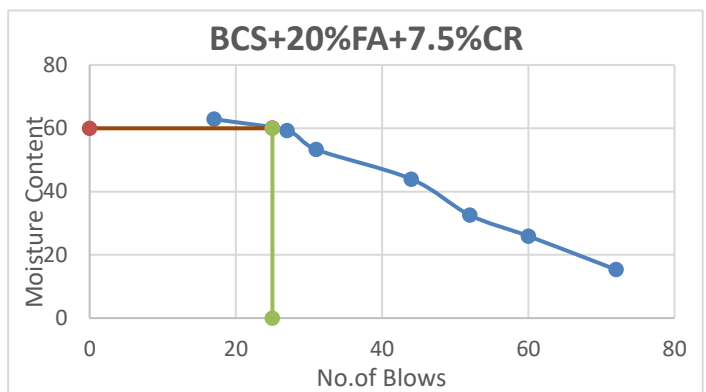
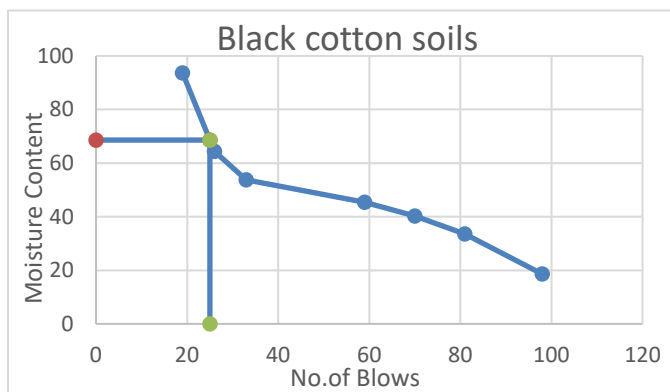
Atterberg limit:

s.no	Type of Soils	Liquid limit (%)	Plastic limit (%)	Plastic index (%)
1	Normal Black cotton soils	68	27	41
2	BCS + 20%FA + 7.5%CR	51.20	34	17.20
3	BCS + 20%FA + 10%CR	54	30	24
4	BCS + 20%FA + 12.5%CR	52	32	20
5	BCS + 20%FA + 15%CR	44	28	16

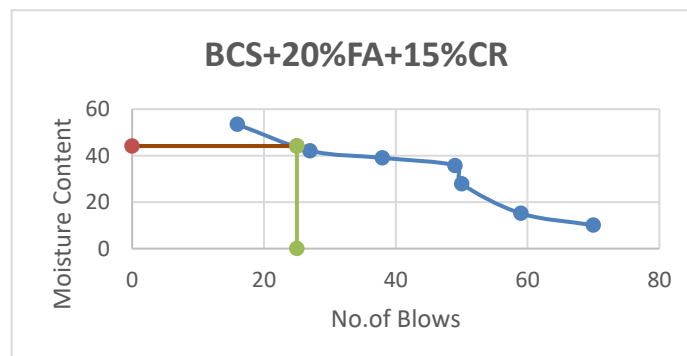
Table.no.2. Atterberg limit of the stabilized soils.



Graph.3&4: Normal Black Cotton Soil & BCS + 20%FA + 7.5%CR



Graph 1&2: normal black cotton soil & BCS + 20%FA + 7.5%CR



Graph. 6: BCS + 20%FA + 15%CR.

In order to determine how the consistency of black cotton soil is changed by the introduction of fly ash and crumb rubber, tests have been conducted with the application of the Atterberg limits. The original soil is shown to have the liquid limit (LL) equal to 68%, plastic limit (PL) equal to 27%, and plasticity index (PI) equal to 41%. After being treated with 20% of fly ash and varying amounts of crumb rubber, the liquid limit was respectively decreased to 51.2%, 54%, 52%, 44% in presence of 7.5%, 10%, 12.5%, and 15% of crumb rubber, while the plasticity index was reduced to 17.2%, 24%, 20%, and 16% to the crumb rubber amounts of 7.5%, 10%, 12.5%, and 15%, respectively.

The decrease in both plasticity index and liquid limit is due to the pozzolanic reaction that occurs with fly ash which leads to the formation of the C-A-H (calcium aluminate hydrate) and C-S-H (calcium silicate hydrate) gels that bind soil particles and lower water affinity. The crumb rubber used in the soil mixture serves as a flexible and non-plastic material which partly substitutes the expansive clay and thus reduces the moisture susceptibility and swelling properties. The combination of 20% fly ash and 7.5% crumb rubber demonstrated the most effective transformation of the consistency characteristics while the mixture with 15% of crumb rubber revealed the least liquid limit. Overall, the combined method of stabilization resulted in the decrease of black cotton soil plasticity and thus improved its dimensional stability and suitability for use as subgrade material in pavement constructions.



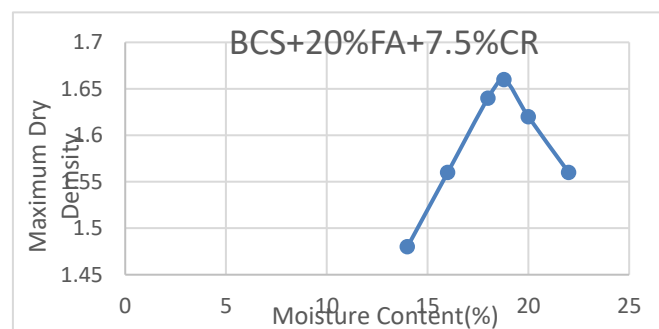
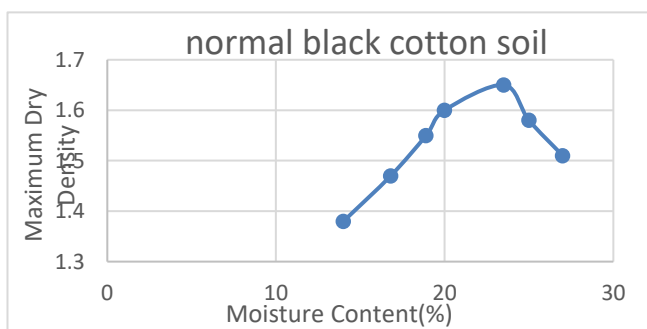
Fig.1- 4. Black cotton soil for

Atterberg limit.

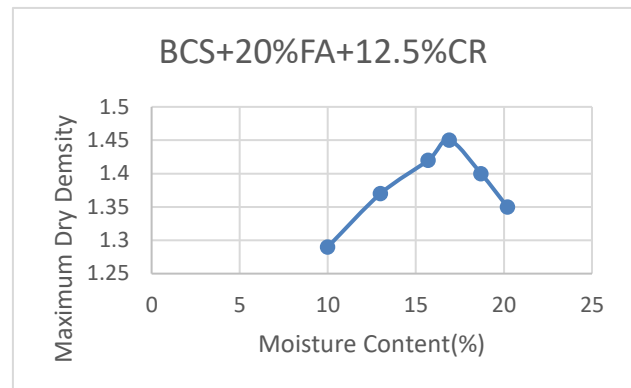
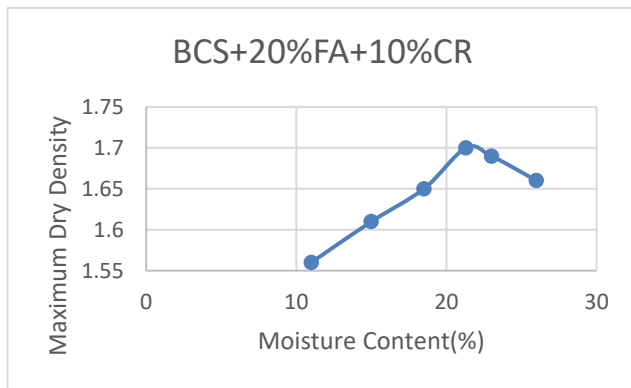
Compaction characters:

s.no	Soil mix	Optimum dry density (%)	Maximum dry density (g/cc)
1	Normal Black cotton soils	21.70	1.57
2	BCS + 20%FA + 7.5%CR	18.80	1.66
3	BCS + 20%FA + 10%CR	21.3	1.69
4	BCS + 20%FA + 12.5%CR	18	1.45
5	BCS + 20%FA + 15%CR	15	1.30

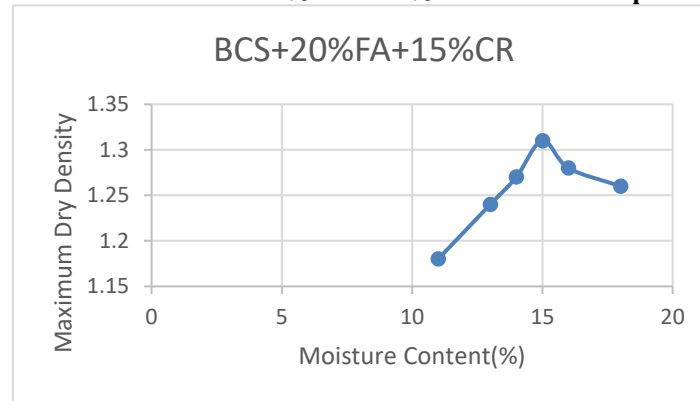
Table.no.3 Standard Proctor Test.



Graphs. 7 & 8: Normal Black Cotton Soil & BCS + 20%FA + 7.5%CR for standard proctor test



Graphs. 9 & 10: Normal Black Cotton Soil & BCS + 20%FA + 7.5%CR for standard proctor test



Graph.11: BCS + 20%FA + 15%CR

The Standard Proctor test was performed on untreated and modified black cotton soil to evaluate Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). The untreated soil had an OMC of 21.7% and MDD of 1.57 g/cm³. By adding 20% fly ash and 7.5% crumb rubber, the OMC value decreased to 18.8% and MDD increased to 1.66 g/cm³, yielding denser soil structure. The greatest MDD attained in the study was 1.69 g/cm³, which means the right number of additives was used to produce dense soil. With the raising of crumb rubber to 12.5% and 15%, MDD decreased to 1.45 g/cm³ and 1.30 g/cm³.

The reason for this decrease is attributed to the low specific gravity and compressibility of crumb rubber, resulting in the increased void ratio, and consequently lowering the entire density of the compacted soil. In general terms, it can be concluded that while moderate amounts of crumb rubber improve compaction properties, too much rubber negatively affects the dry density. The mixture of 20% fly ash and 10% crumb rubber performed best in terms of compaction.



Fig. 5 – 7: Standard Proctor test.

Unconfined Compressive strength (UCS):

s.no	Mix Proportions	UCS (kpa)
1	Normal Black cotton soils	140
2	BCS + 20%FA + 7.5%CR	410
3	BCS + 20%FA + 10%CR	370

4	BCS + 20%FA + 12.5%CR	354
5	BCS + 20%FA + 15%CR	323

Table.no.4: Unconfined Compressive Strength.

To assess the effectiveness of 20% fly ash and different percentages of crumb rubber in improving the strength of black cotton soil, the UCS test was conducted. The initial value of UCS for the untreated black cotton soil was recorded at 140 kPa, reflecting its weaker integrity in terms of load support. After the addition of 20% of fly ash, the UCS reached its highest point of 410 kPa when 7.5% crumb rubber was included in the mixture, indicating a 193% improvement relative to black cotton soil without precedence of stabilization. The UCS values for the mixtures with 10%, 12.5%, and 15% of crumb rubber demonstrated a decreasing range of values equal to 370 kPa, 354 kPa, and 323 kPa, respectively. The gains in strength can be attributed mainly to the pozzolanic activity of fly ash, since this material produces cementitious components, which are calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H), improving the bond between particles and decreasing the plasticity of the soil. The gradual decrease in UCS with increasing amount of crumb rubber is attributed to the rubber's low stiffness and compressibility, as the particles of rubber would decrease the degree of interlocking of soil particles and increase the voids present. Nevertheless, it was observed that the combination of 20% fly ash and 7.5% crumb rubber provided the best strength in compressive tests, thus making this mixture suitable for the stabilization of expansive black cotton soil for its possible use in pavement subgrades.

Shrinkage Limit:

s.no	Soil Mixes	Shrinkage (%)
1	Normal Black cotton soils	12
2	BCS + 20%FA + 7.5%CR	19.7
3	BCS + 20%FA + 10%CR	22
4	BCS + 20%FA + 12.5%CR	18
5	BCS + 20%FA + 15%CR	14

Table.no:5 Shrinkage limit values.

The shrinkage limit test was conducted to study the effectiveness of fly ash and crumb rubber in decreasing the change in volume properties of black cotton soil. The untreated sample showed the shrinkage limit of 12%, which indicates its severe shrinking and cracking during drying. If the sample was treated with 20% fly ash and the different share of rubber crumbs, then the shrinkage limit became 19.7%, 22%, 18%, and 14% respectively for 7.5%, 10%, 12.5%, and 15% of rubber crumbs. The best possible result regarding shrinkage was obtained for 20% of fly ash and 10% of rubber crumbs treatment, where the shrinkage limit was equal to 22%. This rise in shrinkage limit can be attributed to the pozzolanic activity of fly ash, which produces cement-like materials that reinforce the soil matrix causing less volume change due to moisture. The use of crumb rubber pellets also adds flexibility to the stabilized soil making it more capable of coping with shrinkage deformations and thus preventing the development of cracks. The only downside of increasing the crumb rubber share over 10% is the drop in shrinkage limit because of insufficient particle interlocking and more voids. As a result, the composition of 20% fly ash + 10% crumb rubber gives the best results in terms of shrinkage resistance.

**Fig. 8 & 9 Shrinkage Limit.****Permeability Test:**

s.no	Soil mixes	Permeability coefficient (cm/sec)
1	Normal Black cotton soils	1×10^{-6}
2	BCS + 20%FA + 7.5%CR	1×10^{-8}
3	BCS + 20%FA + 10%CR	1×10^{-8}
4	BCS + 20%FA + 12.5%CR	1×10^{-7}
5	BCS + 20%FA + 15%CR	1×10^{-6}

Table.No.6: Permeability Test.

The permeability test was performed in order to assess the impact of fly ash and crumb rubber on the hydraulic conductivity of stabilized black cotton soil. The untreated soil had permeability coefficient equal to 1×10^{-6} cm/s, which corresponds to higher water movement through the soil. Addition of 20% of fly ash together with 7.5% and 10% of crumb rubber helped to reduce the permeability coefficient to 1×10^{-8} cm/s, meaning that two orders of magnitude decrease in hydraulic conductivity was accomplished. This effect can be linked with pozzolanic reaction in fly ash with formation of calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) gels which are responsible for filling voids in soil and creating denser soil. The use of suitable amounts of crumb rubber improves the distribution of particles resulting in a decrease of the connected pore spaces. However, upon increasing the rubber volume to 12.5% and 15%, the permeability coefficient increased to 1×10^{-7} cm/s and 1×10^{-6} cm/s due to the low specific gravity, and elastic properties of rubber particles. All in all, it is the 20 % of fly ash + 7.5% and 10% crumb rubber compositions that are provided with the minimal permeability level confirming the enhanced resistance to water penetration and improved durability used for the pavement subgrade.



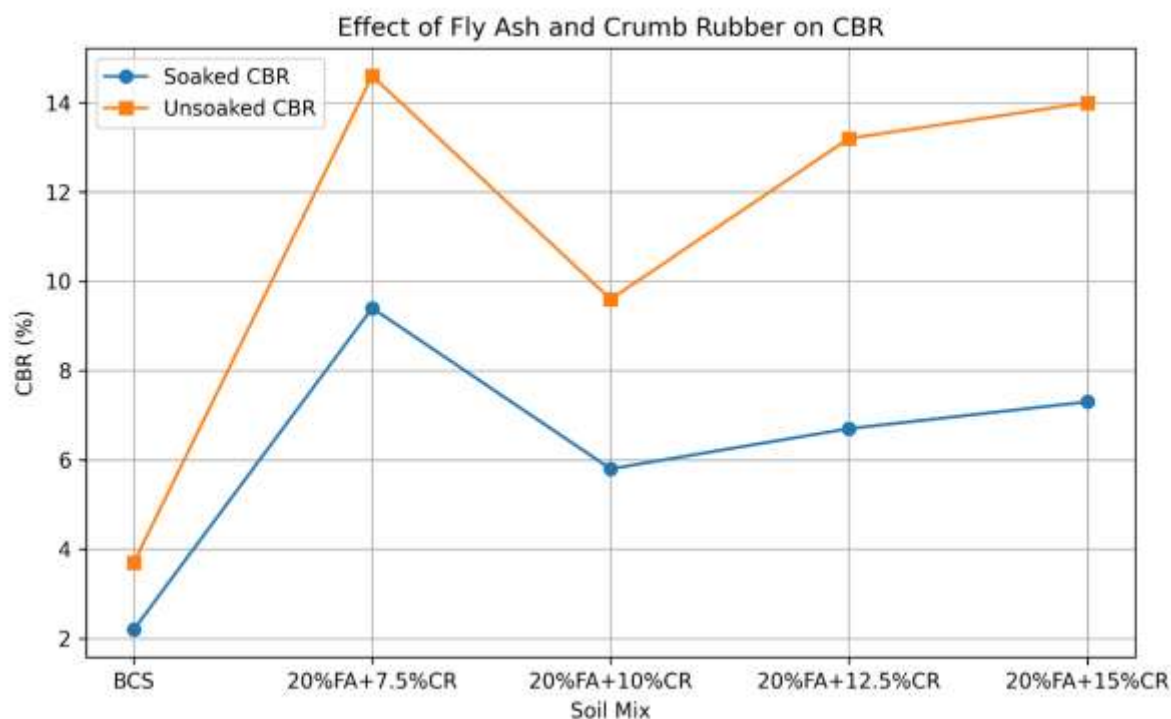
Fig. 10 & 11: Permeability Test.

California Bearing Ratio (CBR):

s.no	Soil mixes	Soaked CBR (%)	Unsoaked CBR (%)
1	Normal Black cotton soils	2.20	3.7
2	BCS + 20%FA + 7.5%CR	9.4	14.6
3	BCS + 20%FA + 10%CR	5.8	9.6
4	BCS + 20%FA + 12.5%CR	6.7	13.2
5	BCS + 20%FA + 15%CR	7.3	14

Table.No:7 California Bearing Ratio.

To evaluate the load-bearing ability of the unstabilized and stabilized black cotton earth for road subgrade, the California Bearing Ratio (CBR) test was performed. The untreated earth was demonstrated to have soaked and unsogged CBR numbers of 2.2% and 3.7%, respectively, illustrating low load-bearing ability. The process of stabilization with 20% fly ash and crumb rubber significantly influenced the CBR number results. The most reliable results were obtained for the mixture of 20% fly ash + 7.5% crumb rubber, specifically soaking and unsoaked CBR values of 9.4% and 14.6%, respectively. The mixtures with the inclusion of 10%, 12.5%, and 15% crumb rubber yielded soaked CBR results of 5.8%, 6.7%, and 7.3% and unsoaked through of 9.6%, 13.2%, and 14.0%. The higher CBR values are said to result from the pozzolanic activity of the fly ash that creates binding compounds responsible for the interparticle adhesion in addition to increasing the stiffness of the soil. Addition of crumb rubber contributes to better stress distribution and increased resistance to deformation. It has to be said that significant amounts of crumb rubber have a slight adverse impact on CBR values due to insufficient soil-rubber interaction and increased number of voids. In general, the mixture of 20% fly ash + 7.5% crumb rubber demonstrates the highest values of CBR that indicates that the mixture is effective for the construction of a pavement subgrade.



Graph No. 12: CBR soaked and Unsoaked conditions of soils.

Results and Discussion

The engineering behaviour of black cotton soil treated with 20% fly ash (FA) and different crumb rubber (CR) proportions (7.5%, 10%, 12.5%, and 15%) was assessed via an extensive laboratory testing procedure. The key variables studied were the effect of stabilization on properties like consistency limits, compaction, unconfined compressive strength, shrinkage characteristics, permeability, and California Bearing Ratio (CBR) to identify the best stabilization dose for subgrade use.

Atterberg's Limit:

The black cotton soil before it was treated had a liquid limit (LL) of 68%, plastic limit (PL) of 27%, and plasticity index (PI) of 41%. This proves that the black cotton soil is highly plastic and expansive in nature. With the treatment, using 20% fly ash and crumb rubber, it was found that the LL reduced to 51.2%, 54%, 52%, and 44%, while the PI reduction occurred down to 17.2%, 24%, 20%, and 16%, when crumb rubber in proportions of 7.5%, 10%, 12.5%, and 15% was used. Plasticity decrease is considered to be due to the fact that fly ash undergoes pozzolanic reaction that leads to formation of calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) gels, during which the clay activity decreases, as well as enhancement in particle bonding occurs. Crumb rubber serves as a non-plastic material that causes the decrease in moisture sensitivity and swelling potential of soil. Out of the various mixtures, the one containing 20% FA and 7.5% CR showed the best consistency characteristics, whereas the 20% FA + 15% mixture had the lowest liquid limit.

Compaction Characters:

The findings from the Standard Proctor test revealed untreated soil with an Optimum Moisture Content (OMC) at 21.7% and Maximum Dry Density (MDD) equal to 1.57 g/cm³. Introducing 20% FA + 7.5% CR reduced OMC to 18.8% while raising MDD to 1.66 g/cm³. MDD reached its peak at 1.69 g/cm³ using 20% FA + 10% CR, suggesting optimum particle arrangement and improved compaction behaviour. Nevertheless, further increase of crumb rubber to 12.5% and 15% lead to MDD decrease to 1.45 g/cm³ and 1.30 g/cm³, respectively. The increase of MDD at first is explained by the void-filling mechanism of FA and more even soil gradation. However, when rubber content exceeds optimal, low specific gravity and compressibility of crumb rubber causes void ratio to increase and efficiency of compaction be reduced. Consequently, 20% FA + 10% CR shows the best parameters for compaction suitable for pavement construction.

Unconfined Compressive strength (UCS):

The untreated black cotton soil showed a UCS of 140 kPa which implies low strength. Stabilization led to a remarkable increase in strength. The maximum UCS observed was 410 kPa when 20% FA + 7.5% CR were used in the mixture resulting in around 193% strength gain in comparison to the untreated soil. The UCS values reduced to 370 kPa, 354 kPa, and 323 kPa when mixed with 10%, 12.5%, and 15% CR respectively. Increase in strength is mainly attributed to the formation of some cementitious compounds (C-S-H and C-A-H) due to the pozzolanic reaction of fly ash which helps in the strengthening of soil skeleton. A moderate amount of crumb rubber helps in better distribution of stress and postpones the cracking. On the other

hand, high amounts of crumb rubber help in decreasing soil contact and creating more voids in the soil thereby lowering stiffness and reducing the strength of the soil. Hence the optimum mixture for strength improvement was 20% FA + 7.5% CR

Shrinkage Limit:

The untreated black cotton soil was found to have a shrinkage limit of 12%, which suggests that it has a high possibility of shrinkage and cracking. The stabilized specimens showed shrinkage limits of 19.7%, 22%, 18%, and 14% for 7.5%, 10%, 12.5%, and 15% CR content respectively. The highest shrinkage limit of 22% was recorded for the 20%FA + 10% CR mixture. The increase in shrinkage limits implies that the shrinkage limit is improved in terms of resistance to volume changes due to moisture. The action of fly ash in reducing clays' activity is due to cementitious bonding while crumb rubber enhances the flexibility of soil matrix and takes care of shrinkage strains. Nonetheless, the rubber content above 10% reduces shrinkage with weaker interparticle bonding leading to increased voids.

Permeability test:

The permeability coefficient for untreated soil is found to be 1×10^{-2} cm/s. The permeability is reduced by two orders of magnitude to 1×10^{-1} cm/s when stabilizing with 20% FA + 7.5% CR or with 20% FA + 10% CR. The permeability is slightly increased to 1×10^{-2} cm/s with 12.5% CR while it gets returned back to its previous value of 1×10^{-1} cm/s with 15% CR. The mechanism of decreasing hydraulic conductivity is related to the formation of C-S-H and C-A-H gels, which occupy the space in pores and render a denser soil structure. The arrangement of particles improves due to moderate crumb rubber content, but too much rubber generates larger volume of voids because of rubber flexibility. Hence, for 20% FA + 7.5% CR and 20% FA + 10% CR combinations, the lowest permeability was achieved and least water flow through soil was resulted.

California Bearing Ratio (CBR):

The black cotton soil that has not undergone treatment had the soaking CBR value of 2.2 and the unsoaked value of 3.7, and thus could not support subgrade construction. The soil stabilization process helped stabilize the values significantly. Mixture of 20% FA + 7.5% CR has reached soaking CBR of 9.4 and unsoaked CBR of 14.6, while the same parameters for 10%, 12.5%, and 15% CR were as follows 5.8%, 9.6% and 6.7%, 13.2% and 7.3%, 14.0% respectively. The increase of CBR value results from interparticle interaction obtained as the result of the pozzolanic reaction of FA and increase of the resistance of the material due to the inclusion of crumb rubber. Causative factors for moderate addition of rubber into the mixture, such as better pressure distribution in the process of loading, whereas if too much rubber is added, its stiffness will be lowered due to its low modulus of elasticity. Taking into account CBR values, mixture containing 20% FA and 7.5% CR provides the best performance, thus can be named as the optimal mix for the stabilization purposes.

Overall evaluation of performance:

Experiments demonstrated that the use of a combination of fly ash (20 percent) and crumb rubber had a positive impact on the properties of black cotton soil. The treatment decreased plasticity, increased compaction, as well as compressive strength, improved shrinkage resistance, permeability, and bearing capacity. It should be noted that though the addition of crumb rubber had a positive influence on flexibility, bigger proportions led to the decrease in the density and stability of the produced mixture due to the increase in the number of pores. Given the obtained results regarding all the engineering properties, the mixture of fly ash (20 percent) with crumb rubber (7.5 percent) was found to have the best characteristics and became recommended as the optimal variant for the stabilization of pavement subgrade. It is worth mentioning that the above-mentioned mix resulting in the highest UCS (410 kPa), both soaked and unsoaked CBR indices (9.4 and 14.6, respectively), low permeability (1×10^{-8} cm/s), and Index of Plasticity (17.2) is an environmentally friendly approach that can be used for the stabilization of weathered black cotton soils.

Compression of Untreated soil and stabilized soils:

The black cotton soil that had not been treated displayed a high plastic index (PI = 41%), low strength (UCS = 140 kPa), high permeability (1×10^{-6} cm/s), and low load capacity (Soaked CBR = 2.2%) making it inappropriate for use as a direct material for road construction. High liquid limit and low shrinkage limit are also indicative of a significant ability of soil to swell, shrink and crack due to seasonal changes in moisture.

The performance of the soil was greatly improved after stabilization was carried out using 20% fly ash and crumb rubber. The liquid limit and plasticity index showed a decrease to 44-54% and 16-24%, so the clay activity was found to be lower and the volumetric stability improved. Furthermore, the maximum dry density was found to be 1.69 g/cm³ for the mixture of soil with 20% FA and 10% CR, which indicated good results in this direction. The value of unconfined compressive strength increased from 140 kPa to 410 kPa and improved by approximately 193% due to pozzolanic reactions. Besides, the values of permeability coefficient was reduced by two orders of magnitude down to 1×10^{-8} cm/s, which reduced the amount of water entering the stabilized soil. Finally, soaked and non-soaked CBR increased to 9.4% and 14.6% correspondingly.

Taking into account all engineering properties, the 20% fly ash/7.5% crumb rubber mixture provided the

best overall balance for strength, durability, hydraulic performance, and bearing capacity while the 20% fly ash/10% crumb rubber mixture showed the best compaction performance ($MDD = 1.69\text{g/cm}^3$) and resistance to shrinkage (Shrinkage Limit = 22%). The results thus show that stabilization has been successful in converting expansive black cotton soil to a material suitable for sustainable roadway subgrade construction.

Table. No: 8 Compression table for untreated and stabilized soils.

S. No	Property	Untreated black cotton soil	Stabilized Black Cotton Soil	Engineering Interpretation.
1	Liquid Limit (%)	68	51.2, 54, 52, 44.	The propensity and water attraction have decreased.
2	Plastic Limit (%)	27	34, 30, 32, 28.	There has been an initial rise in the level of consistency of the soil.
3	Plasticity Index (%)	41	17.2, 24, 20, 16.	The plasticity and expansion characteristics of the soil have improved significantly.
4	Optimum Moisture Content (%)	21.7	18.8, 20.2, 18, 15.	The amount of water used is less and it leads to greater compactness.
5	Maximum Dry Density (g/cm^3)	1.57	1.66, 1.69, 1.45, 1.30.	The amount of water improved at first and decreased at higher CR concentrations.
6	UCS (kPa)	140	410, 370, 354, 323.	The strength has also been considerably increased.
7	Shrinkage Limit (%)	12	19.7, 22.18, 14	The high shrinkage limit ensures stability in size. Decrease in permeability leads to lower water permeability.
8	Permeability (cm/sec)	1×10^{-6}	1×10^{-8} ,	Decrease in permeability leads to lower water permeability.
9	Soaked CBR (%)	2.2	9.4, 5.8, 6.7, 7.3.	The capacity to withstand loads has greatly improved.
10	Unsoaked CBR (%)	3.7	14.6, 9.6, 13.2, 14.	The improved ability to handle traffic impact.

Table. No: 8 Compression table for untreated and stabilized soils.

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