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Augmenting The Properties Of Black Cotton Soil In Chittur Region, Palakkad, Kerala

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Abstract
Black cotton soil, which is common in Chittur Taluk, Palakkad District, Kerala is a problem soil for construction because of its poor load-carrying capacity, high shrink-swell potential, and sensitivity to cracking. It is not an engineering material unless stabilized with proper methods. The present paper aims at enhancing the engineering behavior of black cotton soil using lime, rice husk ash, and coir fiber as stabilizers. Some laboratory tests such as Specific Gravity, Sieve Analysis, Atterberg's Limits, Standard Proctor, California Bearing Ratio, and Unconfined Compressive Strength, were carried out in order to ascertain the efficacy of these stabilizers in improving the performance of the soil. It is shown through the results that stabilization has greatly improved soil strength, density, and stability. Lime was most effective in improving soil strength, plasticity reduction, and load-carrying capacity by the development of cementitious products that act as a binder to soil particles. Natural reinforcement coir fiber improved flexibility in the soil avoided crack development, and enhanced resistance to tensile stresses. These stabilizers combined had a synergistic effect that rendered the black cotton soil appropriate for use in constructions by enhancing the strength and durability of the soil. The study presents the need for stabilizing black cotton soil to reduce structure failures and the life span of structures. Stabilization not only enhances the engineering values of the soil but also the utilization of environment-friendly materials. Lime, rice husk ash, and coir fiber are low-cost materials available locally and are hence the viable options for the improvement of black cotton soil in areas where black cotton soil is dominant. The outcomes of this research are helpful in the realization of the extent to which successful soil stabilization methods can be implemented in actual construction procedures in order to achieve safe and durable infrastructure.
Keywords: *Black cotton soil, Chittur, lime, rice husk ash, coir fiber.*

INTRODUCTION

The development of such high levels of depletion of constructible soil with satisfactory natural bearing capacity has exacerbated dependence on weak and problematic soils for construction, and thus widespread structural foundation failures. As there is more urbanization and infrastructure development, the quality land available for development is decreasing, and engineers and developers are being left with no choice but to build on poor soils, which are very challenging as they possess low load-carrying capacity, excessive settlement, and volumetric instability. Among these problematic soils, black cotton soil is particularly notorious for its highly unpredictable nature, exhibiting extreme swelling during the monsoon season and significant shrinkage during dry periods, leading to severe structural distress such as cracks in foundations, road failures, and damage to pavements. The major reason for the undesirable characteristics of black cotton soils is the presence of montmorillonite clay minerals, which are water absorbing and holding with high capacities and show enormous expansion and shrinkage with loss in water leads to settlement differential and instability. Due to such inherent limitations, black cotton soil is an expansive soil, and naturally, without changing or treating is not suitable for direct use for construction purposes (Chamberlin, K. S et al., 2023). As a result, soil stabilization as a method of improving weak soil by strengthening it has emerged as a critical geotechnical engineering technique that improves its physical and mechanical properties through alteration and modification in its response and composition through the addition of stabilizing agents or mechanical improvement. Soil stabilization refers to any process of change that improves the soil strength, stability, and durability to make it suitable for application in engineering construction like foundations, road subgrades, embankments, and earth structures. Given the necessity of ensuring long-term structural integrity and minimizing foundation-related failures, adopting suitable soil stabilization methods is imperative, particularly in regions where black cotton soil is widespread, such as the Chittur region in South India, where infrastructure projects are often constrained by challenging geotechnical conditions. The success of soil stabilization is mostly a function of stabilizing material selection, for which the main goal is to modify the engineering properties of the soil so that the desired strength and stability requirements are achieved. There are several stabilization methods available, such as mechanical stabilization, cement stabilization, chemical stabilization, and utilization of industrial or agricultural waste materials, each of which has some advantages over others based on site-specific conditions. Among the most commonly employed stabilizers, lime, coir fiber, and rice husk ash have also been extensively used because of their ease of availability, low costs, and good potential to enhance the geotechnical properties of black cotton soil. Lime stabilization is an old and efficient method of treatment of expansive soils, as it greatly enhances the strength of the soil, lowers plasticity, and increases durability owing to pozzolanic reactions. When lime is mixed with black cotton soil, it reacts with the silica and alumina in the clay minerals, forming cementitious compounds that bind soil particles together, thereby increasing cohesion and load-bearing capacity. Additionally, lime reduces the soil's affinity for water, mitigating swelling and shrinkage behavior, which is particularly beneficial in regions experiencing seasonal variations in moisture content. Inclusion of lime also improves compaction characteristics, creating a denser and more stable soil matrix, thus making it a favorite to stabilize expansive soils in construction works. Another hopeful stabilizing material is coir fiber, which is a biodegradable and natural reinforcement material obtained from coconut husk and has been used extensively in geotechnical applications because of its superior tensile strength, longevity, and eco-friendliness. Coir fiber reinforcement increases the shear strength of the soil, minimizes settlement, and increases resistance to cracking by more uniformly distributing stress throughout the soil matrix (Kabeta, W. F et al., 2023). In contrast to synthetic fibers, coir fiber is a natural, renewable resource that is readily available in tropical countries and is therefore an attractive option for soil stabilization, especially where sustainability is a prime factor. The application of coir fiber in black cotton soil stabilization is beneficial in that it increases the soil's flexibility, which inhibits the development of huge shrinkage cracks, which normally occur in untreated expansive soils. Coir fiber also enhances the permeability of the soil, which lowers the chances of waterlogging and improves drainage properties, which are essential parameters in ensuring long-term soil stability. Among the most significant used materials are rice husk ash, an industrial waste product high in silica, thoroughly researched for its pozzolanic activity and capacity to increase soil performance (Hakari, U. D et al., 2014). Rice husk ash activates certain reactions upon blending with lime, thus forming additional cements that increase soil strength, reduce compressibility, and offer durability. Due to high silicate content, the use of rice husk ash encourages pozzolanic reactions, developing a bonding action with soil particles and, hence, improving the overall cohesion of the soil and its load-bearing capacity. Besides, rice husk ash reduces the plasticity index of black cotton soil and makes it less susceptible to changes in volume with moisture, which is very important in controlling problems related to foundations. Combined, lime, coir fiber, and rice husk ash will grant stabilization to black cotton soil to address several geotechnical problems of expansive soils while continuing in a sustainable manner with affordability (Jhariya, S et al., 2018). One of the feasible and cost-effective measures nowadays is stabilizing the weak soils for infrastructure development projects by taking recourse to natural and biodegradable stabilizers that are easily available. A couple of ways these stabilization techniques boost the characteristics of black cotton soil while conserving resources is by utilizing waste like rice husk ash that would not have been so easily disposed of. Also, application of natural reinforcements such as coir fiber clearly follows a worldwide trend of minimizing man-made materials, thus further encouraging sustainable soil stabilization techniques. When applied in Chittur region, where black cotton soil is a major impediment to construction, such stabilization techniques could lead to improved structural performance, reduced maintenance costs, and increased durability of civil engineering works. The effectiveness of lime, coir fiber, and rice husk ash in enhancing the properties of black cotton soil will be determined through in-depth investigations of some key geotechnical parameters like compaction characteristics, unconfined compressive strength, California bearing ratio, and permeability (Pakir, F. 2022). The stabilizers would gradually alter the traditional on soil behavior, this research is intended to present useful insights into their practicability in actual construction processes. Additionally, the results of this research can be used as a guide by engineers and policymakers in choosing proper soil stabilization methods for infrastructure development in expansive soils affected areas. Areas with difficult soil conditions are starting to become locations for urbanization and expansion, which makes it critical that effective and sustainable stabilization methods be considered more effectively and cost-efficiently for long-term structural stability with minimizing the risks caused by adverse soil condition. Finally, the use of lime, coir fiber, and rice husk ash in black cotton soil stabilization is a strategic move towards converting weak subgrade conditions into strong and durable foundation bases, opening the door to safer and more sustainable construction practices in geotechnically difficult areas (Almuaythir, S et al., 2023).

AREA OF STUDY

Chittur Taluk within the south-eastern region of Palakkad district, Kerala, is confronted with troublesome soils that are of serious concern to construction and agricultural activities. Black cotton soil is dominated by its extensive patches in alluvial plains, terraces, and undulating country. The soils are distinct in nature, thus extremely difficult to handle, due to their expansive characteristic (de Araújo, M. T et al., 2023). The elevation of Chittur Taluk is lying between 100 and 300 meters mean sea level (MSL) and possesses some gentle to moderately sloping lands influencing drainage of water, drainage pattern, and retention of moisture from soil. Black cotton soil here ranges from clay loam to clay with a high percentage of fine particles, leading to low permeability with slow drainage. Therefore, it undergoes tremendous volume change seasonally, where it becomes extremely unstable from an engineering standpoint. One major feature of the black cotton soil in Chittur Taluk is the enormous shrink-swell potential owing predominantly to montmorillonite clay minerals. Water-loving clay minerals make the soil swell upon moisture and shrink violently upon drying. When dried, deep cracks may develop, often several centimeters in width. These cracks bring foundations, roads, and other civil structures into instability, leading to structural distress, differential settlement, and collapse. In contrast, during monsoon, water seepages deep into the ground, leading to swelling, that conveys lateral pressure on building foundations, causing heaving or rising of buildings (Singh, N. K et al.,2021). This swelling-shrinking mechanism over a cycle is a threat to construction activity in the area and necessitates proper soil stabilization measures.In addition to these characteristics, black cotton soil from Chittur Taluk has poor load-bearing capacity and cannot support heavy structures in view of the apparently large settlement. Due to the low shear strength and pronounced compressibility of the soil, direct construction cannot be carried out without pre-treatment. Due to some additional limitations associated with drainage properties, this type of soil shows water logging and contributes to the subsequent weakening of the soil structure, thus enhancing susceptibility to erosion and instability. Due to these challenges, there is an increasing need for soil stabilization techniques that can appreciably improve strength, durability, and usability in this area. As a result of these challenges, this study attempts to investigate the effectiveness of the stabilization methods i.e. with lime, coir fiber, and rice husk ash. Lime stabilizes the soil, exhibiting improvements in soil strength and plasticity at the same time; thus, its capacity for load-bearing increases. Coir fiber is also a type of natural fiber. This not only reinforces the soil but also helps in curtailing shrinkage cracks. Rice husk ash, on the other hand, is a pozzolanic material and plays a role in stabilizing the soil through a reaction with lime to create additional binding compounds. Overall utilization of these stabilization techniques would improve the overall performance of black cotton soil for making it a good and reliable sub-structure configuration, thus providing a higher level of safety and durability to infrastructural development in Chittur Taluk (Satish, S. et al.,2018).

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Figure 1: Soil map of Kerala.

Figure 2: Topography map of study area.

PROPERTIES OF LIME

Lime is extensively employed as a stabilizer for soils because it enhances the strength, durability, and plasticity of expansive soils (Singh, S et al., 2013). Lime is mainly composed of approximately 90% calcium oxide (CaO) and 2% magnesium oxide (MgO), which chemically react with soil minerals to produce cementing compounds. Such a reaction helps in increasing the stability of soil by lowering the plasticity and enhancing the cohesion, and therefore lime is one of the principal materials for black cotton soil stabilization. Its low density of 450 kg/m^3 and specific gravity of 2.63 render it lightweight and easy to maneuver. Moreover, lime has a very small water absorption value of approximately 5%, thus avoiding excessive water penetration and limiting soil swelling and shrinkage. One of the best features of lime is its high binding property, which creates a strong internal structure in the soil, avoiding erosion and settlement problems. When combined with clay soils, lime reacts with the alumina and silica components, forming lasting compounds that effectively enhance soil strength (Ikeagwuani, C. C. et al., 2019). This leaves lime-treated soils more resistant to waterlogging and deterioration. Owing to such characteristics, lime is among the finest stabilizers for construction where expansive soils prevail, guaranteeing enhanced ground behavior and long-lasting durability of buildings constructed on these grounds (Etim, R. K et al .,2017).

PROPERTIES OF RICE HUSK ASH (RHA)

Rice Husk Ash (RHA) is a byproduct of industry that is commonly utilized as a pozzolanic material for soil stabilization. It contains 87% silica (SiO_2), 5% alumina (Al_2O_3), and 2% iron oxide (Fe_2O_3), which are responsible for its high binding properties when mixed with lime. RHA has a specific gravity of 2.05 and a density of 650 kg/m³, which makes it light and easy to blend with soil. It has a characteristic gray to black color and occurs in the form of a powdery ash (Gobinath, R et al., 2020). The pozzolanic activity of RHA enables it to react with lime to create additional cementitious substances that consolidate the structure of the soil. It has one of its most important characteristics as a high-water absorption capacity of 20%, which increases soil stability by controlling moisture retention and minimizing the shrink-swell action of expansive soils. RHA is especially effective in enhancing the compressive strength of weak soils by closing pores and minimizing permeability (Goutham, D. R et al., 2021). It also improves the long-term durability of soil blends, increasing their resistance to cracking, erosion, and settlement. Its green character and status as an agricultural byproduct also render RHA an economical and environmentally friendly option for black cotton soil stabilization.

PROPERTIES OF COIR FIBER

Coir fiber is a biodegradable natural material used for reinforcement purposes with high durability and strength. Coir fiber contains 43% cellulose, 45% lignin, and 0.25% ash, but it is highly resistant to biodegradation by biological substances (Kaushal, V et al., 2015). The coir fiber's specific gravity is 1.25 with a density of 1.15 g/cm³, indicating that it is relatively lightweight and very strong (Sivakumar Babu, G. L et al., 2008). The fibers range in color from golden yellow to brown and are inherently flexible, making them simple to mix with soil. The most dramatic feature of coir fiber is that it can absorb 30% water, making it retain water and improve the stability of soil by reducing shrinkage cracks. Unlike RHA and lime, coir fiber does not possess inherent binding properties but adds tensile strength to soil due to its inherent reinforcement effect, preventing excessive deformation upon loading. The fibrous quality of coir promotes the interlocking process between soil particles to enhance the resistance of the soil to erosion as well as settlement. Coir fiber is also very resilient and resistant to microbial breakdown, hence proving long-term efficiency in stabilizing soil. Its biodegradable nature makes it an environment-friendly option for improving the strength and stability of black cotton soil.

Table 1: Properties of Lime, Rice Husk Ash, and Coir Fiber.

Property	Lime	Rice Husk Ash (RHA)	Coir Fiber
Chemical Composition	90% Calcium Oxide (CaO), 2% Magnesium Oxide (MgO)	87% Silica (SiO_2), 5% Alumina (Al_2O_3), 2% Iron Oxide (Fe_2O_3)	43% Cellulose, 45% Lignin, 0.25% Ash
Physical Form	Fine powder	Fine ash	Fibrous strands
Color	White	Gray to black	Brown to golden yellow
Specific Gravity	2.63	2.05	1.25
Density	450 kg/m³	650 kg/m³	1.15 g/cm³
Water Absorption	5%	20%	30%

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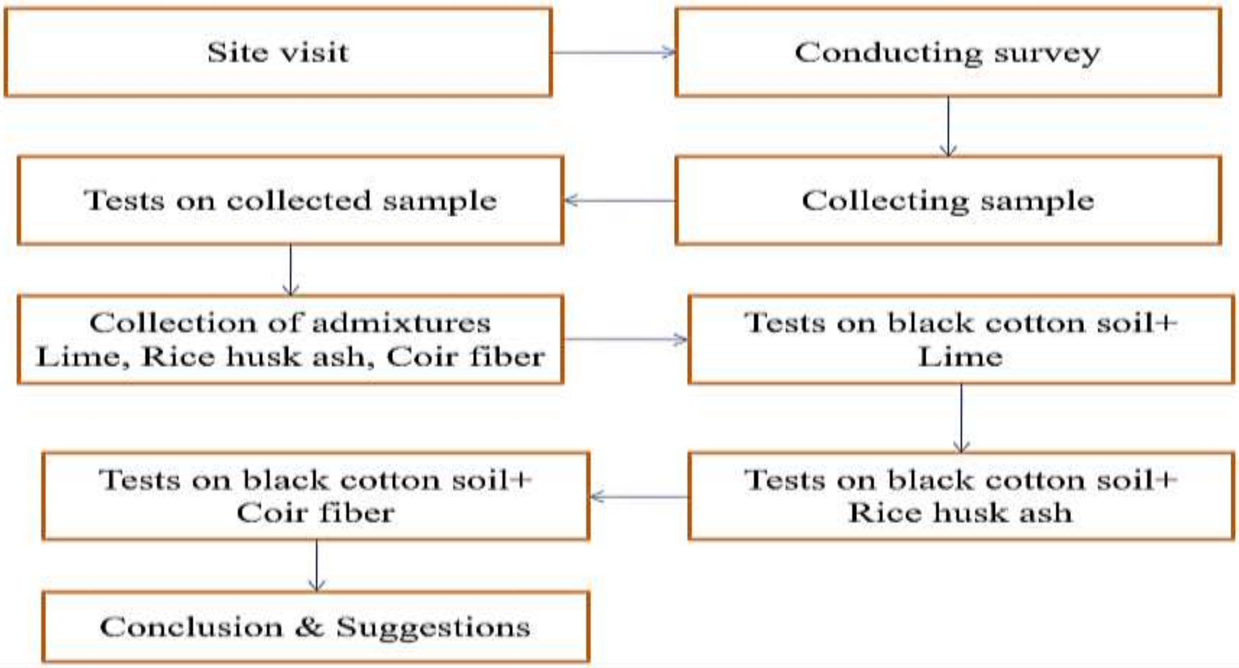
Binding Property	Strong cementation	Pozzolanic (reacts with lime)	No direct binding, but adds reinforcement
Durability	High	Moderate	High (resistant to decay)

METHODOLOGY



Site Visit and Survey

The initial exercise in this research was to organize a site visit and comprehensive survey of Chittur Taluk, which lies in the south-east part of Palakkad district, Kerala. The overall aim of this stage was to evaluate the present soil conditions, record the problems caused by black cotton soil, and gather concerned geographical and environmental information. Chittur Taluk was chosen as the site of study because of the extensive occurrence of black cotton soil with high shrink-swell capacity and poor load-bearing strength and unsuitable for construction unless stabilized. Detailed topographical survey was conducted during site visit to note elevation, slope, and drainage features of the area. Topography here ranges from 100 to 300 meters mean sea level (MSL) with moderate to gentle slopes that affect surface runoff and retention of soil moisture. The occurrence of undulating plains and terraces also increases the difficulties of expansive soil behavior. GPS coordinates were taken to provide accurate identification of the sampling sites. A key component of the survey was consultation with local construction experts, farmers, and engineers to obtain information on issues with soil available in the region. Observation was conducted on buildings already built for evaluation of the apparently visible signs of foundation distress in the form of leaning, settlement, and cracks. In addition, past climate history was examined in an effort to comprehend seasonal soil water content variation and the impacts on soil behavior. Data gathered during this stage were invaluable in the conceptualization of a successful experimental arrangement. Based on the identification of major soil issues, the research sought to come up with a stabilization method adapted to the context of Chittur Taluk to provide eco-friendly and cost-effective measures towards enhancing soil strength and stability. The proposed stabilization techniques will be evaluated for their long-term performance under varying climatic conditions to ensure durability and

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sustainability. Additionally, emphasis will be placed on using locally available materials to minimize environmental impact and reduce overall project costs.

Figure 3: Conduction of Survey near localities.

Collection of Samples

The Selected location for collection of soil samples in the research work is Chittur Taluk in Kerala Palakkad district. It features black cotton soil, found as patches within plains of alluvium, and terraced topography. It also extends into undulated features. The elevation of Chittur Taluk varies between 100 and 300 meters mean sea level (MSL) with gentle to moderate slopes controlling surface runoff, drainage pattern, and soil moisture retention. Such physiographic features make the soil strongly vulnerable to expansion and contraction on a very seasonal basis, and they lead to low bearing capacity and structural instability characteristics. Black cotton soil found in the Chittur Taluk has a texture ranging from clay loam to clay with an intensive proportion of fine particles resulting in poor permeability as well as poor water drain capacity. One of the distinctive features of this soil is its excessive shrink-swell behavior, which is mainly due to montmorillonite clay minerals. When dry, the soil will shrink excessively with deep, several-centimeter wide cracks. Conversely, during the monsoon season, it will expand considerably by sucking up water and induce heaving and instability to the ground (Gidigasu, S. S. R et al., 2013). These extreme changes in volume are responsible for bringing about severe trouble for infrastructure planning and necessitate effective stabilization measures. For conducting a proper analysis of soil parameters, representative samples of soil were collected from numerous locations in Chittur Taluk. Soil excavation was carried out at a depth of 1.5 meters to obtain undisturbed subsoil samples, which are better suited for geotechnical investigations. The samples were placed in airtight containers to prevent moisture loss and contamination. GPS locations, depth readings, and field conditions were recorded for use in future lab tests. Soil samples collected from Chittur Taluk on a systematic basis, this work attempts to introduce effective stabilization practices employing lime, rice husk ash, and coir fibers to enhance strength of the soil


Figure 4: Collection of Sample in Chittur.

Initial Testing of Collected Samples

Specific gravity test was done to identify the relative density of the soil particles that indicates the amount of clay minerals present in it, responsible for the expansive black cotton soil. The sieve analysis test classified the soil in accordance with the distribution of particle sizes and identified that a large portion of the soil contains fine particles, causing a lack of good permeability as well as the issue of retaining water. Atterberg's limit test, such as liquid limit, plastic limit, and shrinkage limit, was conducted to evaluate the consistency, plasticity, and shrink-swell potential of the soil and establish its expansive nature. Standard proctor test was conducted to evaluate the maximum dry density and optimum moisture content, which are necessary to analyze the compaction capability and applicability of the soil for construction. California bearing ratio test was conducted to analyze the strength and load-bearing capacity of soil, and it is important for pavement and road construction; the outcome showed a weak subgrade in need of stabilization. Finally, unconfined compressive strength test was conducted to measure the shear strength of soil as well as its capacity for compression, and it again emphasizes the need for stabilization techniques to enhance its engineering properties and structural stability.

Selection and Collection of Stabilizing Admixtures

Selection and collection of stabilizing admixtures are vital operations in enhancing the engineering properties of black cotton soil. Lime, rice husk ash, and coir fiber were selected in this research as stabilizing agents because they are readily available, cost-effective, and effective in reinforcing soil stability (Zada, U et al., 2023). Lime was used because it can react with black cotton soil clay minerals and produce cementitious compounds that decrease plasticity but increase strength. Lime was obtained from local dealers for consistency in quality. Rice husk ash, being a pozzolanic agent with high silica content, was used because it can increase binding strength of soil when mixed with lime that helps decrease shrink-swell properties and improve durability. It was sourced from rice mills where it is easily available as a byproduct of rice milling. Natural coir fiber, a reinforcing agent, was chosen for its ability to improve soil tensile strength, prevent shrinkage cracks, and stabilize in general. It was sourced from coir processing factories to provide fibers of the right length and consistency. The stabilizers were stored securely under dry conditions to preserve their characteristics prior to using them in the experimental stage. The choice of the admixtures was for the purpose of creating a sustainable and efficient way of stabilizing black cotton soil in Chittur Taluk (Yuan, J et al., 2023).

Preparation of Soil-Stabilizer Mixtures

Soil-stabilizer mixture preparation is one of the important processes to evaluate the effectiveness of lime, rice husk ash, and coir fiber in enhancing the properties of black cotton soil. The soil samples collected were first air-dried to remove excess water and then pulverized to break down large lumps for uniform mixing. The stabilizers were weighed and mixed in proportions as per earlier research and standard guidelines. Lime was blended with varying percentages to record its impact on plasticity loss and gain in strength. Rice husk ash was blended in combination with soil and lime at different percentages to check for pozzolanic reaction and gain in long-term strength. The coir fibers were cut into the specified length and uniformly mixed to achieve satisfactory fiber distribution within the soil matrix, enhancing tensile strength. All the mixtures were thoroughly mixed employing mechanical and hand mixing methods in order to acquire homogeneity. Water was added to attain the best moisture content according to the standard proctor test to enable proper compaction. The pre-mixed combinations were then poured into molds and allowed to cure, where samples were allowed to stabilize under specified conditions for a given duration before testing. Precise preparation of the combinations made possible the precise measurement of their performance in the later tests.

Testing of Stabilized Soil

The stabilized soil was tested under a series of tests to evaluate the improvement in strength, stability, and durability (Adeyemo, K. A et al., 2022). The Atterberg's limit test was performed for identifying the change in plasticity with expectations of reduced liquid and plastic limits owing to stabilizers. The standard proctor test was again performed to determine any change in maximum dry density and optimum moisture content, which is an indication of compaction behavior. California bearing ratio (CBR) test was conducted on stabilized samples to measure the improvement in load-bearing capacity, which is very essential for road and foundation construction. Unconfined compressive strength (UCC) test was employed to analyze the improvement in shear strength and structural strength of the stabilized soil. Swelling and shrinkage tests were conducted to examine the reduction of expansive behavior, especially in lime and rice husk ash mixtures. Permeability tests were also conducted to identify the effects of stabilization on water retention and drainage properties. These tests provided important data for comparison of untreated and stabilized black cotton soil performance (Adane, T. M et al., 2022).

RESULT AND DISCUSSION

Specific gravity test

The specific gravity test is a basic parameter employed to quantify the relative density of soil in terms of its overall composition and constructability. In this research the specific gravity of black cotton soil and IT sensors were measured by the pycnometer method. The study centered on the stabilizing effect of lime, rice husk ash, and coir fiber, gaining understanding into their stabilizing effect on soil densification. The untreated black cotton soil had a specific gravity of 2.63 which lies within the general range of 2.6 to 2.75 for regur soils which are usually encountered in high clay content areas. This value means that black cotton soil contains fine-grained minerals of moderate density. Because it is expansive in nature and has a poor load-carrying capacity, stabilization is required to enhance its engineering characteristics. Lime stabilization resulted in a linear increase in specific gravity. The specific gravity values increased to 2.65, 2.68, and 2.70 for 5%, 10%, and 15% lime content respectively. This rise is caused by the chemical reactions between the lime and the clay minerals that result in cementitious compounds. These compounds can bind soil particles better lessening void areas and enhancing densification. The increase in specific gravity indicates that lime-treated soil is denser and structurally sound a good option to improve black cotton soil. The density increase is also associated with enhanced load capacity and lower shrinkage. Conversely, the addition of rice husk ash (RHA) was responsible for lower specific gravity values. The values of specific gravity fell to 2.62, 2.60, and 2.58 in the case of 5%, 10%, and 15% RHA content respectively. The decrease in density can be attributed to the fact that rice husk ash has a lower density than the soil particles it is replacing. As RHA is a light material, its addition reduces the total density of the soil but continues to provide stabilization by pozzolanic reactions. Although RHA does not have a significant impact on soil densification, it has other advantages, including decreasing compressibility and improving long-term strength development, especially when mixed with lime. The addition of coir fiber resulted in a decrease in specific gravity. In contrast to lime which adds to soil densification, the coir fiber is reinforcement, providing greater tensile strength and resistance to cracking and not a higher density (Sridhar, R et al., 2023). The minor reduction in specific gravity suggests that coir fiber does not weigh heavily on the soil but significantly enhances the flexibility and hardness of the soil. The results of this research indicate the unique impact of various stabilizers on the specific gravity of black cotton soil. Lime increases soil density by cementitious bonding and is thus the best stabilizer to enhance structural stability. Rice husk ash decreases density but contributes to soil refinement and pozzolanic reactivity while coir fiber provides strength and flexibility but not densification. These findings can assist in the determination of suitable stabilization methods for improvement of black cotton soil in Chittur Taluk to work better in construction.

Figure 5: Pycnometer method test on BCS.

Table 2: Specific Gravity test on BCS with Admixtures.

Stabilizer	Percentage (%)	Specific Gravity
Black Cotton Soil (Control Sample)	0	2.63
Lime	5	2.65
	10	2.68
	15	2.70
Rice Husk Ash	5	2.62
	10	2.60
	15	2.58
Coir Fiber	0.25	2.63
	0.5	2.62
	1	2.60

Sieve Analysis Test

Sieve test is a basic test utilized in measuring the particle size distribution of the soil, which is essential in establishing engineering properties. The untreated black cotton soil and the stabilized soils were subjected to sieve analysis during measurement of the effect caused by various stabilizers, e.g., lime, rice husk ash, and coir fiber. Fineness modulus, which is a soil gradation measure, was utilized to quantify the changes in particle distribution caused by stabilization.The fineness modulus of the natural black cotton soil was 2.05 and it was categorized as CH (high plasticity clay) according to the Unified Soil Classification System (USCS). This indicates that the soil has a high proportion of clay, which leads to high plasticity and swelling potential. When lime was added as a stabilizer, there were obvious trends towards enhanced fineness modulus. Values increased to 2.10, 2.15, and 2.20 in case of 5%, 10%, and 15% lime content, respectively. This is the trend showing the reduction in clay activity because lime promotes flocculation and agglomeration of clay's fine particles, causing improved gradation and reduced plasticity. The increase in fineness modulus implies that the soil became coarse in nature after the application of lime, enhancing its engineering properties such as workability and stability. In contrast the addition of rice husk ash (RHA) led to a decrease in the fineness modulus. The values dropped to 2.03, 2.00, and 1.98 for 5%, 10%, and 15% rice husk ash content, respectively. The reason for the decrease in fineness modulus is the fine quality of rice husk ash particles, which tend to fill the porous space between the soil matrix. This activity increases cohesiveness and contributes to densification of the soil. However, while affecting the particle packing RHA does not contribute much to altering the gradation of the soil. Rather, it may assist in other properties of the soil, such as strength and reduction in shrinkage, due to its pozzolanic reaction when blended with lime. Similarly, the introduction of coir fiber had a marginal impact on the fineness modulus. The values of 2.04, 2.03, and 2.01 for 0.25%, 0.5%, and 1% fiber contents, respectively, were recorded. The marginal reduction in fineness modulus with an increase in fiber content suggests that coir fibers have little impact on particle size distribution. In contrast to lime, which actively changes soil gradation, coir fibers mainly act as reinforcement by improving the tensile strength and ductility of the soil. The low impact of coir fiber on fineness modulus suggests that its contribution towards soil stabilization is more towards enhancing load-carrying capacity and arresting crack development than altering particle size distribution (Vengala, J et al., 2024). From the results, it can be seen that lime is the best stabilizer in enhancing black cotton soil gradation by lessening its plasticity and clay activity. On the contrary, rice husk ash and coir fibers both have insignificant effects on sieve analysis but might introduce other advantages like enhanced cohesion, shrinkage reduction, and tensile strength. Their combination might provide the perfect balance among soil gradation, strength, and durability and be extremely effective for engineering purposes, particularly in areas where black cotton soil is difficult to construction and infrastructure construction (Shinde, B et al., 2024)

Table 3: Sieve Analysis test on BCS with Admixtures.

Stabilizer	Percentage (%)	Fineness Modulus (FM)

Black Cotton Soil (Control Sample)	0	2.05
Lime	5	2.10
	10	2.15
	15	2.20
Rice Husk Ash	5	2.03
	10	2.00
	15	1.98
Coir Fiber	0.25	2.04
	0.5	2.03
	1	2.01

Figure 6: Sieve Analysis on Black Cotton Soil.

Atterberg's limit test

Atterberg's limit test was conducted to find the consistency limits of black cotton soil and its stabilized forms. The liquid limit of the untreated soil was 27.5%, plastic limit was 20.54%, and plasticity index (PI) was 7, which represents moderate plasticity (Zhang, P et al., 2019). The optimum moisture content (OMC) was 15%. On the addition of lime, the liquid limit reduced step by step from 26.2% to 23.5% with an increase in lime content from 5% to 15%, whereas the plastic limit rose from 21.5% to 23.0%, lowering the plasticity index considerably. The plasticity index fell to 0.5% at 15% lime, indicating a remarkable improvement in soil stability. The inclusion of rice husk ash also had a lesser influence on plasticity, where the liquid limit reduced marginally from 27.0% to 26.0% and the plastic limit rose slightly to 21.6% at 15% ash content. Coir fiber did not have much influence on plasticity, where the liquid limit was kept close to the natural soil and the plastic limit increased marginally. The findings verify that lime is the most efficient stabilizer in lowering plasticity and enhancing soil workability, with rice husk ash and coir fiber helping moderately in enhancing consistency limits (Yadu, L et al., 2024).

Figure 7: Atterberg's limit test on BCS.

Table 4: Atterberg's limit test Results.

Stabilizer	Percentage (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Optimum Moisture Content (OMC) (%)
Black Cotton Soil	0	27.5	20.54	7	15
Lime	5	26.2	21.5	4.7	16.2
	10	24.8	22.3	2.5	17.0
	15	23.5	23.0	0.5	17.8
Rice Husk Ash	5	27.0	20.8	6.2	15.5
	10	26.5	21.2	5.3	16.0
	15	26.0	21.6	4.4	16.4
Coir Fiber	0.25	27.4	20.6	6.8	15.2
	0.5	27.3	20.7	6.6	15.4
	1	27.1	20.9	6.2	15.6

Standard proctor test

Standard Proctor Test was performed to find the maximum dry density (MDD) and optimum moisture content (OMC) of black cotton soil and its stabilized forms (Singh, S et al., 2013). The dry density of untreated black cotton soil was 1.92 g/cc with an OMC of 15%. Upon addition of lime, the MDD was found to be 1.94 g/cc, 1.96 g/cc, and 1.98 g/cc for 5%, 10%, and 15% lime content, respectively, showing that soil compaction characteristics improved. The OMC also rose as the amount of water needed for hydration reactions increased. Conversely, rice husk ash lowered the MDD by a small margin, with values dropping from 1.91 g/cc at 5% to 1.87 g/cc at 15% because of its lower density and light weight. Coir fiber also lowered the MDD by a small margin, with values dropping from 1.91 g/cc at 0.25% to 1.88 g/cc at 1%, since fiber particles do not add to compaction as fine mineral particles do

Table 5: Standard Proctor Test Result On BCS.

Stabilizer	Percentage (%)	Maximum Dry Density (MDD) (g/cc)	Optimum Moisture Content (OMC) (%)
Black Cotton Soil	0	1.92	15
	5	1.94	16.2

Lime	10	1.96	17.0
	15	1.98	17.8
Rice Husk Ash	5	1.91	15.5
	10	1.89	16.0
	15	1.87	16.4
Coir Fiber	0.25	1.91	15.2
	0.5	1.90	15.4
	1	1.88	15.6

Figure 8: Standard Proctor Test on BCS.

California Bearing Ratio Test

The California Bearing Ratio test is a common method for assessing the strength and load capacity of soil, especially in road construction and subgrade stability (Jayakrishnan, R et al., 2022). Due to the difficult nature of black cotton soil, being very expansive in nature with poor engineering properties it is necessary to improve its strength by stabilization. In this research, the influence of lime, rice husk ash, and coir fiber on black cotton soil CBR values was investigated to establish the best stabilizing agent.The untreated black cotton soil CBR value was 5.12%, which is poor in supporting heavy loads. This verifies the poor structural strength of the soil and its susceptibility to deformation under imposed pressure which renders it unsuitable for direct application in pavement layers without alteration. The addition of stabilizers was intended to enhance this basic property and render the soil more suitable for construction purposes. The CBR was significantly enhanced to 6.8%, 8.5%, and 10.2% for 5%, 10%, and 15% lime content, respectively. The improvement in load-bearing capacity results from the pozzolanic reaction between the lime and clay minerals, which forms cementitious compounds. The soil particles are bound together by these compounds, decreasing plasticity and enhancing strength. The CBR values were raised to 5.6%, 6.1%, and 6.7% for 5%, 10%, and 15% RHA content, respectively. Strength improvement in the soil is due to rice husk ash containing silica, which reacts with clay minerals and improves the structure of the soil. RHA by itself though has a lesser binding capacity compared to lime, restricting its scope to a lesser rise in load-bearing strength. Though it makes the soil more stable it plays a more specific role in compressibility reduction and cohesion enhancement rather than a direct bearing capacity increase. However, the use of RHA in combination with lime can be investigated for cost-effective and eco-friendly stabilization methods. Coir fiber, however, showed a marginal increase in CBR values. The values measured were 5.4%, 5.8%, and 6.2% for 0.25%, 0.5%, and 1% fiber content, respectively (Jayakrishnan, R et al., 2022). In contrast to lime and RHA, which chemically modify soil composition, coir fiber is mostly used as reinforcement. It increases tensile strength, inhibits crack development and redistributes stress better. Its contribution to load-carrying capacity is still low. The fibers enhance soil performance by enhancing durability and flexibility which makes them ideal for use in applications where resistance to shrinkage and cracking is critical.

Table 6: California Bearing Ratio Test Result.

Stabilizer	Percentage (%)	CBR Value (%)
Black Cotton Soil (Control Sample)	0	5.12
Lime	5	6.8
	10	8.5
	15	10.2
Rice Husk Ash	5	5.6
	10	6.1
	15	6.7
Coir Fiber	0.25	5.4
	0.5	5.8
	1	6.2

Figure 9: California Bearing Ratio Test on BCS.

Unconfined Compressive Strength (UCC)

Black cotton soil, which is expansive and has a low bearing capacity, is quite challenging to construct. A range of tests was performed on it to assess its strength and stability properties, i.e., its unconfined compressive strength (UCS) and shear strength both prior to and following stabilization with lime, rice husk ash, and coir fiber (Sawarkar, R et al., 2023). It's very different effects in improving the engineering properties of black cotton soil are seen in the results. The natural black cotton soil had a UCS of 1.8 g/cm² and a shear strength of 0.91 g/cm². These two readings reflect low structural strength, thus not feasible to be utilized in load-carrying projects directly without being stabilized. Based on its plasticity and swell and shrink tendency due to changing water content, the black cotton soil needs stabilization for it to have better quality and performance within the construction processes. Lime was the best stabilizer in highly enhancing soil strength. Adding 5%, 10%, and 15% lime improved UCS to 2.4 g/cm², 3.1 g/cm², and 3.9 g/cm², respectively. Likewise, shear strength also enhanced to 1.2 g/cm², 1.6 g/cm², and 2.0 g/cm². This improvement in strength is due to the chemical interaction between lime and clay minerals resulting in cementitious compounds. These responses enable particle agglomeration, decrease plasticity and form a more compact soil structure. The UCS values were 2.0 g/cm², 2.3 g/cm², and 2.6 g/cm² for 5%, 10%, and 15% RHA content, respectively, and the shear strength values increased to 1.0 g/cm², 1.2 g/cm², and 1.4 g/cm². The modest improvement is due to the silica content in RHA, which reacts with clay particles to purify the soil structure. RHA mainly improves soil stabilization by lowering its compressibility and enhancing cohesion. But it lacks the same cementitious effect as lime and thus is less effective in significantly enhancing soil strength. Notwithstanding this, RHA is still a green and sustainable option for soil stabilization, particularly in conjunction with other stabilizers. The addition of coir fiber had a comparatively small but positive impact on soil stability. With 0.25%, 0.5%, and 1% fiber content, the UCS increased to 1.9 g/cm², 2.1 g/cm², and 2.3 g/cm², respectively. In turn, the shear strength rose to 0.95 g/cm², 1.05 g/cm², and 1.15 g/cm². In contrast to RHA and lime, coir fiber does not have a direct impact on soil compressive strength but increases flexibility, crack resistance, and general durability. The fibers are used as reinforcement, spreading the stresses more efficiently and avoiding failure through sudden fracture (Eberemu, A. O et al., 2013). This makes coir fiber-stabilized soil especially applicable to uses where resistance to cracking and flexibility are essential.

Table 7: Unconfined Compressive Strength Test Result.

Stabilizer	Percentage (%)	Unconfined Compressive Strength (UCS) (g/cm²)	Shear Strength (g/cm²)
Black Cotton Soil (Control Sample)	0	1.8	0.91
Lime	5	2.4	1.2
	10	3.1	1.6
	15	3.9	2.0
Rice Husk Ash	5	2.0	1.0
	10	2.3	1.2
	15	2.6	1.4
Coir Fiber	0.25	1.9	0.95
	0.5	2.1	1.05
	1	2.3	1.15

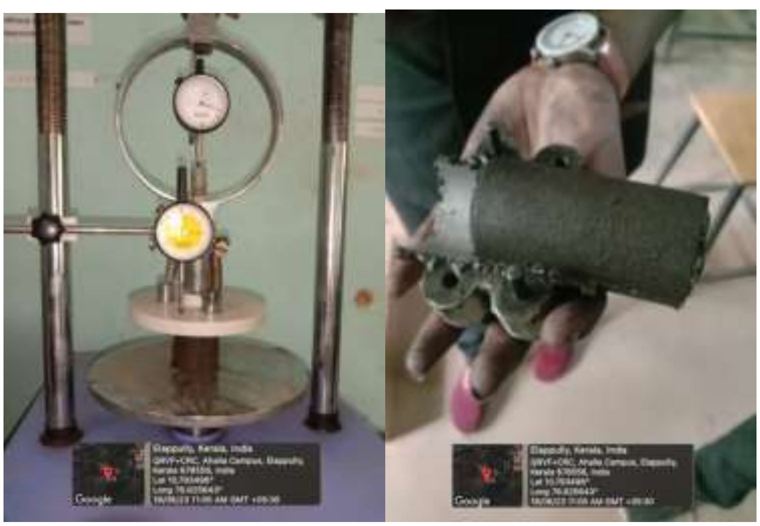

Figure 01: Unconfined Compressive Strength Test on BCS.

CONCLUSION

This research targeted the improvement of engineering properties of Chittur Taluk's black cotton soil, Palakkad District, with stabilizers such as lime, rice husk ash, and coir fiber. Some laboratory tests were performed to find out the influence of these stabilizers on physical and mechanical soil properties. The Specific Gravity test showed that the specific gravity of the untreated soil was 2.63 and increased to 2.91 after adding 15% lime, which meant that the soil matrix density was increased. The Sieve Analysis test showed the soil to be high-plasticity clay (CH) of the Unified Soil Classification System (USCS) with a fineness modulus of 2.05. Atterberg's Limit test showed the liquid limit as 27.5%, plastic limit as 20.54%, and plasticity index as 7, also enhancing the expansive nature of soil. Standard Proctor test calculated the optimum dry density of raw soil as 1.92 g/cc, which rose to 2.12 g/cc in 15% lime, indicating greater compaction and carrying capacity. California Bearing Ratio (CBR) test, which is utilized to find the strength of soil for pavement subgrades, showed a CBR value of 5.12 in the native condition which became much higher with stabilizers especially lime. Unconfined Compressive Strength (UCC) test yielded a UCS value of 1.8 g/cm² and a shear strength value of 0.91 g/cm² for the raw soil. After stabilization, UCS was 3.9 g/cm² and shear strength 2.0 g/cm² at 15% lime, which shows notable improvement in strength. Rice husk ash and coir fiber were also good, though their impact was less compared to lime. It is seen from the results that the best stabilizing agent is lime as it improved the soil strength and stability considerably by developing cementing compounds that can cement soil particles together. Rice husk ash and coir fiber also improved soil quality by improving plasticity reduction, shear strength improvement, and shrinkage cracking limitation. If these stabilizers are used collectively, black cotton soil can even be converted to a more consolidated and structurally sound material with greater applicability in construction usage like roads, embankments, and bed of foundations. The research underscores the use of locally derived stabilizers in eliminating expansive soils' issues for pushing cost-effective along with environmentally friendly soil improvement methods for infrastructure development.

REFERENCES

1. Hakari, U. D., & Puranik, S. C. (2012). Stabilization of black cotton soils using fly ash. Hubballi-Dharwad Municipal Corporation area, Karnatak, India, 12(2).
2. Satish, S., Koganti, S. P., Raja, K. H., & Sai, K. R. (2018). Stabilization of black cotton soil by using cement, lime and rice husk in flexible pavements. International Journal of Engineering & Technology, 7(2.1), 24-27.
3. https://doi.org/10.14419/ijet.v7i2.1.9877
4. Jhariya, S., &Parte, S. S. (2018). Stabilization of black cotton soil by the waste sludge (hypo-sludge). Int. J. Sci. Dev. Res, 3, 445-449.
5. Singh, S., &Vasaikar, H. B. (2013). Stabilization of black cotton soil using lime. Int. J. Sci. Res, 4(4), 2090-2094.
6. Ikeagwuani, C. C., Obeta, I. N., &Agunwamba, J. C. (2019). Stabilization of black cotton soil subgrade using sawdust ash and lime. Soils and Foundations, 59(1), 162-175.
7. http://dx.doi.org/10.1016/j.sandf.2018.10.004
8. Zada, U., Jamal, A., Iqbal, M., Eldin, S. M., Almoshaogeh, M., Bekkouche, S. R., &Almuaythir, S. (2023). Recent advances in expansive soil stabilization using admixtures: current challenges and opportunities. Case Studies in Construction Materials, 18, e01985.
9. http://dx.doi.org/10.1016/j.cscm.2023.e01985
10. Mohamed, A. A. M. S., Yuan, J., Al-Ajamee, M., Dong, Y., Ren, Y., &Hakuzweyezu, T. (2023). Improvement of expansive soil characteristics stabilized with sawdust ash, high calcium fly ash and cement. Case Studies in Construction Materials, 18, e01894.
11. http://dx.doi.org/10.1016/j.cscm.2023.e01894
12. Almuaythir, S., & Abbas, M. F. (2023). Expansive soil remediation using cement kiln dust as stabilizer. Case Studies in Construction Materials, 18, e01983.
13. http://dx.doi.org/10.1016/j.cscm.2023.e01983
14. de Araújo, M. T., Ferrazzo, S. T., Chaves, H. M., da Rocha, C. G., & Consoli, N. C. (2023). Mechanical behavior, mineralogy, and microstructure of alkali-activated wastes-based binder for a clayey soil stabilization. Construction and Building Materials, 362, 129757. http://dx.doi.org/10.1016/j.conbuildmat.2022.129757
15. Adeyemo, K. A., Yunusa, G. H., Ishola, K., Bello, A. A., & Adewale, S. A. (2022). Cassava peel ash modified black cotton soil as material for hydraulic barriers in municipal solid waste containment facility. Cleaner Waste Systems, 3, 100045.
16. http://dx.doi.org/10.1016/j.clwas.2022.100045
17. Adane, T. M., Araya, A. A., Karthikeyan, B., Selvaraj, S. K., Jose, S., John Rajan, A., & Vincent Herald Wilson, D. (2022). A novel technique to utilize second waste of plastic bottle as soil reinforcement: a comparative study on mechanical properties with natural black cotton soil. Advances in Civil Engineering, 2022(1), 7225455.
18. https://doi.org/10.1155/2022/7225455
19. Kabeta, W. F., & Lemma, H. (2023). Modeling the application of steel slag in stabilizing expansive soil. Modeling Earth Systems and Environment, 9(4), 4023-4030.
20. http://dx.doi.org/10.1007/s40808-023-01734-1
21. Pakir, F. (2022). The effect of groundnut shell ash on soil stabilization. Journal of Sustainable Underground Exploration, 2(1), 34-40.

22. http://dx.doi.org/10.30880/jsue.2022.02.01.005
23. Singh, N. K., & Kalita, A. (2021). Use of Bagasse Ash and Coconut Fiber in Stabilization of Black Cotton Soil. In Advances in Sustainable Construction Materials: Select Proceedings of ASCM 2020 (pp. 351-360). Singapore: Springer Singapore.
24. http://dx.doi.org/10.1007/978-981-33-4590-4_33
25. Etim, R. K., Eberemu, A. O., &Osinubi, K. J. (2017). Stabilization of black cotton soil with lime and iron ore tailings admixture. Transportation Geotechnics, 10, 85-95.
26. http://dx.doi.org/10.1016/j.trgeo.2017.01.002
27. Zhang, P., Huang, J., Zhang, P., Wen, W., Li, W., Xu, S., ... & Miao, S. (2019). Swelling suppression of black cotton soil by means of liquid immersion and surface modification. Heliyon, 5(12).
28. http://dx.doi.org/10.1016/j.heliyon.2019.e02999
29. Singh, S., &Vasaikar, H. B. (2013). Stabilization of black cotton soil using lime. Int. J. Sci. Res, 4(4), 2090-2094.
30. Sivakumar Babu, G. L., Vasudevan, A. K., &Sayida, M. K. (2008). Use of coir fibers for improving the engineering properties of expansive soils. Journal of Natural Fibers, 5(1), 61-75. http://dx.doi.org/10.1080/15440470801901522
31. Sridhar, R., Guruprasad, H. C., Naveenkumar, D. T., & Sangeetha, D. M. (2023). Influence of treated coir fiber on durability properties of black cotton soil. Materials Today: Proceedings, 80, 1611-1616. https://doi.org/10.1016/j.matpr.2023.02.127
32. Shinde, B., Sangale, A., Pranita, M., Sanagle, J., & Roham, C. (2024). Utilization of waste materials for soil stabilization: A comprehensive review. Progress in Engineering Science, 100009. https://doi.org/10.1016/j.pes.2024.100009
33. Yadu, L., Tripathi, R. K., & Singh, D. (2011). Comparison of fly ash and rice husk ash stabilized black cotton soil. International Journal of Earth Sciences and Engineering, 4(6), 42-45. https://doi.org/10.12691/materials-2-3-2
34. Gidigasu, S. S. R., &Gawu, S. K. (2013). The mode of formation, nature and geotechnical characteristics of black cotton soils-a review. Sci Res Essays, 1, 377-90.
35. Eberemu, A. O., & Sada, H. (2013). Compressibility characteristics of compacted black cotton soil treated with rice husk ash. Nigerian Journal of Technology, 32(3), 507-521.
36. Jayakrishnan, R., Sukumaran, A., Aswini, M., Saji, A., Faiz, M., & Sivadas, S. K. (2022). Stabilization of black cotton soil using lime, coir fiber & rice husk. International Journal of Engineering and Management Research, 12(2), 93-96.
37. https://doi.org/10.31033/ijemr.12.2.14
38. Vengala, J., Dharek, M. S., Pramod, K., Thejaswi, P., & Poudel, A. (2024). Effect of Sugarcane Bagasse Ash and Lime on Physico-Mechanical Properties of Clayey Soil. Advances in Civil Engineering, 2024(1), 3516016.
39. http://dx.doi.org/10.1155/adce/3516016
40. Sawarkar, R., Rakh, A., & Rathod, R. (2023). Stabilization of Black Cotton Soil Using Lime and Bamboo Fiber Mixture as a Subgrade Material. International Journal for Research in Applied Science and Engineering Technology, 77, 4741-4753.
41. http://dx.doi.org/10.22214/ijraset.2023.54517
42. Chamberlin, K. S., Rao, M. R., & Suresh, K. (2023). Impact of rice husk ash and xanthan gum in road works by improving the characteristics of expansive soil (black cotton soil)–an inclusive study. In E3S Web of Conferences (Vol. 391, p. 01004). EDP Sciences.
43. http://dx.doi.org/10.1051/e3sconf/202339101004
44. Gobinath, R., Raja, G., Prasath, E., Shyamala, G., Viloria, A., & Varela, N. (2020). Studies on strength characteristics of black cotton soil by using novel SiO2 combination as a stabilizing agent. Materials Today: Proceedings, 27, 657-663.
45. Kaushal, V., &Guleria, S. P. (2015). Geotechnical investigation of black cotton soils. International Journal of Advances in Engineering Sciences, 5(2), 15-22.
46. Goutham, D. R., Krishnaiah, A. J., & Pranathi, B. (2021). Advancements In Effective Black Cotton Soil Stabilization: A Review. ADBU Journal of Engineering Technology, 10.