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A study of the shear strength properties of expansive soil treated with fly ash admixture

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A B S T R A C T

The behavior of clay minerals in expansive soils causes them to exhibit shrink-swell characteristics, making them unsuitable for engineering purposes in their natural state. To address this problem, researchers conducted direct shear experiments using fly ash as an admixture and black cotton soil as an expanding soil to explore the strength parameter. The experiments were conducted with varying amounts of fly ash ranging from 2% to 20%. Two arrangements of test series were made, and in the principal series, tests were made utilizing five unique densities and comparing dampness contents. The outcomes showed that the point of inside grating and union expanded directly up to the ideal dampness content and most significant dry thickness before diminishing. The subsequent series showed that the end of inward rubbing grew straightly with the expansion of fly debris admixture, yet attachment reduced after 10% admixture. The decrease in shear strength was because of the diminished passion, as the fly debris' cohesionless attributes took over as the admixture rate increased above 10%. Based on these findings, adding fly ash in small quantities to black cotton soil is recommended to avoid weakening it.

1. Introduction

Black cotton soils cover a significant portion of India's geographical area, with about 20% of the country's total landmass affected. The Deccan Plateau, West Madhya Pradesh, Rajasthan, sections of Andhra Pradesh and Karnataka, and the Bundelkhand region of Uttar Pradesh are among the places with a high concentration of these soils, commonly referred to as expansive soils. Despite being highly fertile and ideal for cotton farming, black cotton soils present significant challenges when used as a building material or foundation due to their propensity for volume changes. Black cotton soils are expansive, dark-colored soils with much clay in them. They have been employed for generations for cotton growing, so they are named as such. Due to their great susceptibility to variations in moisture content, they might cause serious issues when utilized for building. Black cotton soils have the potential to seriously damage any structures erected on them because of their ability to expand and contract when exposed to moisture.

1.1. Stabilization of Black Cotton Soils

Employing black cotton soil as a foundation or building material requires a process known as stabilization, which involves altering its properties to render it fit for construction purposes. To enhance its stability, soil stabilization techniques include incorporating lime, cement, and fly ash into the soil. Several methods of soil stabilization are available, each with its unique benefits and drawbacks.

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1.2. Challenges of Building on Black Cotton Soils

Black cotton soils present significant challenges when used for construction purposes. One of the most critical challenges is their propensity for volume changes. When the soil absorbs water, it swells; when it dries out, it shrinks, which can cause significant damage to structures built on it. This differential settlement can result in cracks in walls and other parts of the building, compromising the structure's integrity. Another challenge of building on black cotton soils is their weak strength characteristics. Clay soils generally have low strength, which presents significant construction challenges. The foundation of a building on black cotton soil needs to be deep enough to avoid the effects of swelling and shrinking, which can cause significant damage to the building's structure.

1.3. Soil Stabilization Techniques

Black cotton soil is a challenging material to use for construction, but various soil stabilization methods can help. Lime adjustment is one such methodology that includes adding lime to the dirt. By responding with dirt minerals, lime delivers a concrete-like substance that builds the dirt's solidarity and diminishes its weakness to dampness changes. Concrete adjustment is one more strategy that includes adding concrete to the ground to work on its solidarity and security. Concrete responds with the ground to create a solidified substance that upgrades the dirt's heap-bearing limit. Fly debris, a side-effect of coal-terminated power plants, is another material that balances dark cotton soil. When combined with the soil, fly ash can improve its strength and decrease its susceptibility to moisture changes, making it more suitable for construction. Overall, several methods of soil stabilization can be utilized, each with its unique advantages and limitations.

1.4. **The Role of Forest Ecosystems in Soil Stabilization**

Forest ecosystems can play a significant role in stabilizing black cotton soil. The dense vegetation cover in forests can help prevent soil erosion and reduce the impact of moisture changes on the ground. Forest ecosystems can also help increase the soil's organic matter content, improving its stability and reducing its susceptibility to erosion. Fig. 1 depicts a dense forest ecosystem in the Kalahandi District of Odisha, India. This image is significant because it highlights the possible contribution of forest ecosystems to soil stabilization and erosion prevention, which can significantly affect land-use planning and the environment's sustainability.

Fig. 1. Photograph of a dense forest ecosystem in the Kalahandi District of Odisha, India

This trait is a consequence of the presence of the mineral montmorillonite. At times, avoiding clayey soil in such locations is challenging because of the need for more feasible alternatives with substantial load-bearing capability. An array of admixtures must be stabilized to augment the subgrade strength of the clay-based ground in this area. Additionally, expansive or black cotton soil is present in some regions of Odisha, such as Cuttack, Balangir, Bargarh, Kalahandi, Titlagarh, and Khordha.

The conduct of stabilized black cotton soil has been the subject of numerous investigations regarding ground-improvement methods. In particular, the effects of incorporating fly ash into expansive soil have been closely scrutinized. This article highlights a few studies on stabilizing expansive soil using various admixtures. For instance, in 2018, Karthick and colleagues evaluated soil with different fly ash replacement levels, including 5%, 10%, and 15%. The results revealed that the soil amended with 10% fly ash replacement exhibited the best performance. Overall, these investigations shed light on the potential benefits of utilizing different soil stabilization methods to enhance the properties of black cotton soil. However, a decline in performance was observed once the replacement level hit 10%. Therefore, utilizing up to 10% of fly ash replacement for soil stabilization may be beneficial.

A scope of inventive techniques has been investigated to upgrade the security of dark cotton soil for development purposes. In one such review, Murmu et al. (2020) analyzed the capability of utilizing fly debris geopolymer to settle the dirt. The specialists gained promising headway by fluctuating the fly debris focus from 5% to 20% and exposing the examples to a 5M NaOH arrangement with low fixation. In a different examination, Bekkouche and group (2002) researched the effect of regular strands on sweeping soils' physical and mechanical properties. The review uncovered that consolidating 1%, 5%, and 10% regular filaments prompted massive upgrades in these properties. The enlarging coefficient of the treated soil diminished by 86%.

Chai and Carter (2011) found that using rice husk debris worked on the strength and soundness of far-reaching soil. One more concentrate by Zhang et al. (2016) showed that the expansion of lignin further developed the pressure execution of expansive soil. In an alternate methodology, Yu et al. (2019) assessed the capability of microbial-prompted calcite precipitation to adjust broad soil. In the meantime, Deng et al. (2021) utilized manufactured strands to improve the mechanical properties of expansive soil. In a similar report, Li et al. (2021) investigated the viability of soil nailing with engineered filaments as an adjustment procedure for sweeping ground.

Concerning the impact of temperature on far-reaching soil, others announced that the unconfined compressive strength of expansive soil expanded with temperature. Notwithstanding, Pei et al. (2020) observed that the impact of temperature on the enlarging conduct of expansive soil was more intricate, as it relied upon elements for example, the dirt kind and dampness content. At last, Huang et al. (2019) concentrated on the shear strength of expansive soil because of freeze-defrost cycles and found that it can harm dirt construction tremendously.

While Seco et al. (2011) and Al-Baidhani and Al-Taie (2019) examine trial discoveries on the usage of waste materials and stone waste materials separately, to balance out far-reaching soils, Petry and Little (2002) give a verifiable outline of the improvements made in understanding and settling expansive soils. In the domain of sweeping soil adjustment, various examinations have analyzed the capability of waste materials to develop soil execution further. Hussein et al. (2019) investigate using capricious materials, for example, flying debris, quarry waste, and rice husk, notwithstanding traditionally added substances like concrete, lime, and sand. Both Hussein et al. what's more, and Fondjo et al. (2021) report enhancements in soil mechanical properties and expansivity decrease while consolidating waste materials. The review introduced in this article centers around fly debris and dark cotton soil blends, with direct shear testing utilized to decide the impact of differing fly debris admixtures and soil densities on shear strength. The Outcomes and Conversations segment subtleties the philosophy employed, while the Ends area alerts against extreme fly debris to forestall a decrease in soil shear strength. The review's discoveries offer significant knowledge into the way of behaving of dark cotton soil blended in with fly debris and add to long-haul answers for extensive soil improvement.

2. Experimental Programme and Methodology

2.1 Raw materials

A soil sample from the neighboring Kalahandi region of Bhawanipatna was procured for the present investigation. The model underwent a free swell test in line with IS:2720-1977 to determine its propensity to swell. The sample obtained from the site was subjected to a rigorous drying process in an oven at 1000 to 1050 degrees Celsius for 24 hours to ensure its absolute dryness. The fly ash added as an agent was sourced from a Kalahandi brick mill that produces fly ash bricks. The properties of the dark cotton soil considered are displayed in Table 1, with a particular gravity of 2.49. The dirt's ideal dampness content (OMC) was 18.557%, while its most significant dry thickness (MDD) was 1.628 gm/cc. The average dampness content of the dirt was 7.28%; it wasn't altogether dry to show that it was. It was found to have the capacity to extend when dampened, as confirmed by a free swell file of the half. The dampness content at which the dirt changes from a plastic to a fluid state, otherwise called as far as not entirely settled, is 54%. As far as possible, the dampness content at which the dirt fails to act like a plastic material was viewed as 31.08%. At long last, as far as possible, the dampness content at which the dirt quits is not entirely set in stone to be 8.2%. These properties are fundamental in appreciating dark cotton soil's behavior and deciphering the review's results.

Table 1. Characteristics of Black Cotton Soi

Sl. No.	Property	Value
1	Specific gravity	2.49
2	Optimum moisture content (OMC)	18.557%
3	Maximum dry density (MDD)	1.628 gm/cc
4	Natural moisture content	7.28%
5	Free swell index	50%
6	Liquid limit	54%
7	Plastic limit	31.08%
8	Shrinkage limit	8.2%

Table 2 presents pertinent information about the characteristics of the fly ash used in the investigation. The experimental analysis revealed that the fly ash had a consistency of 55, surpassing the range prescribed by IS:4031, which typically falls between 45 and 65. Consistency, which gauges the flowability of the fly ash, is a critical factor in determining its efficacy as a construction material. The fineness of the fly ash was found to be 24, according to the analysis, even though IS:4031 does not specify a Fig. Fineness, a metric of the particle size distribution, is a crucial characteristic that influences fly ash's reactivity and pozzolanic activity. Lastly, through experimentation, the fly ash was determined to have a specific gravity of 2.05, which falls within the range of 1.6-2.6 outlined by IS:4031. To accomplish the ideal result, how much fly debris is required in the dirt relies upon its particular gravity, which is a proportion of its thickness contrasted with water. To comprehend the behavior of fly ash and evaluate the study's findings, it is essential to consider the characteristics listed in Table 2.

Table 2. Properties of fly ash

Characteristics	The value obtained experimentally (Class F)	Value specified by IS:4031
Consistency	55	45-65
Fineness	24	NA
Specific gravity	2.05	1.6-2.6

2.2 Methodology

This study plans to examine the capability of fly debris as an added substance material to work on the strength of dark cotton soil. The testing system includes deciding the file characteristics of the dirt and admixture utilizing different tests like direct shear, free swell, and soil compaction. The shear strength conduct of dark cotton soil was broken down under various densities and dampness contents. Furthermore, the effect of blending proportions on the shear strength conduct of fly debris combined with dark cotton soil was likewise noticed. The review used combining harmonies going from 2% to 20% of fly debris. The dirt's expanding potential was viewed as huge and practically identical to different soils being scrutinized for adjustment. Besides, the examination dives into the portrayal of dark cotton soil in geoengineering. File trademark tests were performed to get more familiar with fly debris properties. The rapid shear test was directed to quantify soil strength boundaries under differing dampness content and dry thickness conditions. The test complied with the rules specified in IS: 2720 (Section X) (1991). The review underlines the significance of understanding flying debris and dark cotton soil properties in accomplishing the ideal result. OMC employed a metallic split mold that measured 60mm in breadth, 60mm in width, and 25mm in height to prepare samples for this test. Begin by weighing the initial load of dirt in the pan. Then, subject these samples to direct shear testing at a 1.25mm/min strain rate until the model failed. Determine 15% of the diameter in mm using the height and diameter of the shear box. Assembling the direct shear device requires careful attention. First, insert the shear tube, filter paper, and porous stone. Add sand to the box, level it off, and place the top plate with the ball on top. Once the gap screws are removed, increase the gap between the shear box's two parts to around 0.025 inches using the alignment screw. Weigh the soil's surface and note the amount of dirt used. Zero the gauges, and afterward change the upward burden to a foreordained level before applying it to the dirt example. Turn over the engine at the ideal speed and take estimations from the flat removal measure, vertical dislodging check, and shear load check to guarantee that the consistent shearing rate is coordinated. Continue to take assessments until the even dislodging surpass 15% of the example region or after the top before the level shear power's downfall.

The main test series analyzed the shear strength boundary's behavior under differing densities and dampness contents. In the second test series, the example was created with the most extreme dry thickness, ideal dampness content, and flying debris to various extents to research how the shear strength boundary behaved. Check out Fig. 2 for a visual representation of the testing machine, shear box, and sample following the testing procedure.

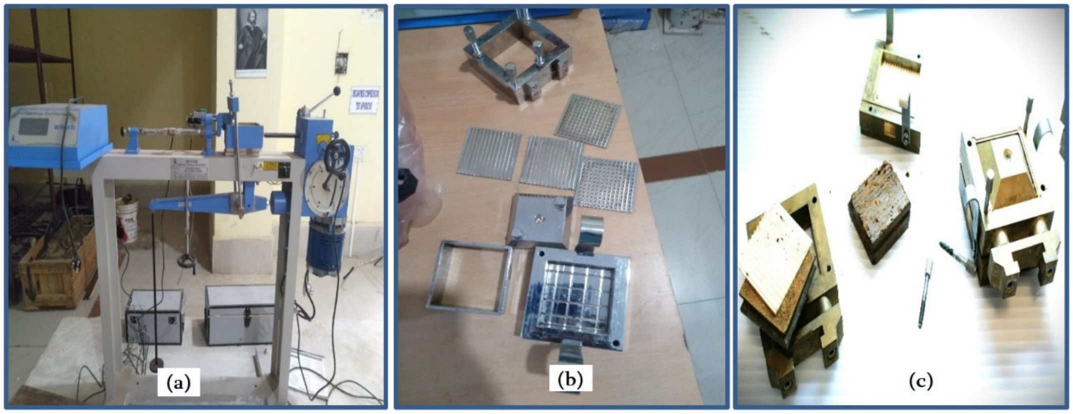

Fig. 2. (a) Direct Shear Testing Machine, (b) Shear box, and (c) Sample after testing

The study by Malik and Priyadarshee (2018) revealed that the incorporation of fly ash in the soil significantly reduced both the swell potential and swell pressure. Deshpande and Puranik (2017) found a direct correlation between the amount of polypropylene and the unrestricted compressive strength of the soil. Besides, the examination led by Rajput and Yadav (2015) showed that the expansion of fly debris to dark cotton soil diminished as far as possible and pliancy record and expanded the ideal dampness content. These discoveries shed light on the effect of different materials on soil properties and can illuminate methodologies for soil adjustment and improvement.

3. Results and Discussions

The particular gravity of fly debris and dark cotton soil is a fundamental property that influences their geotechnical and different applications. While dark cotton soil has a specific gravity of 2.49, the particular gravity of fly debris can go from 1.6 to 2.6, attributable to variables, for example, molecule shape, compound synthesis, and degree. Scientists, for instance, Sivapullaiah et al. (1996), have announced that expanding fly debris to dark cotton soil can work on its actual attributes and reasonableness for use. Naseem et al. (2014) found that the expansion of fly debris and regular soil stabilizer expanded as far as possible, plastic breaking point, versatility list, and California bearing a proportion of dark cotton soil. Likewise, Sridharan et al. (1997) saw that adding fly debris to dark cotton soil could change its solidarity due to the pozzolanic reactivity and silty nature of fly debris. Pandian and Krishna (2003) likewise detailed that the expansion of fly debris upgraded the California Bearing Proportion of dark cotton soil, with the degree of the variety affected by the fly debris' pozzolanic character and molecule size dissemination.

Dark cotton soil contains particles going from residue to fine sand in size, given the grain size conveyance. Then again, the lake debris test shows a uniform degree, with a coefficient of consistency and shape of 6.11 and 2.58, individually. Late exploration by Ambekar and Shahane (2021) found that the expansion of fly debris and steel slag decreased dark cotton soil's volume change potential and its expanding and shrinkage potential. Thakur et al. (2020) likewise found that the versatility file, differential free swell, and fluid restriction of dark cotton soil diminished upon the expansion of marble dust. Moreover, Chansoria et al. (2016) saw that the development of quarry dust further developed the California-bearing proportion and compaction boundaries of dark cotton soil while decreasing its broad behavior. Integrating specific components into dark cotton soil can make its grain size dispersion more reasonable for development purposes.

An examination was done to decide the most noteworthy achievable dry thickness and dampness content of dark cotton soil through compaction properties. Results from the Delegate test uncovered a most extreme dry thickness of 1.628 g/cc and a dampness content of 18.557%. It was found that the dry thickness expanded with dampness content until a specific point, after which it diminished. The consolidated impacts of improved pressing, dampness, and compaction energy as oils added to the ascent in soil thickness. Plenty of exploration has been led on dark cotton soil, uncovering various variables that affect its design properties. More et al. (2021) noticed that an expansion in water content initially prompted an improvement in the dirt's shear strength, trailed by a downfall at higher water contents. Moreover, Singh et al. (2015) found that expanding concrete oven dust developed the dirt's designing properties. Kaushal and Guleria (2015) found that higher mud focuses prompted an increase in the versatility list. Ideal dampness content, then again, was found to bring about higher versatility record, pressure file, and fluid breaking point. Finally, Patidar and Mahiyar (2014) showed that adding certain materials, such as high-density polyethylene fibers, stone dust, and lime, could increase the soil's optimal moisture content while reducing its liquid and plastic limits.

A direct shear test was conducted in test series 1 and 2 to further investigate these findings, evaluating the impact of dry density, moisture content, and admixture. The results indicated a linear relationship between cohesiveness and angle of internal friction with increasing dry density and moisture content, as shown in Fig. 3 and Fig. 4. It was found that the improved interlocking and tighter packing of particles contributed to the enhanced frictional angle and cohesion component in test series 1, which analyzed the effects of dry density and moisture content.

For the second test series, a thorough examination of the impact of fly ash admixture on black cotton soil was conducted. The sample of black cotton soil was prepped with a maximum dry density of 1.628 and an optimal moisture content of 19.55%. Fly ash was added in varying amounts, ranging from 2% to 20%. Ramlakhan et al. (2013) noted that adding fly ash to black cotton soil reduced its maximum dry density while increasing the ideal moisture content and California bearing ratio. Similarly, Modak et al. (2012) reported that fly ash and lime application improved the CBR values of black cotton soil. Naik and Chandrashekhar (2014) found that fly ash treatment of black cotton soil led to enhanced index, compaction, and strength characteristics. Additionally, Sachin et al. (2016) found that combining coconut coir fibers and fly ash increased black cotton soil's CBR and unconfined compressive strength.

As portrayed in Fig. 5, the highest strength of the dirt blend was seen for a blending portion of 10% fly debris. Be that as it may, there was a sharp decrease in power as the admixture content expanded. The lessening in cohesiveness is ascribed to the abundance of fly debris, which has more vulnerable restricting properties than dark cotton soil. Notwithstanding this, dark cotton soil kept areas of strength for a union, even within sight of fly debris. Hence, maintaining a particular degree of fly debris admixture is prescribed to guarantee excellent shear stability. Fig. 6 shows that an expansion in fly debris blending rate prompted an ascent in the inner erosion point, upgrading the grating. The decline in expanding and shrinkage power because of the weight supplanting of plastic fly debris with flexible dark cotton soil added to this pattern. The reviewing of the dirt was worked on by fly debris, bringing about better compaction and different qualities of dark cotton soil. All in all, the impacts of fly debris admixture on the cohesiveness and point of grinding of dark cotton soil ought to be considered, and a unique blending rate should be kept up to guarantee ideal shear strength.

According to recent studies, a combination of fly ash and geopolymer can improve the compressive strength of black cotton soil even without confinement. Additionally, fly ash has been shown to enhance compaction properties and reduce the swell potential of black cotton soil. In contrast, the consolidation properties of black cotton soil can be increased by incorporating fly ash and lime. Expansive soils, which can display unfavorable engineering characteristics due to the clay component's peculiarities, can be challenging to work with. Indiramma et al. (2020) experimented with combining expansive soil with 4% and 8% lime and fly ash mixtures to address this challenge. The resulting data in Table 3 show that as water content increases, dry soil density decreases. Water acts as a lubricant among soil particles, leading to weaker connections, thereby reducing the soil's shear strength. Notwithstanding, expanding water content can likewise prompt an expansion in the point of inner rubbing, showing an ascent in the dirt's shearing opposition. These discoveries give meaningful experiences into dark cotton soil conduct and help improve the mix of fly debris, lime, and expansive soil to accomplish fundamental designing properties.

Table 3. Dry density and moisture content

Water content (%)	Dry Density {gm/cc}	C	ϕ
16.738	1.597	0.1974	26.4255
17.749	1.618	0.1985	28.9849
19.557	1.628	0.2356	29.5272
21.992	1.611	0.1913	24.8257
23.238	1.578	0.1815	22.5285

The impact of fly debris admixture on the shear strength elements of dark cotton soil was inspected through a quick shear test, and the discoveries are displayed in Table 4. The cohesiveness and point of the inside grating of the dirt are shown by C and ϕ values, which changed as how much fly debris admixture was expanded from 0% to 20%. Cohesiveness somewhat expanded as fly debris was added. It arrived at its top at 0.3514 with 10% fly debris admixture due to the pozzolanic collaboration that upgrades interlocking between soil particles and further develops their shear strength. However, the cohesiveness value dropped significantly at 15% and 20% fly ash admixture due to air gaps that reduce interlocking and impair shear power. On the other hand, the angle of internal friction increased gradually as fly ash was added, peaking at 40.776 with 20% fly ash admixture, thanks to the coarse texture of fly ash particles that enhances interlocking and shearing resistance. Therefore, while adding fly ash to black cotton soil can improve its shear strength features, exceeding the recommended admixture amount may lead to a deterioration of its shear strength features.

Table 4

Direct shear test result of varying proportions of fly ash admixture

Fly ash (%)	C	ϕ
0	0.2356	29.527
2	0.2412	30.222
4	0.2654	32.772
6	0.2912	32.846
8	0.3124	34.255
10	0.3514	36.116
15	0.2954	38.127
20	0.1925	40.776

Fig. 3 and Fig. 4 compare the dry density, cohesiveness, and angle of internal friction values in black cotton soil combined with fly ash. Dry density initially increases and decreases after the fly ash admixture reaches 10%, whereas cohesiveness peaks at 10% and declines dramatically. As the amount of fly ash admixture increases, the angle of internal friction consistently rises, as seen in Fig. 5 and Fig. 6. This recommends that fly debris improves interlocking between soil particles. Union likewise encounters an underlying increment with the expansion of fly debris, arriving at its top at 10% before dropping off abruptly. The charts offer essential knowledge about the interaction between dark cotton soil and flying debris, which can be bridled to augment the combination's design properties.

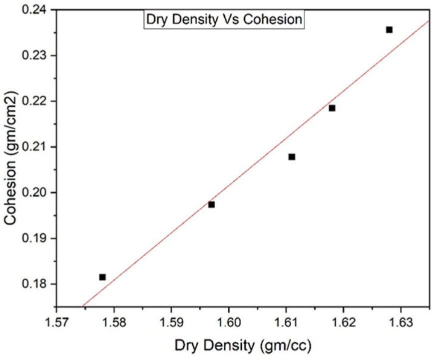

Fig. 3. Comparison of dry density and cohesion

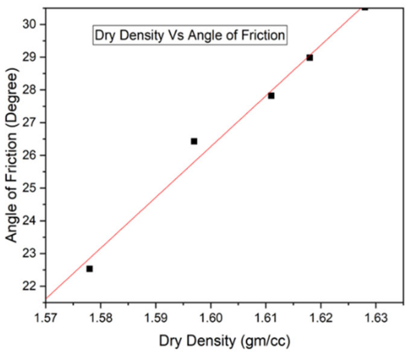

Fig. 4. Comparison of dry density and angle of internal friction

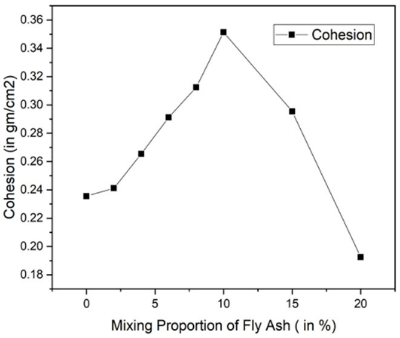

Fig. 5. Variation of Cohesion with Fly ash mixing

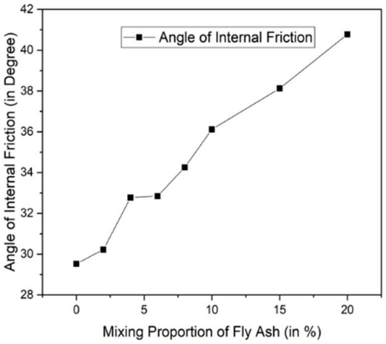

Fig. 6. Variation of the angle of internal friction with Fly ash mixing

Fig. 7 presents a captivating image of a sample of black soil captured by a scanning electron microscope (SEM) that reveals its intricate texture and chemical composition in intricate detail. The ground comprises small, irregularly-shaped particles that appear clustered in some areas, with a rough and uneven surface displaying visible cracks and fissures. As seen in the SEM image, the black cotton soil is of a fine-grained texture and compact nature, with cracks and crevices partially filled by fly ash admixture, resulting in enhanced stability and compactness. These alterations in the physical characteristics of the soil demonstrate the potential of fly ash as a stabilizing agent for expansive black soil.

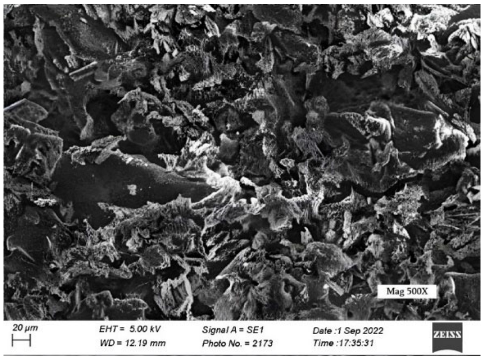

Fig. 7. Scanning electron microscope (SEM) image of expansive black soil treated with fly ash admixture collected from the Kalahandi District of Odisha, India

4. Conclusion

This study was directed to research the impact of fly debris on the shear strength qualities of dark cotton soil. The discoveries demonstrate that the dirt's attributes were essentially different by the fly debris expansion, which increased the most significant dry thickness and ideal dampness content because of increased compaction energy. The rapid shear test uncovered that cohesiveness and point of inside rubbing expanded to the most critical dry consistency, and the outstanding dampness level diminished. The fly debris raised the issue of interior contact, yet it decreased cohesiveness and brought down the shear strength when the fly debris was added above 10%. The insights gained from these graphs are crucial to optimize the mixture's engineering properties. SEM analysis has provided additional insights into the soil's structure and composition, revealing that the fly ash admixture has partially filled the cracks and fissures in the ground, thereby improving its compactness and stability. The outcomes demonstrate that fly debris could be a practical competitor as a settling specialist for sweeping the soil. In any case, choosing the ideal fly debris content is fundamental to achieving outstanding designing properties. Further investigations can develop this work by completing field trials to analyze the drawn-out adequacy of fly debris admixture and the aggregate impacts of fly debris and different admixtures on the dirt's shear strength qualities. By and large, this examination reveals new possibilities for investigation and gives valuable bits of knowledge into how dark cotton soil behaves when joined with fly debris.

Author Contributions

Jajati Keshari Naik, Dilip Kumar Bagal, and Pradyut Kumar Muduli played instrumental roles in this study. Jajati Keshari Naik provided invaluable contributions, including the original manuscript's conceptualization, methodology, investigation, and drafting. Meanwhile, Dilip Kumar Bagal and Pradyut Kumar Muduli also played pivotal roles, contributing to the study's conceptualization, process, formal analysis, data curation, and writing.

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Availability of Data and Materials

The information here includes all the data created or examined throughout the investigation.

Declarations

The information was analyzed and construed, the paper was composed or rigorously reviewed for pivotal intellectual substance, and the concluding draft was authorized by Jajati Keshari Naik, Dilip Kumar Bagal, and Pradyut Kumar Muduli. The document has no affiliation with any institution that possesses any financial interest in the subject matter, whether directly or indirectly, and is not presently submitted to any other journal or publishing platform.

Ethical Approval

Ethics approval was unnecessary for this research as it did not involve human participants, human data or tissue, or animal subjects. Therefore, we did not seek ethical clearance from an institutional review board or other relevant ethics committees. This research relied solely on publicly available data and did not involve case reports or series.

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