Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 1, November : 2023

EXPERIMENTAL STUDY ON SOIL STABILIZATION BY THE ADDITION OF FLY ASH, LIME AND CEMENT

Mr. Jajati Keshari Naik, Assistant Professor, Civil Engineering Department, Government College of Engineering, Kalahandi
Mr. Alok Patel*, Assistant Professor, Civil Engineering Department, Government College of Engineering, Keonjhar
Ms. Sasmita Sahoo, Assistant Professor, Civil Engineering Department, Government College of Engineering, Kalahandi

Abstract
Clay mineral component behaviour is problematic and contributes to the shrink-swell characteristics of expansive soils, expanding soils are not suitable for direct engineering applications in their natural state due to their shrink-swell properties. Stabilising the soil using different materials and techniques has been attempted to make it more feasible for building. The extent to which expanded soil stabilisation techniques and chemical applications enhance the soil engineering characteristics is examined in detail. Engineers stabilise expansive soil by generally balancing the volume change and plasticity or workability features in order to greatly boost the strength properties. In this investigation to investigate the characteristics of shear strength, an unconfined compressive strength test was conducted for expansive soil, fly ash, cement, and lime are added in different proportions in the current study: fly ash at 5%, 10%, 15%, and 20%; cement at 2%, 4%, 6%, and 8%; and lime at 2%, 4%, 6%, and 8%. The results indicate that the maximum strength at the mix proportion of 5% fly ash + 2% PPC cement ,15% fly ash + 6% lime and 15% fly ash + 6% cement+ 6% lime.

Keywords:
expansive soil, Admixture, Black Cotton Soil, Fly ash, Cement, Lime, unconfined compressive strength, compaction, swelling.

I. Introduction

Enhancing the strength, durability, and load-bearing capability of soil by improving its engineering properties is an essential activity [1,2]. It is employed in various construction and civil engineering projects to ensure the stability and performance of structures built on or with soil. By modifying the soil's physical, chemical, and mechanical characteristics, soil stabilization techniques mitigate the undesirable properties of natural soil, making it more suitable for construction purposes [3].In civil engineering, stabilising soil is a crucial procedure that tries to strengthen the soil stability and engineering aspects for building. It involves modifying the soil's physical, chemical, and mechanical characteristics to increase its load-bearing capacity, reduce settlement, and mitigate other undesirable properties [4]. The application of soil stabilization techniques is vital for ensuring the integrity and durability of structures built on or with soil.

II.Literature

High plasticity and volume changes in response to changes in moisture, expansive soils present serious construction issues [5,6]. Expansive soils can be stabilised with the help of admixtures like cement, lime, and fly ash, and their performance is discussed in this paper. These admixtures have been extensively studied and proven to enhance soil stability and mitigate volume changes. Cement improves soil strength and reduces swelling potential by providing a binding agent [7,8,9]. In contrast, lime strengthens and decreases the soil's plasticity, making it more stable [10,11]. Fly ash, a byproduct of coal combustion, improves soil properties by enhancing its workability, reducing plasticity, and increasing strength [8,9]. The combined use of cement, lime, and fly ash offers promising solutions for stabilizing expansive soils, providing a stable foundation for construction projects [12,13].

In a study conducted by Mengmeng Li et al. [14] the effects of applying various amounts of fly ash and bio cement to large soil samples were analysed. The addition of 25% FABC resulted in the highest ultimate consolidation strength (UCS) of 719.4 kPa, indicating that a combination of fly ash and bio cement can significantly increase the strength of expansive soil.

Fusheng Zha et al. [15] studied the impact of fly ash and lime on soil stabilisation. The optimal water content and maximum dry unit weight of the soil were found to be affected by the fly ash and lime levels. Shear strength was significantly increased by using lime, with the optimal percentage of fly ash for 7-day-cured treated soils falling between 9 and 12 %.

P Rai et al. [16] investigated the effectiveness of landfill fly ash and regular Portland cement (OPC) for stabilising soil. The unconfined compressive strength (UCS) was significantly improved by increasing the fly ash to cement binder ratio and the curing duration. Using 20% fly ash and 8% cement and curing it for a day yielded the highest UCS of 167.75 kPa.

N. Vijay Kumar et al. [17] examined the impact of cement and fly ash on black cotton soil, finding that the addition of 10% fly ash and cement significantly increased soil strength and effectively stabilized the sub-base of pavement compared to regular soil.

K Grower et al. [18] The study utilized cement and bitumen emulsions for soil stabilization, revealing that the addition of bitumen emulsion enhanced soil cohesion and shear strength, with a 7% bitumen emulsion resulting in a 65% increase in shear strength.

Habeeb Solihu [19] examined the application of cement in soil stabilisation. The cohesiveness and angle of shearing resistance decreased with increasing cement content. A 1%, 3%, or 5% cement concentration was recommended for treating a silty sand soil, depending on the target unconfined compressive strength.

Ys Ünsever et al. [20] The clay soil with the highest unconfined compressive strength (UCS) was found to be stabilised by adding 25% fly ash and 2% lime. UCS rose in tandem with an increase in curing time. Fortifying weak clay soil with a 73% to 25% to 2% ratio was the best ratio.

Mohammed Shukri Al-Zoubi [21] investigated the effects of cement concentration on undrained strength. Undrained strength increased with increasing cement content, with the fastest rate of increase observed for soil with a cement content of 6-10%. The presence of a high concentration of Ca (OH)2 indicated significant pozzolanic activities in this range of cement content.

R P Munirwan et al. [22] used ashes from coffee husks to stabilize loose soil. Coffee husk ashes increased the soil's specific gravity and decreased its liquid limit. The inclusion of coffee husk ashes resulted in a modest rise in the plastic limit. As the proportion of coffee husk ashes increased, the index plasticity parameter consistently decreased.

III. Experimental Work and Methodology

The objective of this research is to examine changes in the index qualities of black cotton soil after it has been mixed with fly ash. The proctor test was used to examine the shear strength of black cotton soil at various densities and moisture levels. The shear strength of black cotton soil was tested before and after the addition of fly ash, cement, and lime. Fly ash was added at 5%, 10%, 15%, and 20%; cement was applied at 2%, 4%, 6%, and 8%; and lime was added at 2%, 4%, 6%, and 8%. The ideal moisture content and maximum dry density of the black cotton soil were calculated using the proctor test. Soil shear strength was then evaluated with a direct shear test. Both untreated black cotton soil and soil that had been treated with fly ash, cement, and lime were used in the experiment. The study found that the shear strength of black cotton soil was greatly increased after cement, lime, and fly ash were added to it. The blend of 15% fly ash, 6% cement, and 6% lime showed the highest shear strength. A decrease in shear strength was also observed when the amount of fly ash and cement was increased

over a particular threshold. The study's findings about how the addition of fly ash, cement, and lime affects the shear strength of black cotton soil are instructive. The research has potential application in civil engineering projects that use black cotton soil.
Kalahandi district soil samples are taken from areas close to Bhawanipatna and Bargarh and subjected to a free swell test in accordance with IS 2720 1977 to determine their swelling potential. After collecting a sample from the site, it is dried in an oven at 100 to 1050 degrees Celsius for 24 hours and then stored in an airtight container.

3.2.1 Swelling Potential

Table 3.1: Swelling Potential

Swell potential	FSI (%)
Low	<50
Medium	50-100
High	100-200
Very high	>200

Table 3.2: Expansive soil classification based on FSI

SAMPLE NO.	V_d	V_k	FSI In %
1	12.5	9	38.9
2	14	10	40
3	15	8.5	76.47

$$\text{FSI (\%)} = \left[\frac{Vd - Vk}{Vk}\right] 100,$$

Where, V_d is volume of distilled water and V_k is volume of kerosene.
Further experimental works are carried out with sample no.3, which have 76.47% swelling index [medium swell potential type].

Table 3.3: Properties of Black cotton soil

Properties	Obtained value
Moisture content %	16.1
Liquid limit %	38.9
Plastic limit %	20.8
Plasticity index %	18.1
Specific gravity %	2.49
Free swell index %	76.49
Dry density (g/cm3)	1.752
UCS (kPa)	78.80

3.3.3 Standard Proctor Test

The test was conducted by a proctor in accordance with IS 2720-7(1980) on selected soil sample i.e., black cotton soil.

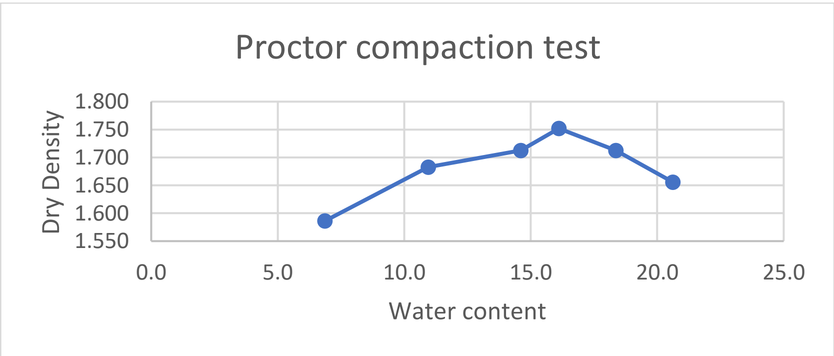

Figure 1: Proctor Compaction test graph

3.3.4 Unconfined compression test

According to the IS standard IS 2720 (Part 10) : 1991

Sample details

Type UD/R: soil description

Specific gravity (GS)= 2.71, Bulk density=1.752 gm/cm^3

Water content Degree of saturation= 16.1%

Diameter (Do)=3.9cm of the sample cm Area of cross-section (Ao) = 11.946cm2

Initial length (Lo) of the sample = 7.8cm

Unconfined compression strength of the soil = qu =78.80 Kpa

Shear strength of the soil = qu/2 = 39.40 Kpa

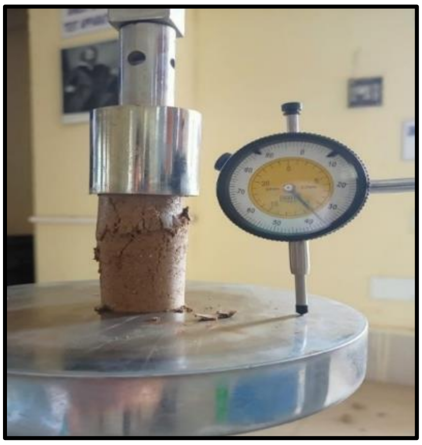

Figure 2: Unconfined compression test

Table.3.4 Comparison of unconfined compression strength for various moisture contained soil sample.

Moisture content	Dry unit wt.	UCS (qu) Kpa
14.60%	1.712	78.8
16.10%	1.752	111.83
18.40%	1.713	34.61

3.4. Test of black cotton soil by adding fly ash and cement

3.4.1. Liquid Limit

As per the IS 2720(Part 5):1985 the liquid limit tests were carried out ,the sample prepared at the proportions of 5% fly ash 2% cement, 10% fly ash 4% cement, 15% fly ash 6% cement, and 20% fly ash 8% cement,.

3.4.2. Plastic Limit

Plastic Limit test carried according to the IS 2720(Part 5):1985. These tests were carried out following the mixing of 5% fly ash with 2% cement, 10% fly ash with 4% cement, 15% fly ash with 6% cement, and 20% fly ash with 8% cement respectively.

Table 3.5: Atterberg limits in Black cotton soil by adding fly ash and cement.

Mix Ratio	PL	LL	Plasticity Index
0% Fly ash + 0% PPC Cement	20.8	38.9	18.1
5% Fly ash + 2% PPC Cement	22	40.8	18.8
10% Fly ash + 4% PPC Cement	25.8	38.6	12.8
15% Fly ash + 6% PPC Cement	24.8	37	12.2

IV. Results and discussions

4.1 The effect of adding fly ash on the UCS value

Table 4.1: unconfined compression strength for soil sample with fly ash

Mix proportion	UCS(Kpa)
Black cotton soil +5%Fly ash	52.58
Black cotton soil+10% Fly ash	65.76
Black cotton soil+15% Fly ash	39.17
Black cotton soil +20%Fly ash	28.88

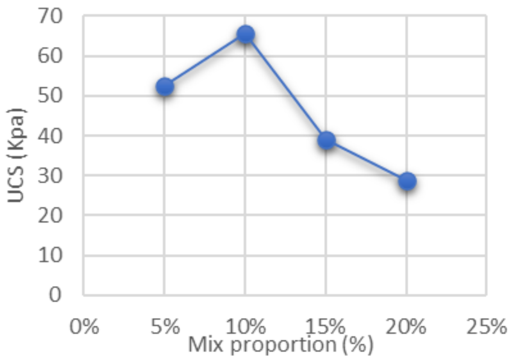

Figure: 4.1 Effect of flyash on UCS value

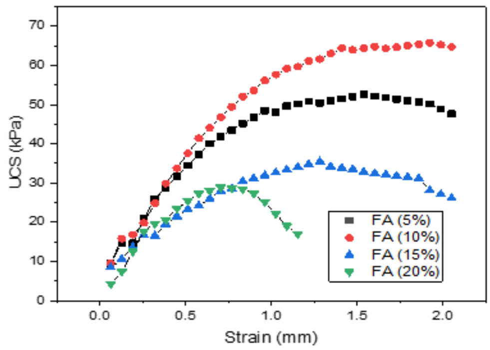

Figure: 4.2 UCS vs strain at FA5%, FA10%, FA15% and FA20%

The unconfined compressive strength (UCS) vs strain curve is a crucial tool for assessing the effectiveness of soil stabilization methods. A study involving different proportions of fly ash (5%, 10%, 15%, and 20%) was conducted to evaluate the effectiveness of these methods. The results showed that the maximum UCS value was achieved when fly ash was added at a 10% percentage, indicating that adding fly ash at a 10% proportion is the most effective way to boost soil strength. Increasing fly ash by 5% also significantly improved soil strength. The highest UCS value was achieved when soil was blended with 10% fly ash. Fly ash, a byproduct of coal combustion, offers several benefits, including low cost, abundance, and ability to improve soil strength and reduce volume changes. It is widely available globally, making it a cost-effective and environmentally friendly solution for improving civil engineering project performance.

4.2 The effect of adding fly ash and Cement on the UCS value

Table 4.2: unconfined compression strength for soil sample with fly ash and PPC Cement

Mix proportion	UCS(Kpa)
Black cotton soil +5%Fly ash+2%PPC Cement	67.78
Black cotton soil+10% Fly ash+4% PPC Cement	90.24
Black cotton soil+15% Fly ash+6% PPC Cement	127.33
Black cotton soil +20%Fly ash+8% PPC Cement	113.31

This study closely examines the UCS values of various black cotton soil, fly ash, and Portland pozzolana cement (PPC) blends. Black cotton soil is typically stabilised by mixing in fly ash and PPC cement, which increases its strength and makes it less susceptible to volume variations. The results reveal that the percentages of fly ash and PPC cement lead to higher UCS values. The UCS value of the mixture consisting of 10% fly ash and 4% PPC cement was the highest, at 90.24 Kpa, followed by the mixture consisting of 15% fly ash and 6% PPC cement, at 127.33 Kpa. Further study is required to establish the ideal mix proportion for getting the maximum UCS value, as the UCS value was lower for the combination containing 20% fly ash and 8% PPC cement.

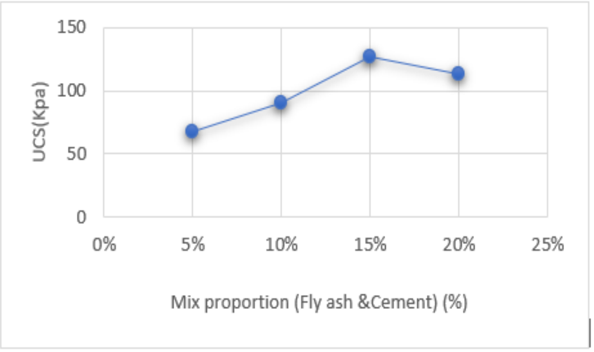

Figure: 4.3 Effect of fly ash and cement on UCS

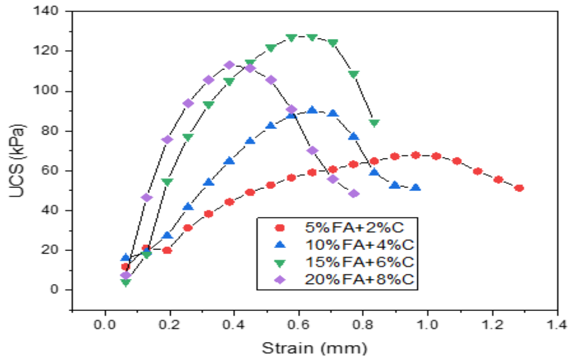

Figure: 4.4 Strain vs UCS of 5%FA+2%C, 10%FA+4%C,15%FA+6%C, 20%FA+8%C

In this graph it is observed that different proportions of fly ash and different proportions of cement are mixed. The plotted curves indicates that the maximum value is reached at 15%FA+6%C.

4.3 The effect of adding fly ash and Lime on the UCS value

Table 4.3: unconfined compression strength for soil sample with fly ash and Lime

Mix proportion	UCS(Kpa)
Black cotton soil +5%Fly ash+2%Lime	72.55
Black cotton soil+10% Fly ash+4% Lime	59.77
Black cotton soil+15% Fly ash+6%Lime	103.35
Black cotton soil+20% Fly ash+8%Lime	104.37

The study examines the unconfined compressive strength (UCS) values of different mix proportions of black cotton soil, fly ash, and lime. The addition of these materials can enhance the soil's strength and reduce its vulnerability to volume changes. The results show that the UCS values increase with the proportion of fly ash and lime, up to a certain point. The mixture with 15% fly ash and 6% lime had the highest UCS value of 103.35 Kpa, significantly higher than untreated black cotton soil. The mixture with 20% fly ash and 8% lime had a slightly lower UCS value of 104.37 Kpa, suggesting an optimal mix proportion. However, the mixture with 10% fly ash and 4% lime had a lower UCS value of 59.77 Kpa. The study suggests that the proportion of fly ash and lime significantly impacts the UCS value of stabilized soil.

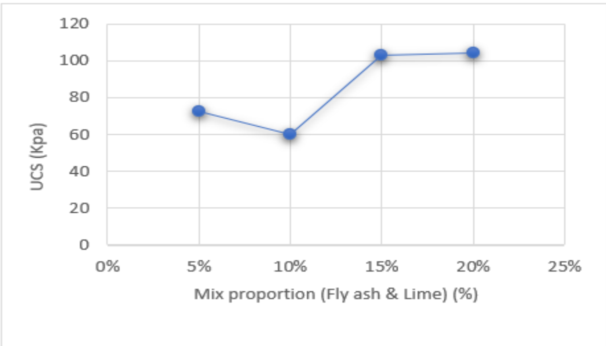

Figure: 4.5 Effect of flyash and lime on UCS value

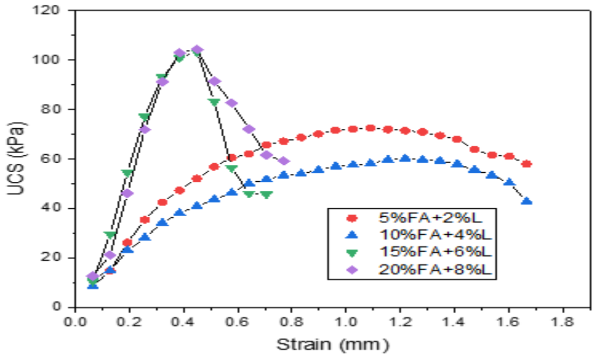

Figure: 4.6. Strain vs UCS of 5%FA+2%L, 10%FA+4%L, 15%FA+6%L

In this graph it is observed that different proportions of fly ash and different proportions of cement are mixed. Here we can find that there is very less difference between 15%FA+6%C and 20%FA+8%C. The plotted curves indicates that the maximum value is reached at 20%FA+8%L. The combination of 15%FA+6%C shows a rapid fall in the strength of the soil whereas the combination of 20%FA+8%L shows a gradual decrease in the strength of the soil.

4.4 The effect of adding fly ash, Cement and Lime on the UCS value

Table 4.4: unconfined compression strength for soil sample with fly ash, Cement and Lime

Mix proportion	UCS(Kpa)
Black cotton soil +5%Fly ash+2%PPC Cement+2%Lime	67.71
Black cotton soil+10% Fly ash+4%PPC Cement+4% Lime	54.88
Black cotton soil+15% Fly ash+6%PPC Cement+6%Lime	73.18

The results presented in the table demonstrate the influence of different mix proportions on the unconfined compressive strength (UCS) of black cotton soil stabilized with fly ash, Portland Pozzolana Cement (PPC), and lime. The analysis and discussion of these results provide valuable insights into the effectiveness of these stabilizers and the optimal mix proportions for enhancing soil strength. The UCS values obtained from the laboratory tests indicate variations in soil strength depending on the mix proportions. The mix proportion of black cotton soil with 5% fly ash, 2% PPC cement, and 2% lime resulted in a UCS value of 67.71 kPa. This indicates a significant improvement in the soil strength compared to its natural state.

However, increasing the percentages of fly ash, PPC cement, and lime to 10% and 4%, respectively, resulted in a slightly lower UCS value of 54.88 kPa. This suggests that the specific combination of 5% fly ash, 2% PPC cement, and 2% lime may have provided an optimal balance for soil stabilization in this case, and further increasing the proportions did not yield additional improvements in strength. On the other hand, increasing the mix proportions to 15% fly ash and 6% PPC cement resulted in a higher UCS value of 73.18 kPa. This indicates that this mix proportion was more effective in enhancing the soil's strength. These findings highlight the importance of selecting appropriate mix proportions for stabilizing black cotton soil. The results suggest that there exists an optimal range of mix proportions for achieving the highest UCS value. Beyond this range, the effectiveness of the stabilization may diminish or become less significant.

In geotechnical engineering, expansive soils are often treated with stabilisers such fly ash, PPC cement, and lime. Black cotton soil's flexibility is lessened and its strength is enhanced by these stabilisers. Stabiliser concentrations can be modified according to mix proportions to produce materials with the required engineering qualities. It should be noted that the matching UCS value for black cotton soil stabilisation using 20% fly ash and 8% PPC cement is not available, hence more study is needed to determine the best mix proportion. Moreover, a full evaluation of the stabilised soil's performance could be attained through testing that included additional factors like durability, permeability, and volume change characteristics.

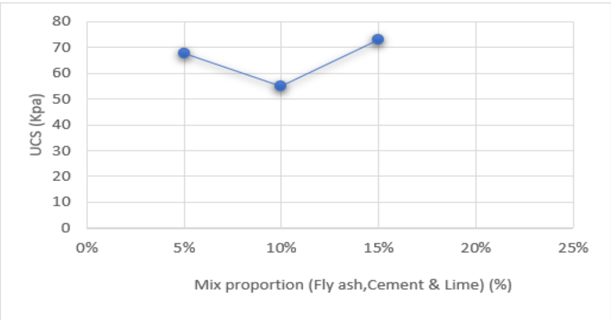

Figure: 4.7 Effects of flyash, cement and lime on UCS value

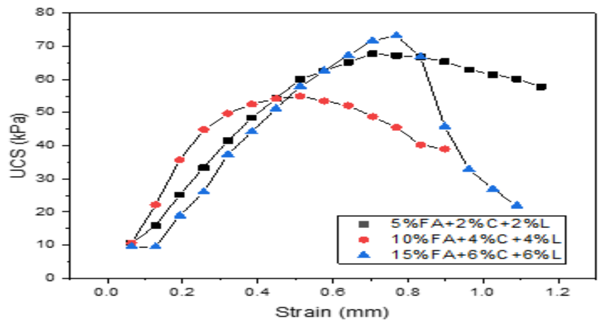

Figure: Strain vs UCS of 5%FA+2%C+2%L, 10%FA+4%C+4%L, 15%FA+6%C+6%L

In this graph we observed the various proportions of Fly Ash, Cement & Lime are mixed together for stabilisation process. The plotted curves indicate maximum value is reached at 15%FA+4%C+4%L.

4.5 The effect of adding Cement and Lime on the UCS value

Table 4.5: unconfined compression strength for soil sample with fly ash and Lime

Mix proportion	UCS(Kpa)
Black cotton soil +2%PPC Cement+2%Lime	76.49

Black cotton soil+4%PPC Cement+4% Lime	79.11
Black cotton soil+6%PPC Cement+6%Lime	100.26
Black cotton soil+8%PPC Cement+8%Lime	97.86

The results presented in the table demonstrate the influence of different mix proportions of Portland Pozzolana Cement (PPC) and lime on the unconfined compressive strength (UCS) of black cotton soil. The analysis and discussion of these results provide valuable insights into the effectiveness of these stabilizers and the optimal mix proportions for enhancing soil strength.

The UCS values obtained from the laboratory tests indicate variations in soil strength depending on the mix proportions. The mix proportion of black cotton soil with 2% PPC cement and 2% lime yielded a UCS value of 76.49 kPa, indicating an improvement in the soil strength compared to its natural state. Increasing the percentages of PPC cement and lime to 4% resulted in a slightly higher UCS value of 79.11 kPa. This suggests that a higher concentration of stabilizers contributed to a slight increase in the soil strength.

However, the most notable increase in UCS was observed when the mix proportion was further increased to 6% PPC cement and 6% lime, resulting in a UCS value of 100.26 kPa. This indicates that this particular mix proportion was highly effective in enhancing the soil's strength.

It is worth noting that the UCS value for the mix proportion with 8% PPC cement and 8% lime decreased slightly to 97.86 kPa. This suggests that increasing the proportions beyond the optimal range may not provide additional improvements in soil strength and could even result in a slight reduction. These findings highlight the importance of selecting appropriate mix proportions for stabilizing black cotton soil using PPC cement and lime.

The results of this study provide valuable guidance for engineers and practitioners involved in soil stabilization projects. By selecting the appropriate mix proportions, it is possible to enhance the strength and stability of black cotton soil, making it more suitable for construction applications. Further research could focus on investigating the long-term performance and durability of the stabilized soil using the optimal mix proportion. Additionally, considering other engineering properties such as permeability and compressibility would provide a more comprehensive understanding of the stabilized soil's behaviour.

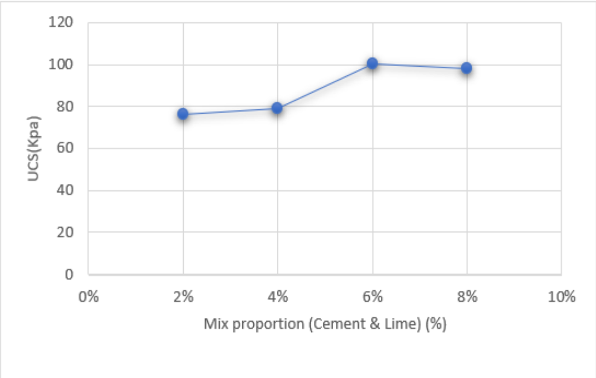

Figure: 4.9 Effects of cement and lime

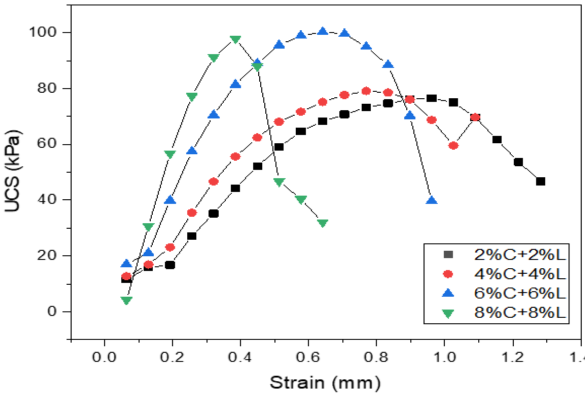

Figure: 4.10 Strain vs UCS of 2%C+2%L, 4%C+4%L, 6%C+6%L, 8%C+8%L

In this graph we observed the 2%, 4%, 6% & 8% combination of cement and lime. the plotted curves indicate maximum value is reached at 6% of mixture.

4. 6 Comparison of unconfined compression strength for soil sample with and fly ash and cement mixture after 1Day, 7Day and 14Day.

Table 4.6: Unconfined compression strength for soil sample with fly ash and PPC Cement (after 1Day, 7Day and 14Day)

	UCS (Kpa)

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 1, November : 2023

Mix proportion	(1DAY)	(7DAY)	(14DAY)
Black cotton soil +5%Fly ash+2%PPC Cement	279.87	1136.09	1729.93
Black cotton soil+10% Fly ash+4% PPC Cement	330	1089.93	647.6
Black cotton soil+15% Fly ash+6% PPC Cement	353.68	370.44	768.78
Black cotton soil +20%Fly ash+8% PPC Cement	561.92	1037.72	852.01

This investigation compares the unconfined compressive strength (UCS) of black cotton soil treated with fly ash and Portland Pozzolana Cement (PPC) during various curing times. The results suggest that the UCS values can be effectively improved by adjusting the mix proportions of fly ash and PPC cement.

For a mix proportion of black cotton soil with 5% fly ash and 2% PPC cement, the UCS values increase significantly with the curing period. However, the UCS value decreases slightly at 7 days and 647.6 kPa at 14 days, suggesting that the mix proportion of 10% fly ash and 4% PPC cement may not be as effective in enhancing the long-term strength of the soil.

For a mix proportion of black cotton soil with 15% fly ash and 6% PPC cement, the UCS value shows mixed results across the curing periods. At 1 day, the UCS value is 353.68 kPa, indicating an initial improvement in strength. However, at 7 days, the UCS value decreases to 370.44 kPa, suggesting a temporary reduction in strength.

The study emphasizes the importance of selecting appropriate mix proportions and considering the curing period in soil stabilization using fly ash and PPC cement. Further research could investigate the underlying mechanisms and chemical reactions during the stabilization process to provide a deeper understanding of observed variations in UCS values.

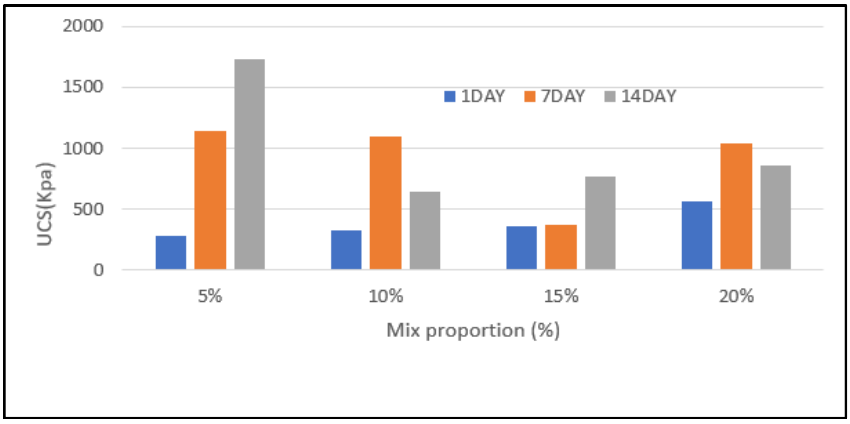

Figure: 4.11 Comparison between 1 day, 7 day and 14 day of UCS with fly ash and cement

Table 4.7: Unconfined compression strength for soil sample with fly ash and PPC Cement after 1Day

Mix proportion	UCS (Kpa) (1DAY)
Black cotton soil +5%Fly ash+2%PPC Cement	279.87
Black cotton soil+10% Fly ash+4% PPC Cement	330
Black cotton soil+15% Fly ash+6% PPC Cement	353.68
Black cotton soil +20%Fly ash+8% PPC Cement	561.92

The results presented in the table demonstrate the effect of different mix proportions of fly ash, PPC cement, and lime on the unconfined compressive strength (UCS) of black cotton soil. The analysis and discussion of these results provide valuable insights into the effectiveness of these stabilizers and the optimal mix proportions for enhancing soil strength.

Laboratory tests show that the UCS values of soil strength vary depending on the mix proportions of PPC cement and lime. The initial UCS value of black cotton soil with 2% PPC cement and 2% lime shows a moderate improvement. The addition of PPC cement and lime increases bonding and

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 1, November : 2023

cohesion, leading to increased strength. Increasing the proportions to 4% results in a higher UCS value of 79.11 kPa, indicating further improvement. Continuing to increase the proportions to 6% leads to a significant improvement in soil strength, promoting increased cementitious activity and bonding agents. However, the UCS value decreases slightly to 97.86 kPa when the proportions are increased to 8%, suggesting an optimal range for strength development. The most effective mix proportions should consider soil properties and stabilizer interactions.Overall, the results indicate that the addition of PPC cement and lime can significantly enhance the unconfined compressive strength of black cotton soil. The optimal mix proportions may depend on various factors such as the specific properties of the soil, the desired strength requirements, and the environmental conditions.

Further research could focus on evaluating the long-term strength development and durability properties of the stabilized soil using different mix proportions. Additionally, investigating the microstructural changes and chemical reactions occurring within the soil-stabilizer system would provide a deeper understanding of the mechanisms responsible for the observed variations in UCS values.

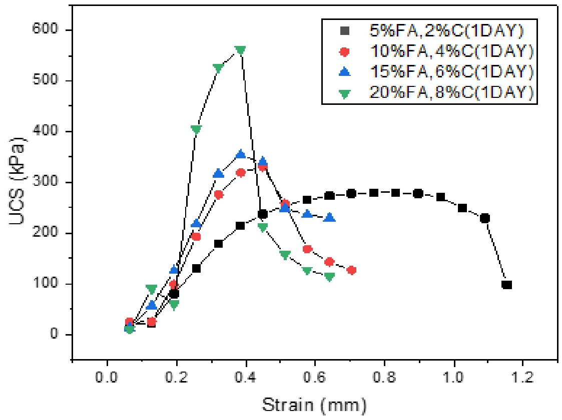

Figure: 4.12. Strain vs UCS of (DAY 1) 5%FA+2%C, 10%FA+4%C, 15%FA+6%C, 20%FA+8%C

In this graph the different proportions of fly ash and cement are shown. The test was conducted on the same day. The mixture of 20%FA and 8% cement shows a higher strength of the soil.

Table 4.8: Unconfined compression strength for soil sample with fly ash and PPC Cement after 7Day

Mix proportion	UCS (Kpa)(7DAY)
Black cotton soil +5%Fly ash+2%PPC Cement	1136.09
Black cotton soil+10% Fly ash+4% PPC Cement	1089.93
Black cotton soil+15% Fly ash+6% PPC Cement	370.44
Black cotton soil +20%Fly ash+8% PPC Cement	1037.72

The table presents the unconfined compressive strength (UCS) values of black cotton soil stabilized with varying mix proportions of fly ash and Portland Pozzolana Cement (PPC) after a curing period of 7 days. The analysis and discussion of these results provide insights into the effectiveness of different mix proportions in enhancing the strength of black cotton soil.

The study reveals variations in soil strength based on the composition of fly ash and PPC cement. For a mix of black cotton soil with 5% fly ash and 2% PPC cement, the UCS value is 1136.09 kPa, indicating a significant improvement in soil strength. The addition of fly ash and PPC cement enhances bonding and cohesion, thereby increasing the soil's load-bearing capacity. When the proportions are increased to 10% and 4%, the UCS value decreases slightly to 1089.93 kPa, but still shows improved strength. Increasing the proportions to 15% and 6% results in a significant drop in the UCS value to 370.44 kPa, suggesting a less favourable interaction between soil particles and stabilizers. The optimized content of fly ash and PPC cement in this mix proportion provides a better balance between soil stabilization and strength enhancement.

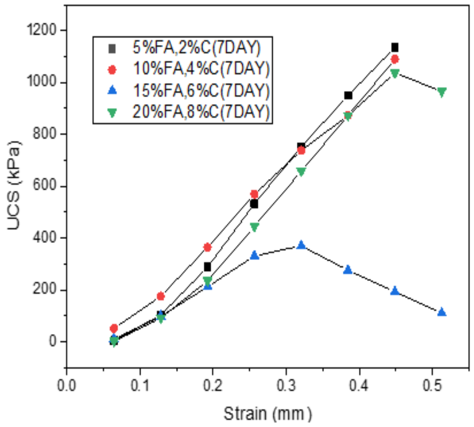

Figure: 4.13. Strain vs UCS of (day 7) 5%FA+2%C, 10%FA+4%C, 15%FA+6%C, 20%FA+8%C

In this graph the different proportions of fly ash and cement are shown with the same number of days. The mixture of 5%FA and 2% cement shows a higher strength of the soil.

Table 4.9: Unconfined compression strength for soil sample with fly ash and PPC Cement after 14Day

Mix proportion	UCS (Kpa)(14DAY)
Black cotton soil +5%Fly ash+2%PPC Cement	1729.93
Black cotton soil+10% Fly ash+4% PPC Cement	647.6
Black cotton soil+15% Fly ash+6% PPC Cement	768.78
Black cotton soil +20%Fly ash+8% PPC Cement	852.01

Black cotton soil was stabilised with different ratios of fly ash to Portland Pozzolana Cement (PPC) and then tested for unconfined compressive strength (UCS) after 14 days of curing. Insights into the efficiency of various mix proportions in boosting the strength of black cotton soil over a prolonged curing period are provided by the analysis and discussion of these data.

Different combinations of fly ash and Portland cement were shown to lead to different increases in soil strength. After 14 days of curing, the UCS value for black cotton soil that was amended with 5% fly ash and 2% PPC cement is 1729.93 kPa, suggesting a considerable increase in soil strength. The combination of fly ash and PPC cement promotes bonding and cohesiveness within the soil matrix, boosting its load-bearing ability. When the percentages of fly ash and PPC cement are raised to 10% and 4%, respectively, the UCS value drops to 647.60 kPa, showing an increase in soil strength. The decline, however, hints at a sweet spot for mix proportions, beyond which adding more stabiliser could not improve things much. The UCS value of 768.78 kPa for the mixture of 15% fly ash and 6% PPC cement demonstrates an increase in soil strength. Improved UCS values can be attributed to the optimal mix proportion of fly ash and PPC cement, which strikes a better balance between soil stabilisation and strength enhancement.

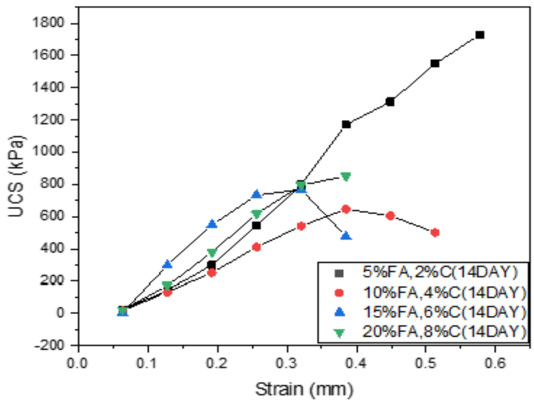

Figure: 4.14. Strain vs UCS of (DAY 14) 5%FA+2%C, 10%FA+4%C, 15%FA+6%C, 20%FA+8%C

In this graph the different proportions of fly ash and cement are shown with the same number of days. The mixture of 5%FA and 2% cement shows a higher strength of the soil.

Table 4.10: Unconfined compression strength for soil sample with 5%Fly ash and 2%PPC Cement after 1day, 7day, 14day

Variation of days	Black cotton soil +5%Fly ash+2%PPC Cement UCS (Kpa)
1 day	279.87
7 day	1136.09
14 day	1729.93

The table present the variation in unconfined compressive strength (UCS) of black cotton soil stabilized with a mix proportion of 5% fly ash and 2% Portland Pozzolana Cement (PPC) over different curing periods.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 11, No. 1, November : 2023

The study found that the UCS value of black cotton soil increases with curing time. After a day of curing, the UCS value is 279.87 kPa, indicating initial strength development. This is due to early hydration reactions between PPC cement and water and pozzolanic reactions between fly ash and calcium hydroxide. Over time, these reactions lead to the formation of cementitious compounds, which stabilize the soil and increase its strength. After 7 days, the UCS value increases to 1136.09 kPa, indicating continued progress in hydration and pozzolanic reactions. The highest UCS value is 1729.93 kPa after 14 days, indicating further strength development. This suggests that longer curing periods promote greater strength gain and enhance the stability of the soil. The study emphasizes the importance of sufficient time for the stabilization process, as it allows stabilizers to react fully and form durable bonds within the soil structure. Further research and field trials are needed to validate these findings and optimize the mix design for practical implementation.

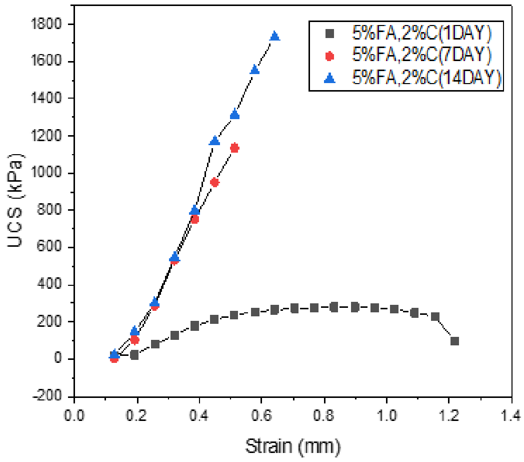

Figure: 4.15. Strain vs UCS value of (5%FA+2%C) 1 day, 7 day, 14 day

This graph is the combination of 5%FA with 2%C. The plotted curves are of various days showing the increase in strength as the number of days increases

Table 4.11: Unconfined compression strength for soil sample with **10%Fly ash and 4%PPC Cement after** 1Day, 7DAY, 14DAY

Variation of days	Black cotton soil +10%Fly ash+4%PPC Cement UCS (Kpa)
1 day	330
7 day	1089.93
14 day	647.6

The study examines the unconfined compressive strength (UCS) of black cotton soil stabilized with a mix of 10% fly ash and 4% Portland Pozzolana Cement (PPC) over different curing periods. The results show that the UCS increases with an increase in the curing period up to 7 days, but slightly decreases after 14 days. The initial strength development is attributed to early hydration reactions and pozzolanic reactions between PPC cement and water. After 7 days, the UCS value increases significantly to 1089.93 kPa, indicating the progress of hydration and pozzolanic reactions. However, after 14 days, the UCS value decreases slightly to 647.6 kPa, possibly due to the completion of hydration and pozzolanic reactions. Despite this, the stabilized soil still shows improved strength compared to the unsterilized state. The study emphasizes the importance of an optimal curing period for achieving maximum strength. It is crucial to consider site-specific conditions, project requirements, and soil and stabilizer characteristics when determining the optimal curing period. Further research and field studies are recommended to validate and optimize the mix design and curing period for stabilizing black cotton soil with different proportions of fly ash and PPC cement.

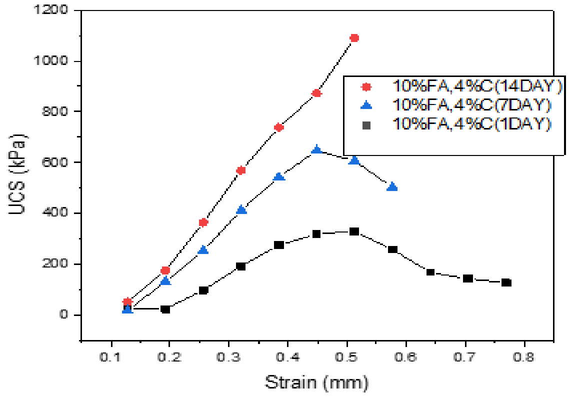

Figure: 4.16. Strain vs UCS value of (10%FA+4%C) 1 day, 7 day, 14 day

This graph is the combination of 10%FA with 4%C. The plotted curves are of various days showing the increase in strength as the number of days increases

Table 4.12: Unconfined compression strength for soil sample with 15%Fly ash and 6%PPC Cement after 1day, 7day, 14day

Variation of days	Black cotton soil +15%Fly ash+6%PPC Cement UCS (Kpa)
1 day	353.68
7 day	370.44
14 day	768.78

The study reveals that the UCS of black cotton soil stabilized with 15% fly ash and 6% PPC cement varies over different curing periods. The initial strength development is 353.68 kPa after 1 day, indicating early hydration and pozzolanic reactions. After 7 days, the UCS increases slightly to 370.44 kPa, indicating continued strength development. The extended curing period allows for the progression of chemical reactions and the formation of additional cementitious compounds, enhancing load-bearing capacity. After 14 days, the UCS increases significantly to 768.78 kPa, indicating continued progress of hydration and pozzolanic reactions. The longer curing period leads to higher UCS values, indicating the importance of curing time in achieving desired soil strength.

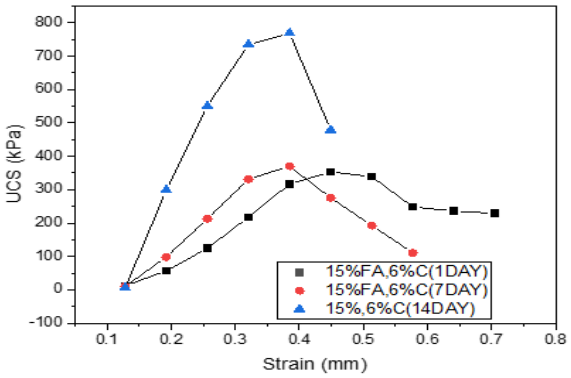

Figure: 4.17. Strain vs UCS value of (15%FA+6%C) 1 day, 7 day, 14 day

Table 4.13: Unconfined compression strength for soil sample with **20%Fly ash and 8%PPC Cement after** 1day, 7 day, 14 day

variation of days	Black cotton soil +20%Fly ash+8%PPC Cement UCS (Kpa)
1 day	561.92
7 day	1037.72
14 day	852.01

The graph shows the strength of black cotton soil stabilized with 20% fly ash and 8% PPC cement over different curing periods. After 1 day, the UCS value is 561.92 kPa, indicating initial strength development. After 7 days, the UCS value increases significantly to 1037.72 kPa, indicating further strength development due to continued hydration and pozzolanic reactions. After 14 days, the UCS value decreases slightly to 852.01 kPa, possibly due to moisture loss or completion of hydration and pozzolanic reactions. Further investigation is needed to understand the underlying causes of the observed decrease in strength.

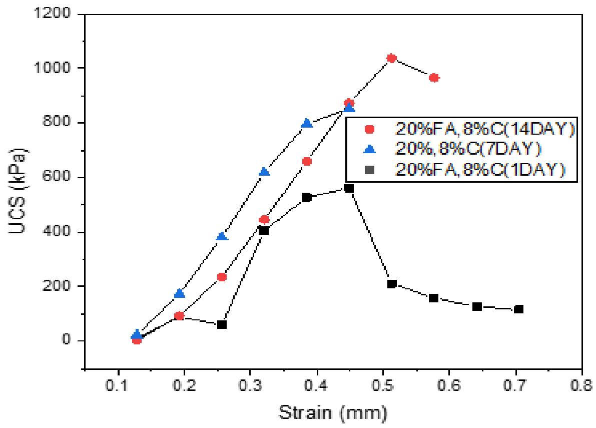

Figure: 4.18. Strain vs UCS value of (20%FA+8%C) 1 day, 7 day, 14 day

The findings emphasize the importance of curing time in achieving the desired strength of the stabilized black cotton soil. The results indicate that an extended curing period of 7 days leads to substantial strength development, while a 14-day curing period may result in some strength loss.

In this graph we find that there is a constant increase in strength of the soil as the effect of cement shows in Day1, Day 7 and Day14.

V.Conclusion

According to the study, the moisture content of black cotton soil, which is a form of clay mineral, can cause it to expand or contract. With a coefficient of curvature of 2.61 and a uniformity of 6.13, pond ash's particle sizes fall in the middle between silt and fine sand. It is clear that the soil is expansive and plastic, and that the addition of cement and fly ash increases the Atterberg limit. 10% fly ash and 4% cement are the ideal ratios for making PL and LL, with 5% fly ash and 2% cement generating LL. The UCS test revealed that while the maximum strength of the fly ash-cement mixture was noticeably lower, the strength of the soil rose with the addition of fly ash and cement. The engineering qualities of black cotton soil, such as its unconfined compressive strength, California bearing ratio, and swell potential, can be enhanced by the stabilising effects of fly ash and cement.

According to a study, adding fly ash to soil can greatly increase its strength and ability to support weight. When 10% fly ash is mixed into the soil, the maximum UCS value is reached. In civil engineering projects, this economical and eco-friendly approach can be applied. The study also discovered that the UCS values of black cotton soil may be considerably raised by adding fly ash and PPC cement. 15% fly ash and 6% lime is the ideal mix ratio to get the maximum UCS value. The study also emphasised how crucial it is to choose the right mix proportions and take the curing time into account in order to attain the required soil strength and guarantee long-term stability. The results also demonstrated how important curing time is to getting the best strength possible in the stabilised soil. To investigate other mix proportions, improve curing conditions, and assess long-term performance for real-world field applications, more study is required.

References

[1]Afrin, H. (2017). A review on different types soil stabilization techniques. International Journal of Transportation Engineering and Technology, 3(2), 19-24.

[2]Archibong, G. A., Sunday, E. U., Akudike, J. C., Okeke, O. C., & Amadi, C. (2020). A review of the principles and methods of soil stabilization. International Journal of Advanced Academic Research| Sciences, 6(3), 2488-9849.

[3]Afrin, H. (2017). A review on different types soil stabilization techniques. International Journal of Transportation Engineering and Technology, 3(2), 19-24.

[4]Nayem, N. H. (2023). Enhancement of Soil Characteristics Using Different Stabilization Techniques. Environmental Engineering, 8(4), 71-79.

[5]Gromko, G. J. (1974). Review of expansive soils. Journal of the Geotechnical Engineering Division, 100(6), 667-687.

[6]Ikeagwuani, C. C., & Nwonu, D. C. (2019). Emerging trends in expansive soil stabilisation: A review. Journal of rock mechanics and geotechnical engineering, 11(2), 423-440.
[7]Liu, Y., Chang, C. W., Namdar, A., She, Y., Lin, C. H., Yuan, X., & Yang, Q. (2019). Stabilization of expansive soil using cementing material from rice husk ash and calcium carbide residue. Construction and Building Materials, 221, 1-11.
[8]Okonkwo, U. N., & Kennedy, C. (2023). The Effectiveness of Cement and Lime as Stabilizers for Subgrade Soils with High Plasticity and Swelling Potential. Saudi J Civ Eng, 7(3), 40-60.
[9]Bulbul Ahmed, M. A. A., & Sayeed, M. A. (2013). Improvement of soil strength using cement and lime admixtures. Earth Science, 2(6), 139-144.
[10] Asgari, M. R., Baghebanzadeh Dezfuli, A., & Bayat, M. (2015). Experimental study on stabilization of a low plasticity clayey soil with cement/lime. Arabian Journal of Geosciences, 8, 1439-1452.
[11] Babu, N., & Poulose, E. (2018). Effect of lime on soil properties: A review. International Research Journal of Engineering and Technology, 5(5).
[12] Amiralian, S., Chegenizadeh, A., & Nikraz, H. (2012). A review on the lime and fly ash application in soil stabilization. International Journal of Biological, Ecological and Environmental Sciences, 1(3), 124-126.
[13] Deepak, M. S., Rohini, S., Harini, B. S., & Ananthi, G. B. G. (2021). Influence of fly-ash on the engineering characteristics of stabilised clay soil. Materials today: proceedings, 37, 2014-2018.
[14] Li, M., Fang, C., Kawasaki, S., & Achal, V. (2018). Fly ash incorporated with biocement to improve strength of expansive soil. Scientific reports, 8(1), 2565.
[15] Zha, F., Liu, S., Du, Y., & Cui, K. (2008). Behavior of expansive soils stabilized with fly ash. *Natural hazards*, *47*, 509-523.
[16] Rai, P., Qiu, W., Pei, H., Chen, J., Ai, X., Liu, Y., & Ahmad, M. (2021). Effect of fly ash and cement on the engineering characteristic of stabilized subgrade soil: an experimental study. Geofluids, 2021, 1-11.
[17] Kumar, N. V., Asadi, S. S., Karthik, C. D., Goud, P. G., & Prasad, B. B. (2019). Effect of Fly-Ash and Cement on Expansive Soil for Flexible Pavement Design. International Journal of Transportation Engineering and Traffic System, 5(2), 48-55.
[18] Grower, K. U. L. D. E. E. P., & Goyal, E. T. (2019). Experimental study of waste foundry sand and marble dust as a soil stabilizing material. no. June, 1265-1272.
[19] Solihu, H. (2020). Cement soil stabilization as an improvement technique for rail track subgrade, and highway subbase and base courses: A review. Journal of Civil and Environmental Engineering, 10(3), 1-8.
[20] ÜNSEVER, Y. S., & DİALLO, M. L. (2019). Stabilization of clay soils using fly ash. Black Sea Journal of Engineering and Science, 2(3), 81-87.
[21] Al-Zoubi, M. S. (2008). Undrained shear strength and swelling characteristics of cement treated soil. Jordan Journal of Civil Engineering, 2(1), 53-62.
[22] Sundary, D., Munirwan, R. P., Al-Huda, N., Sungkar, M., & Jaya, R. P. (2022). Shear strength performance of dredged sediment soil stabilized with lime. Physics and Chemistry of the Earth, Parts A/B/C, 128, 103299.