IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Study Of Characteristics Of Subgrade In Black Cotton Soil Stabilised With Fly Ash And Naoh In Flexible Pavements

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Abstract: Rapid population growth and urbanization have limited accessible high-quality land, leading to construction on weak soils like black cotton soil. Despite being fertile, black cotton soil is unsuitable for foundations due to its expansive nature, which causes shrink-swell behavior with moisture changes. Cracks form during dry seasons, and even minimal rainfall can make these soils impassable. In India, 20% of the area is covered by black soil, posing challenges for highway engineers. Weak subgrade s in road construction can cause pavement failure. This study explores improving black cotton soil's geotechnical properties us ing geopolymer stabilization, an eco-friendly alternative to energy-intensive Portland cement. Fly ash (5–20%) is activated with sodium hydroxide, significantly enhancing soil strength and load-bearing capacity through geopolymerization.

Index Terms **– Black cotton soil, Fly Ash, Sodium hydroxide, Geopolymer.**

I. INTRODUCTION

Transportation is essential for mobility, economic activity, and travel. Efficient road networks, built with properly designed layers such as the surface course, base course, sub-base, and subgrade, ensure smooth transportation. The subgrade, made of locally available soils, often lacks the required strength to support pavement loads. Weak soils, like black cotton soil, with expansive properties, cause challenges in construction due to their tendency to shrink when dry and swell when wet. These movements result in pavement failures such as cracking, settlement, and uneven surfaces, making stabilizing such soils a necessity for improving road durability and performance. Stabilization enhances the soil's strength, volume stability, and durability while reducing costs and pavement thickness.

Black cotton soil, covering 20% of India, is a type of expansive clay with high compressibility. Its extreme shrink -swell behavior causes significant issues for roadway engineers, such as deep cracks, vertical displacement, and foundation damage. These soils become weak when wet and rigid when dry, making them unsuitable for construction without modification. Traditional solutions like substituting poor-quality soils with better materials are often costly and environmentally unsustainable. Stabilization techniques, particularly using sustainable alternatives, provide a practical solution to this challenge. One such promising approach is using geopolymers as a binder, an eco-friendly substitute for conventional materials like cement.

Geopolymers are created by activating alumino-silicate materials, such as fly ash, with alkalis. This process reduces CO2 emissions compared to cement production while enhancing soil properties like strength and durability. Geopolymers also resist heat, chemicals, and weathering, making them suitable for infrastructure projects. This study focuses on using geopolymerization to stabilize black cotton soil, highlighting its cost-effectiveness and sustainability. Geopolymers emerge as a viable alternative for improving weak subgrade soils in road construction while addressing environmental concerns.

Black Cotton Soil

Several studies have explored the stabilization of expansive soils using various materials to enhance their engineering properties. Pandian et al. (2001) found that adding 20% Class-F fly ash significantly improved the California Bearing Ratio (CBR) of black cotton soil by up to 200%. Similarly, Satyanarayena et al. (2004) identified an optimal 70:30:4 ratio of fly ash, lime, and soil for road and embankment construction. Kumar and Sharma (2004) observed that increasing fly ash content reduced the fluidity, swelling, and hydraulic conductivity of expansive soil blends while improving their strength and penetration resistance. Studies by Amue et al. (2005) demonstrated that stabilizing soil with 9% cement and 3% fly ash achieved better results in terms of CBR and shear resistance compared

to using 12% cement alone. Furthermore, Kalyanshetti et al. (2013) reported that fly ash additions up to 20% noticeably decreased swelling properties and increased the CBR by 70%–75%.

Research has also focused on alternative stabilizers. Gupta et al. (2002) and Gulsah (2004) highlighted the role of quarry dust and rock powder in reducing swelling potential and improving soil stability. Other innovative stabilizers, such as lime, rice husk ash (RHA), and bagasse ash, have also been tested. Bhasin et al. (1988) found that lime and lime sludge combinations significantly improved the strength metrics of black cotton soil, while Sharmea et al. (2008) showed that RHA, lime, and calcium chloride enhanced the stress-strain properties of expansive soils. Similarly, marble dust (Swami, 2002) and phosphogypsum (Mishra & Mathur, 2004) proved effective in improving soil workability, reducing swelling, and increasing CBR values when used in appropriate proportions.

Recent advancements in soil stabilization have emphasized the use of geopolymers. Zhang et al. (2013, 2015) demonstrated that geopolymerization of clay using metakaolin significantly improved compressive strength, reduced swelling, and enhanced microstructural uniformity. Phummiphan et al. (2016) found high-calcium fly ash-based geopolymers effective in stabilizing lateritic soils for pavements. Similarly, Ahirwar et al. (2016) reported an 18% increase in shear strength and reduced plasticity index of black cotton soil stabilized with 6% geopolymer. These studies underscore the potential of sustainable materials like geopolymers and industrial byproducts to address the challenges of expansive soil stabilization while minimizing environmental impact.

II. SCOPE AND OBJECTIVES OF THE STUDY

The study aims to enhance soil properties by using eco-friendly materials like fly ash, lime, and geopolymers to improve strength and reduce swelling and shrinkage in expansive soils. It focuses on sustainable stabilization techniques to optimize road construction materials, improve pavement performance, and lower costs.

a) **Enhancing Soil Properties:** To explore the use of fly ash, lime, geopolymers, and other materials for improving the strength, stability, and load-bearing capacity of expansive soils.

b) **Reducing Soil Swelling and Shrinkage:** To identify stabilizers that effectively control the swelling and shrinkage characteristics of black cotton and other expansive soils.

c) **Sustainable Stabilization Techniques:** To evaluate the potential of eco-friendly and industrial byproducts (e.g., fly ash, RHA, phosphogypsum, geopolymers) as alternatives to traditional stabilizers.

d) **Optimizing Road Construction Materials:** To investigate the impact of stabilized soils on pavement performance, thickness reduction, and cost-effectiveness in construction.

III. MATERIALS USED IN THIS STUDY

In the current review, the material study includes study of properties of black cotton soil, fly- ash and activator solution. The soil and fly-ash properties are found out by the tests like sieve analysis, Atterberg's limits, XRD etc.

1. Black cotton soil:

Soil stabilization is carried out for weak soils having low strength and poor engineering properties.

Table 1 Geotechnical properties of black cotton soil

S.l. No	Test	Result
1.	Specific gravity (G)	2.70
2.	Maximium dry density (MDD)	1.62 g/cc
3.	Optimum moisture content (OMC)	21.8 %
4.	Differential free swell	69.15 %
5.	Liquid limit	77 %
6.	Plastic limit	39 %
7.	Shrinkage limit	11 %

2. Fly ash:

Fly-ash has a number of applications. It is frequently utilized for building roads, dams, embankments, backfilling, mine filling, structural fills, and soil stabilization. It is also utilized in the production of fly ash concrete, light weight concrete, bricks and blocks, grout, and pozzolana cement

Table 2: Properties of Fly Ash

Sr.No.	Test	Result
1	Specific Gravity	1.90
2	Liquid Limit	33 %
3	Class	F

3. Activator Solution:

To prepare 100 mL of 5M NaOH solution, 20g of sodium pellets (ratio 0.2) are dissolved in 100mL distilled water. As the reaction is highly exothermic, the solution is made a day prior for cooling and stabilization before use in sample preparation.

IV RESULTS AND DISCUSSION

Soil was replaced with fly-ash in 5%, 10%, 15%, and 20% weight ratios. Water and activator solution were added based on the mix's optimal moisture content. Various tests were conducted to evaluate the soil-fly ash mixture properties under different replacement levels, ensuring consistent moisture during preparation and testing.

1. Standard proctor compaction test
2. Unconfined compression strength
3. Atterberg's limits
4. California bearing ratio

4.1 Testing of soil with fly ash

The following tests are done on soil by adding 5%, 10%, 15% and 20% of fly-ash.

4.1.1 Atterberg's limits test:

Table 3: Atterberg's limits of BCS with different % of fly ash

Property	**Fly-ash (%)**			
	5	**10**	**15**	**20**
Liquid limit	75	72	64	62
Plastic limit	37	35	31	30

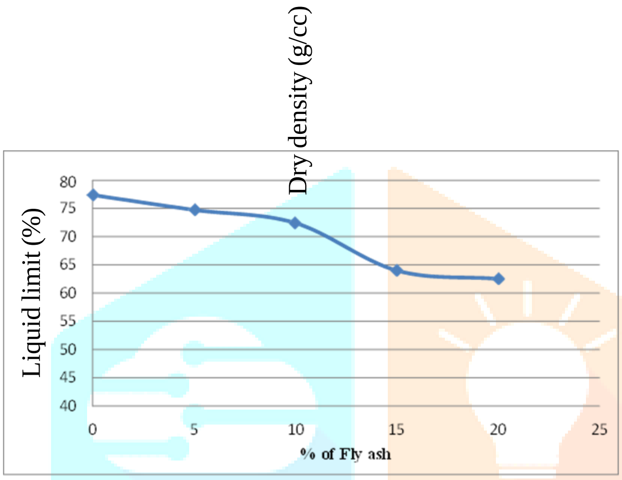

Figure 1 Variation of liquid limit

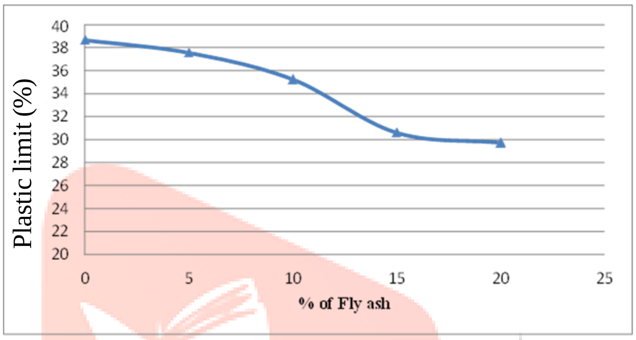

Figure 2 Variation of plastic limit

4.1.2 Compaction test:

Table 4: Variation of OMC and MDD with different % of fly ash

	Fly-ash (%)				
	0	**5**	**10**	**15**	**20**
OMC (%)	21.6	23.5	24.3	23.3	21.5
MDC (g/cc)	1.62	1.53	1.51	1.50	1.52

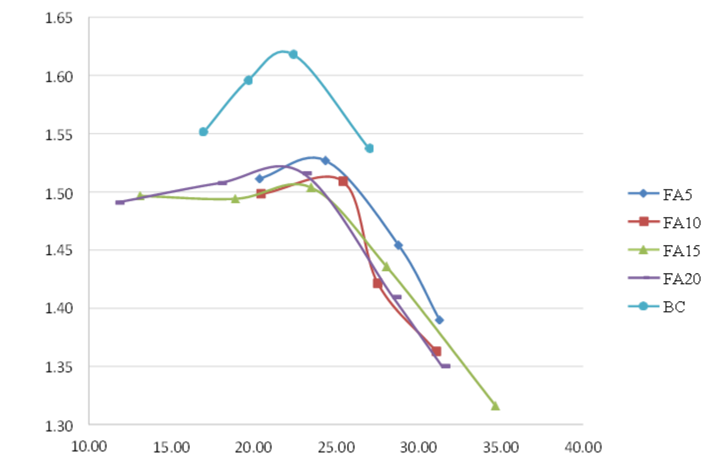

Figure 3 Compaction curves for different fly ash proportions

4.1.2 Unconfined compression strength test:

Table 5: UCS results of F-5, F-10, F-15, F-20

Curing period (days)	**Unconfined compressive strength (kPa)**			
Specimen name	**F-5**	**F-10**	**F-15**	**F-20**
0	165.63	173.03	192.70	210.95
7	167.63	189.90	207.77	232.60
14	177.38	197.90	210.67	246.42
28	192.27	202.18	214.58	276.36
90	414.31	434.46	453.46	487.47

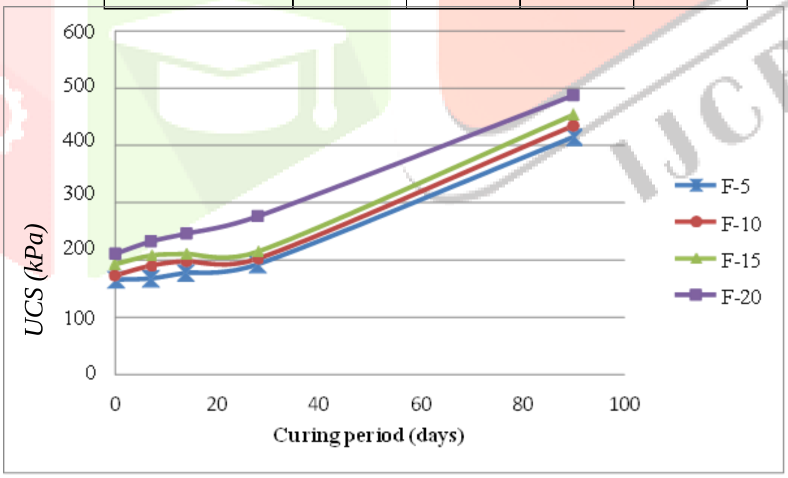

Figure 4 Variation of UCS with different fly ash proportion

4.1.3 California bearing ratio test:

Table 6: Variation of unsoaked and soaked CBR values with different fly ash proportions

Specimen name	Unsoaked CBR value	Soaked CBR value
F-5	6.157	2.605
F-10	6.73	2.70
F-15	8.99	4.229
F-20	9.32	5.00

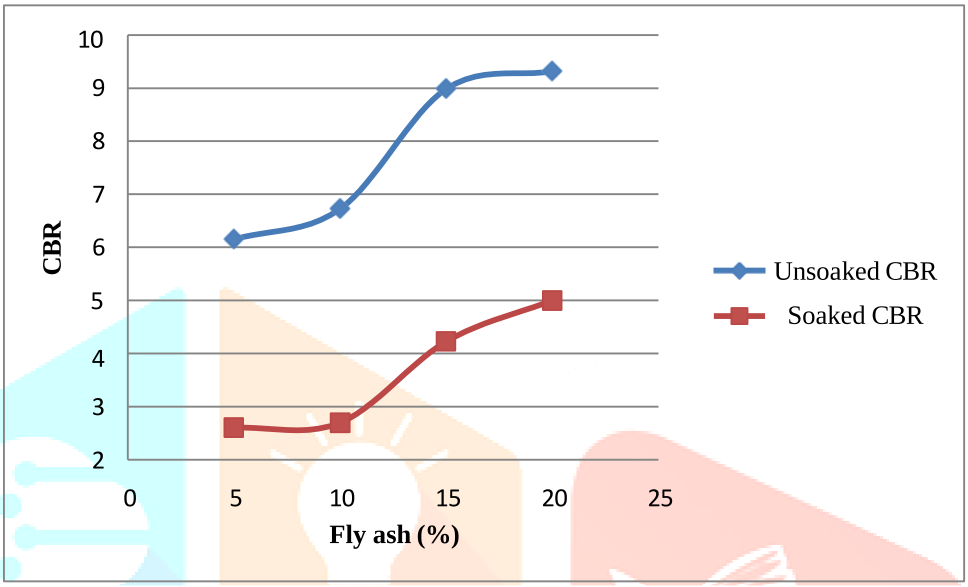

Figure 5 Variation of unsoaked and soaked CBR values with different % fly ash

4.2 Testing of soil with geopolymer

4.2.1 Unconfined compression strength test:

An unconfined compression strength (UCS) test was conducted on geopolymer-treated soil with varying fly ash contents and curing times. Table 7 shows UCS increases with higher fly ash percentages and extended curing times. Figure 6 highlights that the AF-20 mix achieves the highest UCS, particularly during the 90-day curing period, outperforming other mixes and shorter curing durations.

Table.7: UCS results of AF-5, AF-10, AF 15 & A20

Curing period(days)	Unconfined compressive strength (kPa)			
Specimen name	**AF-5**	**AF-10**	**AF-15**	**AF-20**
0	184.86	192.46	210.58	489.93
7	909.75	978.6	1093.82	1272.92
14	1004.33	1137.80	1371.32	1635.85
28	1243.43	1436.46	1683.30	1838.10
90	1649.98	1628.10	1882.82	2394.81

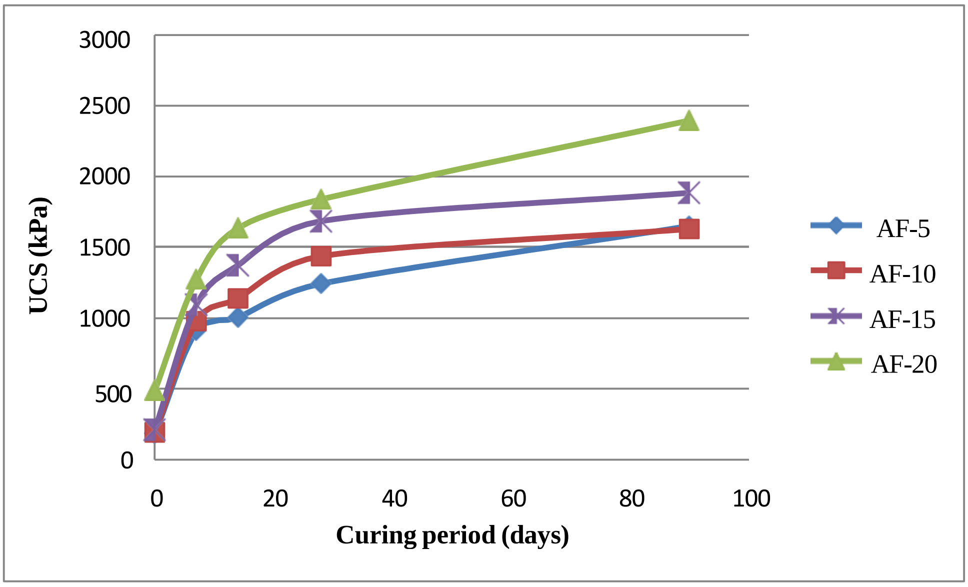

Figure 6: Variation of UCS with different % of fly ash activated using NaOH

4.2.2 California bearing ratio test:

CBR tests were conducted under soaked and unsoaked conditions during a seven-day curing period using various fly ash amounts activated with NaOH. Table 8 indicates that 20% fly ash yields the highest CBR values in both conditions. Interestingly, soaked CBR values exceed unsoaked ones, possibly due to water infiltration improving sample compaction.

Table 8: Variation of unsoaked and soaked CBR values with different % fly ash activated with NaOH

Specimen name	Unsoaked CBR value	Soaked CBR value
AF-5	25.37	31.80
AF-10	29.36	32.68
AF-15	30.44	34.51
AF-20	31.19	41.20

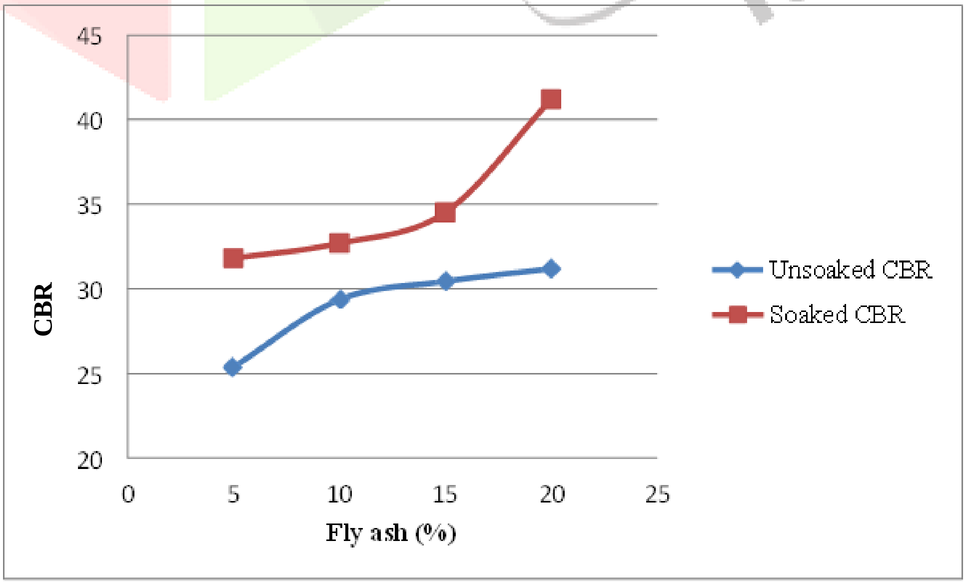

Figure 7 Variation of unsoaked and soaked CBR values with different % fly ash activated with NaOH

4.3 Comparison of results for fly ash and geopolymer

4.3.1 Unconfined compression strength test:

The UCS of soil treated with geopolymer significantly outperformed soil treated with fly ash alone. Untreated soil refers to UCS samples made with BCS, fly ash, and water, while treated soil incorporates BCS, fly ash, and a 5M NaOH solution, highlighting the impact of alkaline activation on strength.

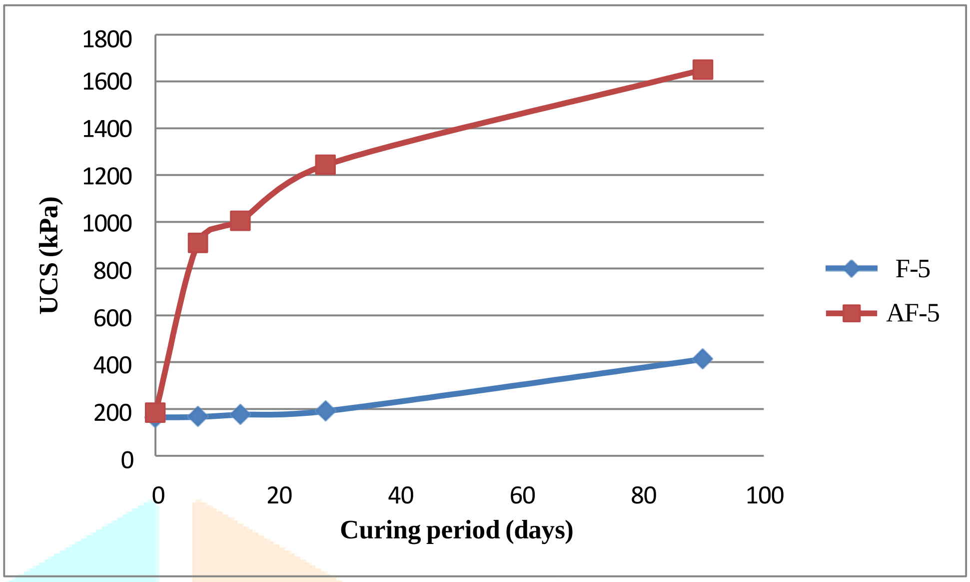

Figure 8: Treated and untreated soil containing 5% fly ash

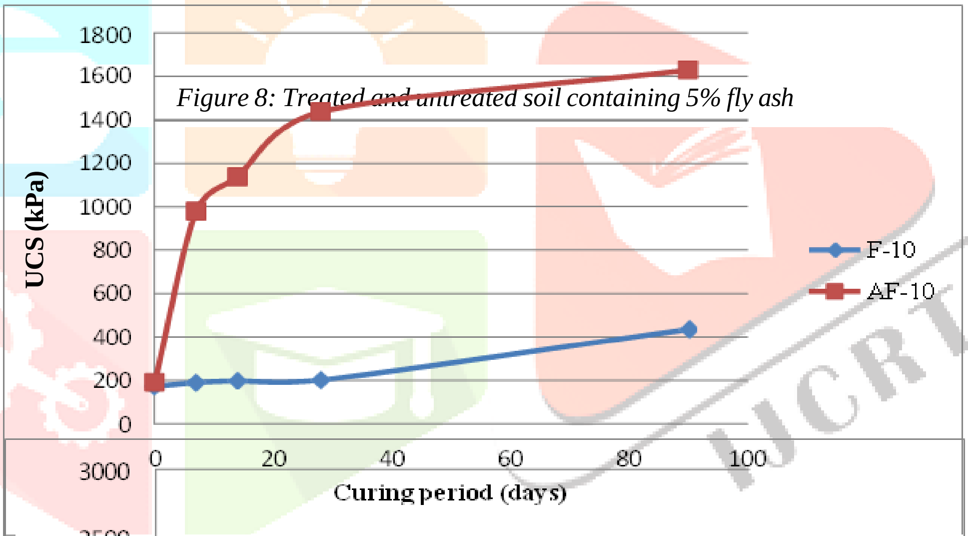

Figure 9: Treated and untreated soil containing 10% fly ash

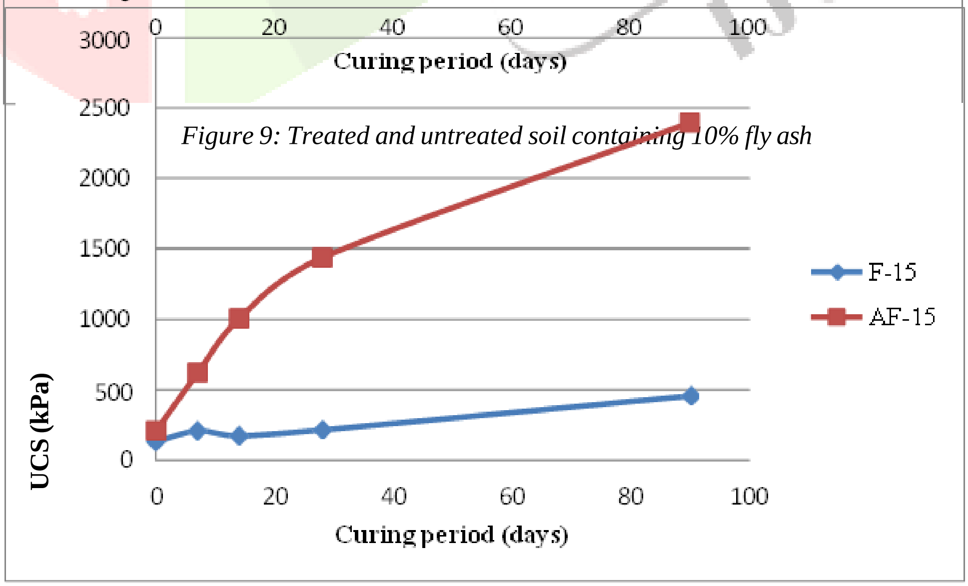

Figure 10: Treated and untreated soil containing 15% fly ash

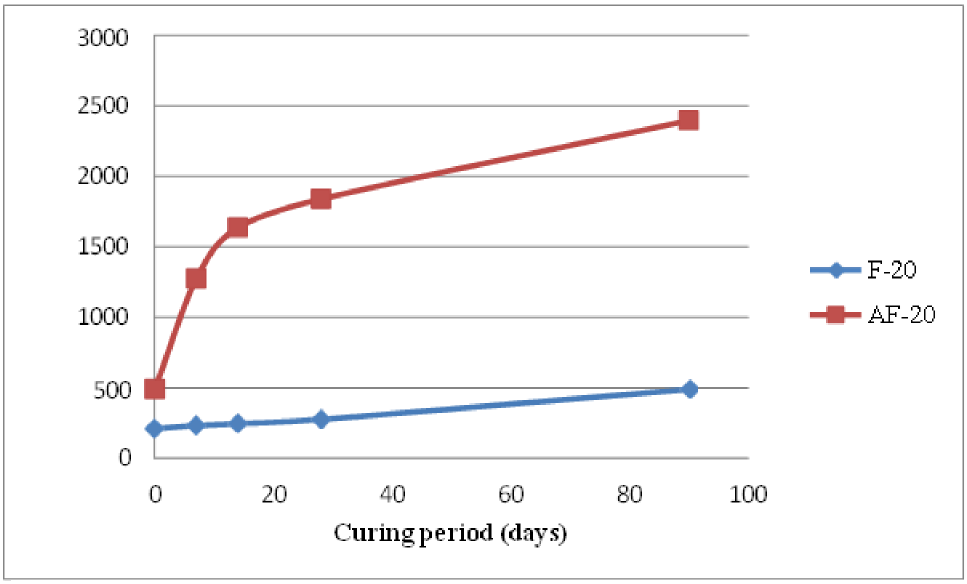

Figure 11: Treated and untreated soil containing 20% fly ash

4.3.2 California bearing ratio test:

Here, too, it is evident that the soil treated with geopolymer had a significantly higher CBR than the soil treated with fly ash.

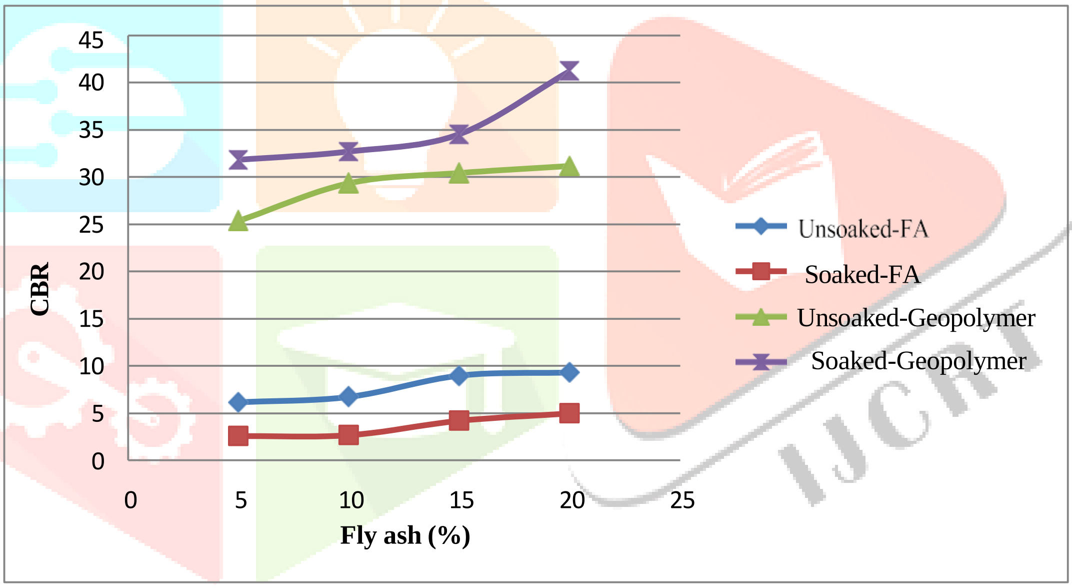

Figure 12: Unsoaked and soaked CBR values for treated and intreated soil

VII. CONCLUSIONS

In the present study, the enhancement of various soil properties was achieved by incorporating geopolymer and fly ash, with a comparative analysis performed between the two. The soil was mixed with fly ash in varying proportions of 5%, 10%, 15%, and 20%. The unconfined compressive strength (UCS) and California Bearing Ratio (CBR) values were observed to vary depending on the proportion of fly ash, the activation of fly ash using NaOH, and the curing period. Notably, there was a consistent increase in both UCS and CBR with up to 20% fly ash addition, highlighting its positive impact on soil strength. Furthermore, activating fly ash with NaOH led to a substantial enhancement in both UCS and CBR values, emphasizing the benefits of alkali activation.

The liquid limit (LL) and plastic limit (PL) of black cotton soil (BCS) decreased with the addition of fly ash, improving the soil's workability. At 0 days of curing, the UCS of BCS with 20% fly ash showed a 27.84% increase compared to untreated BCS. This strength improvement became more pronounced with extended curing periods. At 90 days of curing, the UCS of BCS with 20% fly ash was approximately 2.31 times greater than the UCS at 0 days of curing, demonstrating the long-term benefits of curing on strength development.

The activation of fly ash using NaOH further amplified the soil's strength. At 0 days of curing, the UCS of BCS with 20% activated fly ash was found to be nearly 2.96 times greater than that of untreated BCS. After 90 days of curing, the UCS of BCS with 20% activated fly ash was approximately 4.88 times greater than the UCS of untreated BCS. Similarly, a comparison between 20% fly ash and 20% activated fly ash revealed significant differences. At 0 days of curing, the UCS of BCS with 20% activated fly ash was 2.32 times greater than that of BCS with 20% regular fly ash. After 90 days of curing, this difference was slightly reduced, with the UCS of BCS with 20% activated fly ash being 1.44 times greater than the UCS of BCS with 20% fly ash. CBR testing also revealed noteworthy findings. At 7 days of curing, the unsoaked CBR of soil with 20% activated fly ash was approximately 3.34 times greater than that of soil with 20% regular fly ash. Similarly, the soaked CBR of soil with 20% activated fly ash was 8.24 times greater than that of soil with 20% fly ash. These results highlight the superior performance of activated fly ash in enhancing soil strength under both soaked and unsoaked conditions.

Interestingly, the soaked CBR values of activated fly ash-treated soil were consistently higher than the unsoaked values, even at 7 days of curing. This trend could be attributed to water infiltration, which potentially improved the compaction and bonding of the treated soil.

Overall, the study demonstrates the significant improvements in soil strength and durability achieved through the addition of fly ash, particularly when activated with NaOH, and underscores the importance of curing time in optimizing these benefits.

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