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Improving Black Cotton Soil with Sodium Hydroxide and Fly Ash: An Assessment of Optimum Moisture Content, Dry Density, and California Bearing Ratio

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Abstract

This study investigates the stabilization of Black Cotton Soil (BCS), an expansive clayey soil primarily composed of montmorillonite minerals, using sodium hydroxide (NaOH) and fly ash. Due to its high plasticity and significant volume changes with moisture, BCS is challenging for construction purposes. Adding NaOH and fly ash can potentially improve the soil's moisture tolerance, compressibility, and reduce its plasticity, making it more suitable for structural applications. The research evaluates key soil properties that affect its performance in construction: Optimum Moisture Content (OMC), Maximum Dry Density (MDD), and California Bearing Ratio (CBR). OMC is the moisture level at which soil achieves maximum compaction, and MDD represents the highest achievable density, both of which are important for load-bearing capacity. CBR values measure the soil's strength under load, a critical factor in pavement and foundation design. Additionally, Unconfined Compressive Strength (UCC) is assessed to understand the soil's resilience under direct compressive loads. Various ratios of NaOH (4%, 7%, 10%, 13%, 16%, and 19%) and fly ash (5%, 10%, 15%, 20%, 25%, and 30%) are incorporated into the BCS to analyze their effects on these parameters. The study's findings show that increasing NaOH and fly ash content enhances the OMC, MDD, CBR, and UCC values, indicating a positive impact on soil stability and strength. In summary, the addition of NaOH and fly ash effectively transforms Black Cotton Soil into a more stable and load-bearing material, making it a viable option for construction in areas with high BCS presence. This approach presents a sustainable method to address BCS-related challenges in infrastructure projects.

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Keywords: Fly ash, mechanical properties, synthetic soil, sodium hydroxide, CBR.

INTRODUCTION

Soil stabilization enhances engineering by modifying soil through mechanical or chemical methods. Mechanical stabilization uses equipment like scarifiers and rotary mixers, while chemical stabilization involves binders and emulsions to control dust, erosion, and leaching. Accurate soil classification is crucial for choosing the right method and materials. Mechanical stabilization includes compaction and fibrous reinforcements to improve soil quality for various structures. Advances in engineering and economy drive the use of chemical agents in sub-grades for added strength and durability, with recycled materials like old asphalt and tire chips enhancing stability.

Stabilized clay has less swelling and more appropriate hydration. Bade, R. G., et al [1]. Unconfined compressive strength stress and strains surged 106% and 50% when fly ash content was raised from 0 to 25%. Fly ash used with RHA (Rice Husk Ash) at 15% can reduce swell. Brooks, R. M [2]. Lime or fly ash prevents soil shrinking and swelling. Same-category AASHTO soils shrank differently. Buhler, R. L., & Cerato, A. B [3]. SDA, a low-cost adequate stabilizing agent for subbase and base course in clayey fills, is an industrial waste. Its efficacy may be increased by mixing it with other bonding elements such as lime, and it can be used to minimize road building expenses, particularly in rural areas. Butt, W. A, et al [4]. Non-combustible, odorless, white flake sodium hydroxide degrades into ions that alter soil minerals. Krishna keshav, et al [5]. Soil volume reduced during stabilization based on pH, density, moisture, clay content, curing duration, stabilizer ingredients, and addition rates. Sulfate-rich expansive soil volumetric swellings are reduced by Class C fly ash and 50/50 fly ash-cement mixtures, Mahedi, et al [6].

Blast furnace slag, fly ash, and lime strengthen BCS. Using industrial waste to improve black cotton soil (BCS) engineering qualities has raised sustainability and cost-effectiveness concerns, Maneli, A. et al [7]. Improvement of clay using GGBS (Ground Granulated Blast Furnace Slag) and groundnut shell. This work catalysed the improvement of clay soil's bearing strength, making it ideally suited for numerous geotechnical activities. Manimaran, A [8]. Fly ash low unit weight helps poor soils. Low specific gravity, easily draining, easy compaction, insensitivity to moisture content, and strong frictional qualities allow it to be utilized in embankment, roadways, low-lying land reclamation, fill behind retaining structures, and other applications, Mehta, A., et al [9]. Mishra, B. studied BCS engineering and lime stabilization. Applying lime to BCS causes pozzolanic reaction, stabilizing the soil [10]. Geopolymerization stabilizes BC soils, solidification is linked to chemical links like Al-O-Al (Si) or Si-O-Si (Al) KOH- activated materials show zeolitic frameworks and killitization. Miao, et al [11]. For specimens prepared at Moulding water content ranges of 16.7-21.6% and 17.2-19.3%, accordingly, the overall acceptable zone for cement kiln dust (CKD) processed black cotton soil was attained at 12 and 16% CKD concentration. Oriola, F. O. P., et al [12].

Stabilization of BCS with sand and cement as a pavement subgrade raises CBR and reaches a good CBR value, Ramteke, N. B., et al [13]. A small amount of lime boosted the soil's pozzolanic reactivity. Unconfined compressive strength tests recommend adding 20% binder. Sharma, Sivapillaiah [14]. Micro-fine slag diminishes the soil's plasticity index, liquid limiyand OMC. Shukla, R. P, Et al [15]. The effect of lime and fly ash on BCS's engineering characteristics revealed that, while waste materials like fly ash can be used successfully in civil engineering projects, lime increases their efficiency, Singh, S., et al, Ramlakhan, B., et al [16, 17]. Considering its economics due to its low CaCl2 concentration, it was discovered that the ideal amount of material for a favourable composition is soil + 6% of Ultra-fine slag + 1% CaCl2 was taken for future study. Suresh, R., et al [18]. According to experimental findings, the liquid limit, plasticity index, free swell index, optimal moisture content, and compression index have all decreased. Improvements in cohesiveness and angle of shearing resistance were seen in triaxial tests. Terrazyme proved to work best when applied at 2% of the dry soil's weight. Vasiya, V., et al [19]. Less soil swelling and a rise in OMC are signs of stabilizing Black cotton soil. Results from MDD, LL, and PL all show that combining fly ash and lime stabilized at 5% is superior to combining fly ash and lime stabilized at 5%, 10%, and 15%. Kalyane, A., et al [20].

Sodium hydroxide stabilization and concluded that NaOH improves the shear strength of black cotton soil by reducing its plasticity and increasing its cohesion, thus enhancing its compaction properties [21]. Found that mixing fly ash with black cotton soil at a 20% ratio reduced the OMC and increased the dry density, leading to improved strength and stability for use in construction [22]. Investigated the combined effect of sodium hydroxide and fly ash on black cotton soil. Their results showed that the optimal mix of 4% NaOH and 20% fly ash resulted in the highest CBR value and significant improvements in compaction properties, reducing both OMC and swelling potential [23]. Also explored the synergistic effects of NaOH and fly ash. Their findings indicated that the combination of 5% NaOH and 15% fly ash yielded the best results in terms of increased CBR and reduced plasticity, suggesting that this mixture could be used for road construction and other geotechnical applications [24].

MATERIALS AND METHODS

Materials

- *Soil:* BCS was amassed from Chavella village in Andhra Pradesh. Soils were gathered at a depth of about 1 m just under the natural soil surface. The floor was allowed to dry completely at room temperature. The dry soil that had become lumpy was carefully pulverized so that individual particles would not fall apart. The dirt was then sieved with a 200mm (IS. 480) sieve and preserved in containers. The index properties and the engineering properties of the native soil sample were thoroughly tested.
- *Fly ash:* The fly ash used for research was gathered in Secunderabad. The fly as oven dried, as it was moist. Care was taken to see that it is not overheated. The purities such as underdone coal etc. were removed.
- *NaOH:* The NaOH used in the test was bought from a certified laboratory chemical seller.

Methods

In this present work, BCS is stabilized using NaOH and Fly ash by adding different proportions of NaOH (0, 4, 7, 10, 13, 16, 19%) and Fly ash (5, 10, 20, 25, 30%) and various tests were conducted such as CBR (soaked and unsoaked CBR), standard proctor test and UCC test accordingly. Standard proctor test (IS: 2720-Part 7-1980) is carried out as per IS specification (IS: 2720- Part VII-1980). This test is designed to analyze the link between a soil's moisture content and dry density for a certain proportional active effort. California Bearing Ratio (IS: 2720-Part16-1979) is carried as per IS specification (IS: 2720-Part 16-1979) this test is carried out to determine CBR value using soaked and unsoaked CBR test. Unconfined compressive strength: (IS: 2720-Part 10-1991) is conducted according to IS (IS: 2720-Part 10-1991) after the CBR test, this test is carried out to determine the maximum compressive strength of the soil.

RESULTS AND DISCUSSIONS

Effect of Compaction

NaOH: Compaction values and curves of NaOH stabilized soil Figure 1 and 2 illustrate soil MDD and OMC curves with NaOH concentration increasing from 4% to 19%. Both the curves are nonlinear. The curves migrated to the left side higher as the proportion of NaOH increased. This results in a raise in MDD and a drop in OMC up to 13% of NaOH, followed by a decrease in MDD (Table 1).

Figure 3 and 4 depict OMC and MDD curves for soil with 5% to 30% fly ash concentration changes and are nonlinear. It is observed that when the proportion of fly ash increased, the curves migrated to the left side upwards. This implies that there will be a rise in MDD and a drop in OMC of up to 20% of fly ash, followed by a decrease in MDD (Table 1).

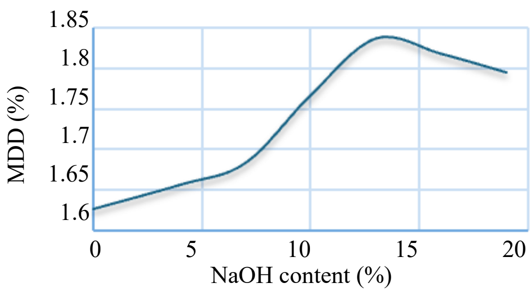

Figure 1. MDD variation with NaOH content.

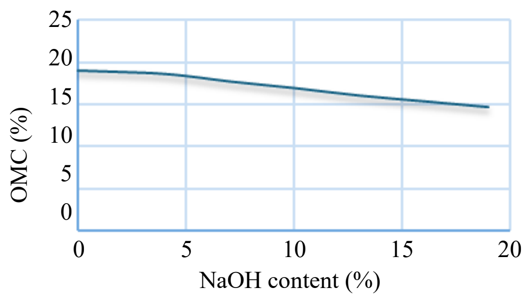

Figure 2. OMC variation with NaOH content

Fly Ash: Compaction values and curves of fly ash stabilized soil

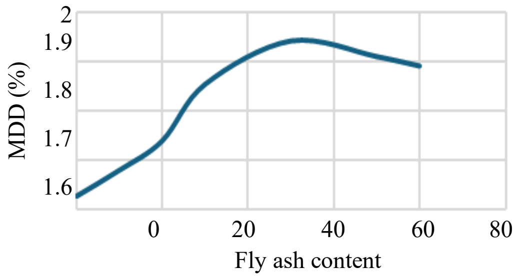

Figure 3. MDD variation with fly ash content.

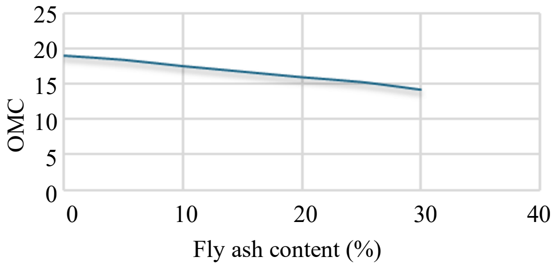

Figure 4. OMC variation with fly ash content.

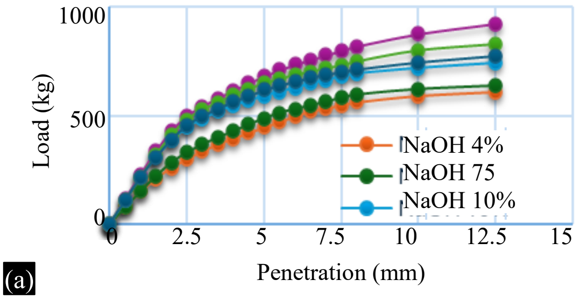

Figure 5(a). Load vs penetration for unsoaked condition.

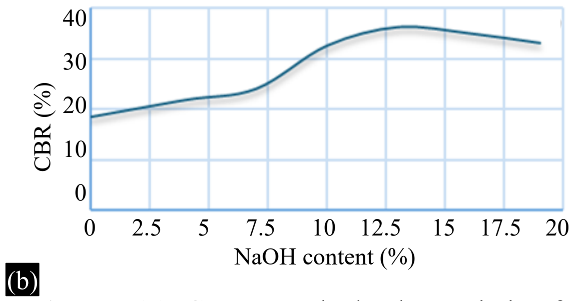

Figure 5(b). CBR unsoaked value variation for NaOH content.

Table 1. NaOH and fly ash stabilized soil compaction properties.

Content		Percentage (%)						
NaOH	%	0	4	7	10	13	16	19
	MDD	1.627	1.657	1.684	1.768	1.838	1.819	1.796
	OMC	19.1	18.7	17.8	17	16.1	1.4	14.7
Fly ash	%	0	5	10	15	20	25	30
	MDD	1.627	1.641	1.672	1.693	1.73	1.722	1.706
	OMC	19.1	18.5	17.6	16.8	16	15.3	14.2

Table 2. Unsoaked NaOH stabilized soil CBR values.

Sl. No	NaOH content (%)	Unsoaked CBR (%)
1	1	18.54
2	2	21.89
3	3	24.1
4	4	32.62
5	5	36.27
6	6	35.05
7	7	33.13

EFFECT OF CBR

Effect of CBR on NaOH

Unsoaked Condition

Table 2 summarizes the results of unsoaked CBR values for NaOH content. Figures 5(a) and 5(b) demonstrate load penetration curve plots for the unsoaked condition with NaOH as an admixture. The curve in Figure 5(b) demonstrates that the CBR grows with increasing NaOH level up to 13% and then steadily decreases with increasing NaOH content, and both curves are nonlinear.

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Soaked Condition

Table 3 summarizes the results for soaked CBR values of NaOH stabilized soil for 4,7 & 28 days (about 4 weeks), respectively. Figures 6 to 8 are the plots of load penetration curves for soaked (4 days, 7 days, 28 days) condition with NaOH as admixture.

The curves in Figures 6(a) and 6(b) demonstrate that the CBR grows with increasing NaOH levels up to 13% and then steadily drops with increasing NaOH content and both the curves are nonlinear.

The curve in Figure 7(a) and 7(b) shows that nonlinear behaviour, the CBR grows with an increase in NaOH level up to 13% and then steadily drops with the increasing NaOH content.

The curve in Figure 8(a) and 8(b) demonstrates that nonlinear behaviour CBR grows with an increase of NaOH level up to 13% of NaOH content and then steadily drops with the increasing of NaOH content.

Table 3. Soaked NaOH stabilized soil CBR values.

Sl. No	NaOH content (%)	Soaked CBR (%)		
		4 days	*7 days*	*28 days*
1	0	6.57	6.57	6.57
2	4	8.9	10.77	12.07
3	7	10.58	12.63	14.78
4	10	13.43	16.1	18.92
5	13	18.32	21.89	25.23
6	16	17.81	21.03	24.14
7	19	15.62	18.41	21.66

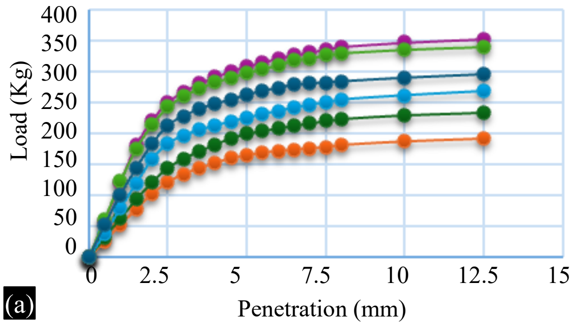

Figure 6 (a). Load vs penetration for soaked condition over 4 days

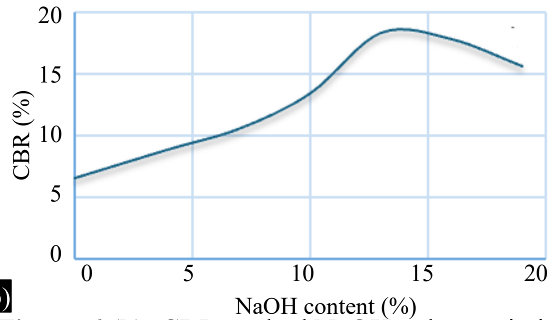

Figure 6 (b). CBR soaked NaOH value variation over 4 days

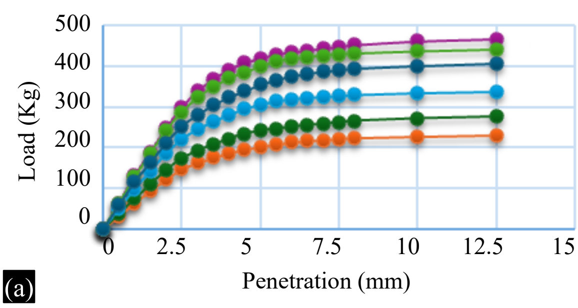

Figure 7 (a). Load vs penetration for soaked condition over 7 days.

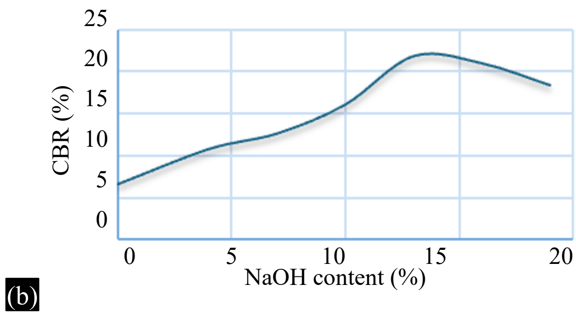

Figure 7 (b). CBR soaked NaOH value variation over 7 days.

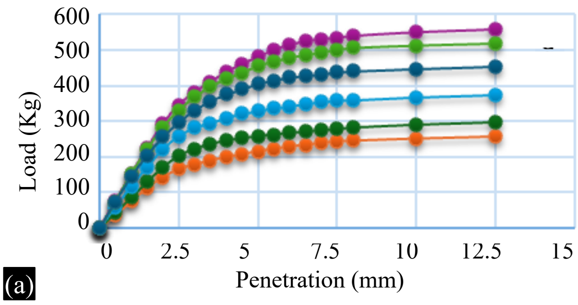

Figure 8 (a). Load vs penetration for soaked condition for 28 days (about 4 weeks).

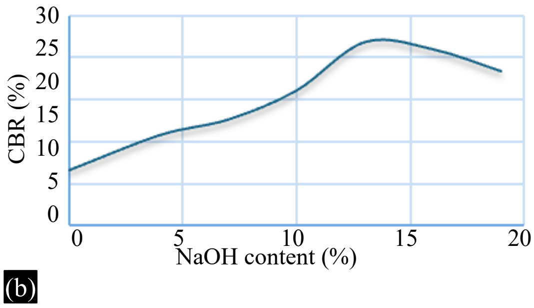

Figure 8 (b). CBR soaked NaOH value variation for 28 days (about 4 weeks).

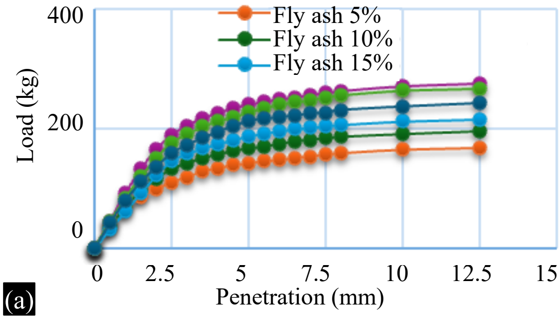

Figure 9 (a). Load vs penetration for fly ash concentration (Unsoaked).

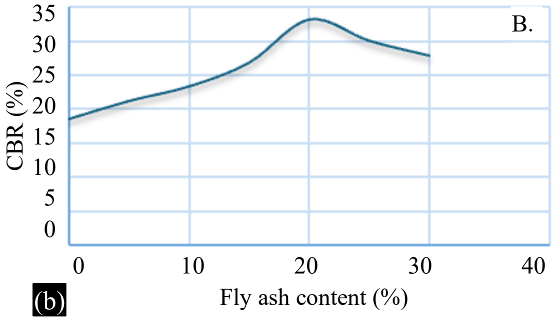

Figure (b). CBR unsoaked value variation for fly ash concentration.

Table 4. Unsoaked fly ash stabilized soil CBR values.

Sl. No	Fly ash content (%)	Unsoaked CBR (%)
1	0	18.54
2	5	21.2
3	10	23.35
4	15	26.86
5	20	33.21
6	25	30.07
7	30	27.88

Effect of CBR on Fly ash

Unsoaked Condition

Table 4 summarizes the results of unsoaked CBR values for fly ash concentration. Figure 9(a) and 9(b) are the plots are nonlinear of load penetration curves for unsoaked condition with fly ash as admixture.

The curve in Figure 9(b) demonstrates the CBR grows with rise of fly ash concentration up to 20% of fly ash concentration and then steadily drops with the rise of fly ash concentration.

Soaked Condition

Table 5 summarizes the results of soaked CBR values for fly ash content after being soaked. Figure 10 to 12 are the plots of load penetration curves for soaked (4 days, 7 days, 28 days) condition with fly ash as admixture.

The curve in Figures 10(a) and 10(b) demonstrate the nonlinear behaviour growth, CBR grows with rise of fly ash concentration up to 20% of fly ash concentration and then steadily drops with the rise of fly ash concentration.

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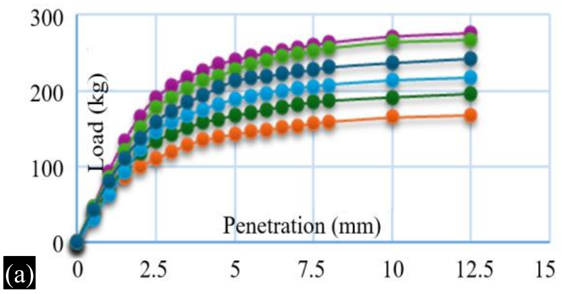
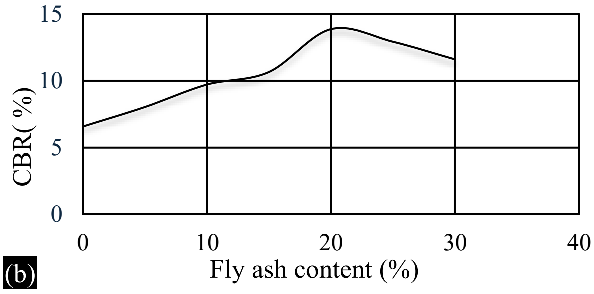
Table 5. CBR values of soaked fly ash stabilized soil.

Sl. No	Fly Ash content (%)	Soaked CBR (%)		
		4 days	*7 days*	*28 days*
1	0	6.57	6.57	6.57
2	5	8.03	8.18	8.21
3	10	9.71	9.83	9.8
4	15	10.65	10.85	10.89
5	20	13.86	13.96	13.92
6	25	12.92	13.02	13.12
7	30	11.6	11.77	11.62



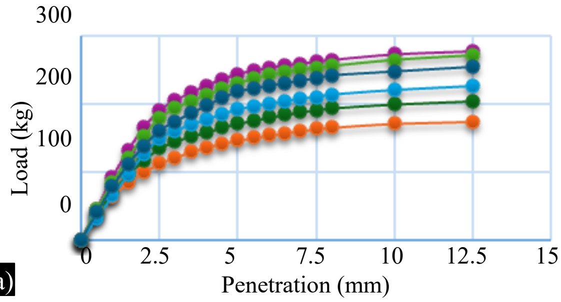
(a)

Figure 10 (a). Load vs penetration - CBR soaked fly ash value variation for 4 days.



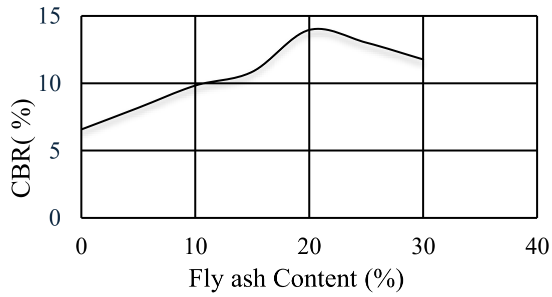
(b)

Figure 10 (b). CBR soaked fly ash value variation for 4 days.



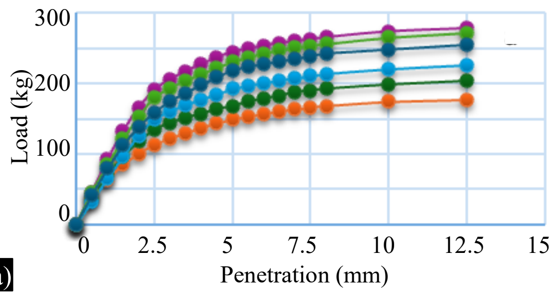
(a)

Figure 11 (a). Load vs penetration - CBR soaked fly ash value variation for 4 days.



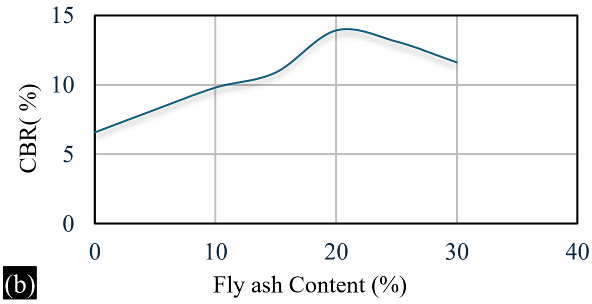
(b)

Figure 11 (b). CBR soaked fly ash value variation for 4 days.



(a)

Figure 12 (a). Load vs penetration - CBR soaked fly ash value variation for 28 days.



(b)

Figure 12 (b). CBR soaked fly ash value variation for 28 days.

The curve in Figure 11(a) and 11(b) demonstrates nonlinear behaviour growth, the CBR increases with rise of fly ash concentration up to 20% of fly ash concentration and then steadily drops with the rise of fly ash concentration. The curve in Figure 12(a) and 12(b) demonstrates the nonlinear behaviour growth, CBR grows with rise of fly ash concentration up to 20% of fly ash concentration and then steady drops with the rise of fly ash concentration.

Effect of Compressive Strength

Effect of Compressive Strength on NaOH

Table 6 demonstrates the results of the variation of strength values with variation of NaOH content. Figure 13(a) and 13(b) are plots are nonlinear behaviour growth, of Unconfined Compression test for NaOH as an admixture.

The result demonstrates compressive strength is increasing with increase of admixture up 13% for NaOH content.

Effect of Compressive Strength on Fly Ash

Table 7 demonstrates results of the change of strength values with variation of fly ash concentration. Figure 14(a) and 14(b) are plots are of nonlinear behaviour growth, Unconfined Compression test for fly ash as an admixture.

The result demonstrates compressive strength is increasing with increase of admixture up 20% for fly ash concentration.

Table 6. NaOH stabilized soil compressive strength values.

Sl. No.	NaOH Content (%)	Compressive strength (kg /cm^2)
1	0	1.9
2	4	3
3	7	4.8
4	10	9.6
5	13	13.7
6	16	12.9
7	19	11.2

Table. 7 Fly ash stabilized soil Compressive Strength values.

Sl. No.	Fly Ash Content (%)	Compressive strength (kg /cm^2)
1	0	1.9
2	5	2.2
3	10	3.8
4	15	5.6
5	20	9.4
6	25	8.8
7	30	7.2

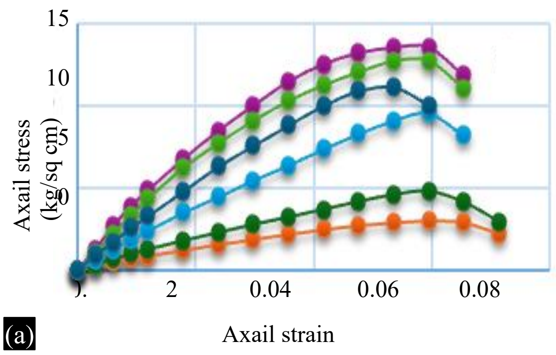


Figure 13(a). Stress vs strain variation with variation of NaOH content.

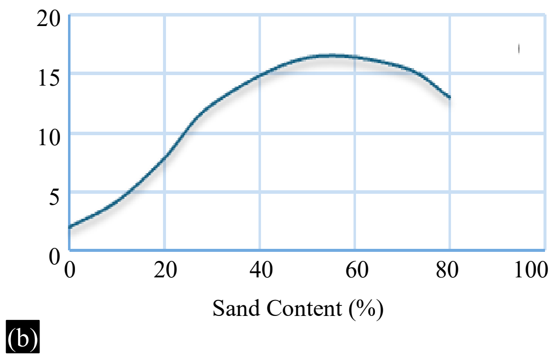


Figure 13 (b). Compressive strength variation with variation of NaOH content.

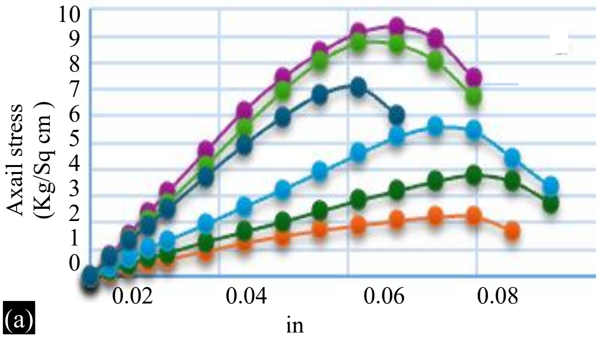


Figure 14 (a). Stress vs strain variation with variation of fly ash content.

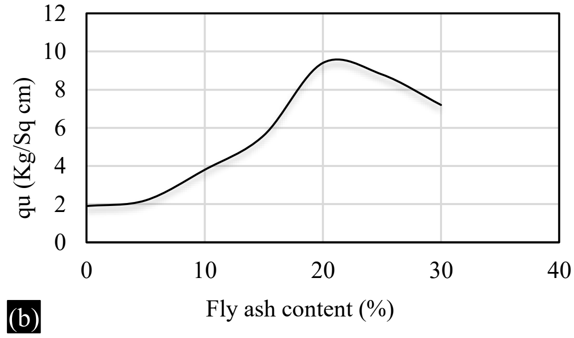


Figure 14 (b). Compressive strength variation with variation of Fly ash content.

CONCLUSION

Compressibility, plasticity, and strength nature can be improved with suitable addition of NaOH and fly ashcan drastically lower road construction costs. Depending on the compaction values, the following findings were derived from experimental studies.

- The value of OMC and MDD of natural soil obtained is1.627 (gm/cc) and 19.1% respectively. At 13% NaOH stabilized soil 1.838(gm/cc) value of MDD is obtained at 16.1% OMC. At 20% fly ash stabilized soil 1.73(gm/cc) value of MDD is obtained at 16.0% of OMC.
- CBR Values for unsoaked conditions remain as the natural soil CBR value obtained as 18.54%. The greatest value of CBR achieved using NaOH soil stabilization was 36.27%. The greatest CBR obtained for fly ash soil stabilization is 33.21%.
- At soaked condition, the natural soil CBR value (4 days) obtained as 6.57%. For NaOH soil stabilization, the greatest value of CBR (4 days) achieved is 18.32%, the greatest value of CBR (7 days) achieved as 21.89%, and the greatest value of CBR (28 days) achieved as 25.23%. For fly ash soil stabilization, the greatest value of CBR (4 days) achieved is 13.86%, the greatest value of CBR (7 days) achieved as 13.96%, the greatest value of CBR (28 days) achieved as 13.92%.
- UCC Values displays for the natural soil UCC value obtained as 1.9%. The greatest value of compressive strength that achieved at 13% of NaOH stabilized soil is 13.7 (kg/cm^2). The greatest compressive strength obtained with 20% of fly ash soil stabilization was 9.4(kg/cm^2).
- Based on the outcome, it is determined that the stabilization of soft clay soil using NaOH is far more successful than the stabilization of fly ash soil. It is also suggested that this type of NaOH soil stabilization be utilized for the formation of sub-grade soils and even sub-base course.

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