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Strength, Physicochemical and Morphological Characteristics of Fly Ash Stabilized Black Cotton Soil

S. S. Kushwaha, D. Kishan, N. Dindorkar

Abstract*: Black Cotton (BC) soil is one of the problematic soil deposits in India. These soils are problematic due to their poor engineering properties and high shrinkage and swelling properties due to high affinity to water. This paper, explore stabilization of Black cotton soil having poor strength characteristic and high shrinkage and swelling characteristic, with Class F Fly Ash (FA) to verify its scope for use as soil sub-base construction material. Fly ash is a good soil stabilizing additive in alone or along with other additives. It improves the index and engineering properties of Black cotton soil as verified from previous research work. In this research work, a Laboratory experimental program was planned with Fly ash, variation from 0% to 50% and humid curing period varies from 0 to 28 days. In the first stage of the experiment, Atterberg's limits and compaction test have performed on Black cotton soil with all mixture and found their respective Optimum Moisture Content (OMC) and Maximum Dry Densities (MDD). In the second stage of the experiment, UCS and CBR tests were carried out for immediate, 7, 14, 28 and 45 days curing periods. The Atterberg's limits, OMC, MDD, UCS, and CBR of Fly ash stabilized Black cotton found much satisfactory at 20% FA and 28 days curing period. CBR and UCS value get increments of 77.91% and 83.45% respectively. From the physicochemical analysis through X-Ray Diffraction (XRD) and Scanning of Electron Microscope (SEM), it was noticed That enhancement of strength is due to the pozzolanic reaction which causes the formation of new crystalline mineral of Alumino-Silicate-Hydrates (ASH) and Calcium-Alumino-Silicate-Hydrates(CASH) in void space of the matrix.

Index Terms: Atterberg's limit, Black cotton soil, Fly ash, Plasticity index, Stabilization

I. INTRODUCTION

The rapid growth of society require rapid growth of industries and infrastructure but the availability of land for the development of commercial, industrial and transportation infrastructure are limited especially in urban areas. This scarcity of land causes the accusation of agriculture land for infrastructure development and socio-economic growth of society. The agriculture land in India is mostly composed of black cotton soil deposits and it is spread over a large area about 20% of total land [1]. The black cotton soil is a problematic soil due to its poor shear strength and high shrinkage and swelling characteristic due to a high affinity of montmorillonite mineral toward the water. Due to the lack of good construction sites, there is a need to acquire marginal sites with poor geotechnical properties has become compulsory [2]. These soils suffer a huge change in volume during rainy seasons and a decrease in volume during summertime [3]. Nevertheless, development of civil engineering constructions on black cotton soil, pretend a significant danger to the structure. This is due to the higher degree of uncertainty in these sorts of clays. If minor character soil is possible at the construction place, the safest choice is to adjust the characteristics of the soil so that it reaches the requirements of infrastructure development. Stabilization of regionally accessible marginal soils becoming inadequate geotechnical attributes has been an engaging approach to infrastructure designer [4]. Because the quality and features of native soil differ broadly, a proper stabilization method has to be selected for a special location subsequent pending the soil qualities. The Lime, Bitumen, and Cement are the traditional soil stabilizers, whose effectiveness have been extensively described in the previous research work [4]. Nevertheless, these methods have not cost efficient and some have been remarked as not remaining environment-friendly [5]. Fly ash is industrial waste comes from thermal power plant after firing of coal as fuel. In India, most of the fly ash is of Class F fly ash, which has low lime content. This has forced researchers to ascertain cheap and environment-friendly alternative materials. Few industrial waste materials whose stabilizing influences have been studied and described constitute: blast furnace slag, corncob bash, recycled basanite, fly ash, steel slag, marble dust, rice husk ash, and microbe-inspired cementing, etc. Besides, this lime and other alkaline stabilizer cause erosive effect have a negative environmental influence in contempt of its easy availability and cheap [6], [7].

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S. No.	Laboratory Tests	Numerical Value
1	Specific Gravity	2.58
2	Gravel (%)	0
3	Sand (%)	5
4	Silt (%)	9.4
5	Clay (%)	85.6
6	Colour	Black
7	Liquid Limit (LL), %	62.55
8	Plastic Limit (PL), %	32.33
9	Plasticity Index (PI), %	31.36
10	Shrinkage Limit (SL), (%)	6.75
11	Indian Standard Soil Classification (ISSCS)	CH
12	Maximum Dry Density (MDD) (kN/m^3)	15.7
13		17.9
14	Optimum Moisture Content (OMC, %)	20.54
15		14.51
16	CBR, Soaked (%)	1.08
17	CBR, Unsoaked (%)	4.87
18	UCS (kN/m^2)	127.52

Consequently, the present study aims at evaluation of the effects of stabilization of black cotton soil with fly ash on the Atterberg's Limit, Compaction characteristics, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) of the soil for use as a highway embankment construction. Further, an attempt has been made to explore the cause of strength gain, by knowing the Physico-chemical and Morphological characteristics of fly ash stabilized soil using XRD and SEM analysis.

II. MATERIALS AND METHODOLOGY

A. *Black Cotton Soil*

Concerning to this research work, Black cotton soil was procured from Maulana Azad National Institute of Technology, Bhopal campus. The Black cotton soil was accumulated in the semi-dry state from the site. To make it suit to accept as a civil engineering material, improve compressive strength and bearing capacity, it requires some additives such as fly ash to stabilize it to get the desired geotechnical properties. The expansive soil has the chemical and geotechnical properties abstracted in Table I and Table II sequentially.

I Chemical Compositions of Raw Black Cotton Soils

S. No.	Constituents	Percentage
1	SiO_2	51%
2	Al_2O_3	4%
3	$CaCO_3$	7.5%
4	Montmorillonite Mineral	37%
5	Organic Content	0.5%
6	pH Value	7.2

A. *Fly Ash*

Fly ash may become a profitable construction material depends on the availability of the free lime in it and because of its self-hardening properties. According to ASTM C 618-03 (2003a) [8], fly ash can classify, as two types: class C and class F, depending upon the availability of free lime. For this study, low lime-fly ash (class F) are used and collected from Kota Thermal Power Plant, Kota, Rajasthan. The fresh fly ash was obtained in anhydrous phase from an electrostatic precipitator and commonly named as raw fly ash at the plant which has moderate pozzolanic stability. The composition of raw fly ash in the form of oxides is shown in Table III.

II Geotechnical Properties of Black Cotton Soil

III Chemical Compositions of Raw Fly Ash

S. No.	Constituents	Percentage
1	SiO_2	52.60
2	Al_2O_3	30.73
3	Fe_2O_3	5.72
4	CaO	1.40
5	MgO	0.12
6	Loss in ignition	5.84
7	Others	3.59
8.	pH	7.4

III. METHODOLOGY

All The experiments conducted are classified within two heads; Experiments conducted to ascertain the Atterberg's limits and strength characteristics of all specimen blends. Atterberg's limits characteristics are Liquid Limit (LL), Plastic Limit (PL), Plasticity Index (PI), etc, strength aspects are Compaction test, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), etc. The Liquid and Plastic Limits of the soil found as per the procedure stated in IS 2720: Part 5 [11]. The Standard Proctor test was performed in accordance with IS 2720: Part 7 to explore the compaction properties i.e. Optimum Moisture Content (OMC) and Maximum Dry Density (MDD), of the soil [12]. The California Bearing Ratio (CBR) test was conducted as per IS 2720: Part 16 to find out the unsoaked and soaked (CBR) of the soil specimen [13], while the unconfined compressive strength (UCS) of the soil specimens were explored as per IS 2720: Part 10 [14], for all blends prepared at OMC, investigated for several characters. The Black cotton soil blends with 10%, 20%, 30%, 40% and 50% by weight of soil and five samples were prepared and tested for Atterberg's Limits, Strength, morphological and physiochemical properties of soil and fly ash matrix for immediate to 28 days curing period.

IV. RESULTS AND DISCUSSIONS

A. *Virgin Black Cotton Soil*

The geotechnical features of the black cotton soil are manifested in Table II. The soil sample is classified as clay of high compressibility (CH), according to Indian Standard Soil Classification System (ISSCS). Although the soil is containing 85.6% clay, 9.5% silt, and 5% sand which means its particles are fine. It has specific gravity 2.68 and extremely plastic in character. The soil has high volume variation property due to shrinkage and swelling nature. Its shrinkage limit was recorded as 6.7, which shows the large volume variation character. The strength of black cotton soil, as represented by its unconfined compressive strength 127.52 kN/m^2, unsoaked and soaked CBR values 4.87% and 1.08%, respectively, which was very low from geotechnical concern.

B. *Black Cotton Soil Treatment with the Fly Ash (FA)*

Liquid limit tests have been carried out by the addition of a different percentage of fly ash. The liquid limit of raw expansive soil was found 62.55%. Addition of 10% fly ash to expansive soil liquid limit reduces to 58.23% on immediate testing. Liquid limit reduces further with the increase in the rate of fly ash up to 50% and it was noted to be 44.73% on immediate testing. This change in liquid limit with the increase in fly ash content may be due to the slow of pozzolanic reaction between black cotton soil and fly ash. This decrement in liquid limit may be due to the reduction in the depth of the diffused dual layer leading to a decrease in the water carrying capability [15]. This may be also due to replacement of fine-grained expansive soil with silty and coarse-grained nature of fly ash, which makes the mixture more frictional. As the curing period increase the liquid limit of black cotton soil-fly ash mixture decreases due to pozzolanic reactions causes the formation of various types of cementing compounds resulting in the formation of coarser particles. The cementation of these flocculated particles results in a marginal increase of liquid limit with curing. This is due to the increase in the flocculation and entrapped water in large void spaces of flocculated structure [16]. The changes of the liquid limit of black cotton soil with different percentage of fly ash with different curing days are shown in Table IV and Fig. 1. The plastic limit of raw black cotton soil was reported as 32.33%. With the addition of 10% fly ash to black cotton soil, the plastic limit reduces to 29.64% on immediate testing. Further plastic limit of expansive soil continuously decreases with an increase in the portion of fly ash up to 50%. This reduction in plastic limit may because due to the exhaustion of diffused dual film depth and consequent gathering. However, the fly ash is completely non-plastic in nature and having silty grains, when mixed with expansive soil causes immediate reduction in plastic limit of mixture. With the increase in the curing period the plastic limit of expansive soil and fly ash mixture increases up to 50% that may be due to the increase in the flocculation and entrapped water in large void spaces of flocculated structure. The change of the plastic limit of black cotton soil with different portion of fly ash with curing periods is shown in Table V and Fig 2. Table VI shows the plasticity index black cotton soil stabilized with fly ash for various curing periods.

IV Liquid Limit of Stabilized Black Cotton Soil with Fly Ash

S. No.	Mixtures	Liquid Limit (%)				
		Curing period in days				
		0	7	14	28	45
1	C alone	62.55	-	-	-	-
2	FA alone	25.76	-	-	-	-
3	C+10 FA	58.23	58.45	58.65	58.85	58.96
4	C+20 FA	54.47	54.61	54.96	55.13	55.31
5	C+30 FA	51.28	51.39	51.48	51.63	50.78
6	C+40 FA	47.47	47.62	47.75	47.92	48.09
7	C+50 FA	44.73	44.85	44.97	45.11	45.34

V Plastic Limit of Stabilized Black Cotton Soil with Fly Ash

S. No.	Mixtures	Plastic Limit (%)				
		Curing period in days				
		0	7	14	28	45
1	C alone	32.33	-	-	-	-
2	FA alone	NP	-	-	-	-
3	C+10FA	33.64	33.73	33.87	33.96	34.15
4	C+20FA	35.54	35.78	35.93	36.23	36.43
5	C+30FA	36.57	36.65	36.85	36.96	37.21
6	C+40FA	35.93	36.24	36.53	36.87	36.95
7	C+50FA	34.34	34.56	34.75	34.94	35.17

VI Plasticity Index of Stabilized Black Cotton Soil with Fly Ash

S. No.	Mixtures	Plasticity Index (%)				
		Curing period in days				
		0	7	14	28	45
1	C alone	30.4	-	-	-	-
2	FA alone	25.8	-	-	-	-
3	C+10FA	24.59	24.72	24.78	24.89	24.81
4	C+20FA	18.93	18.83	19.03	18.9	18.88
5	C+30FA	14.71	14.74	14.63	14.67	13.57
6	C+40 FA	11.54	11.38	11.22	11.05	11.14
7	C+50FA	10.39	10.29	10.22	10.17	10.17

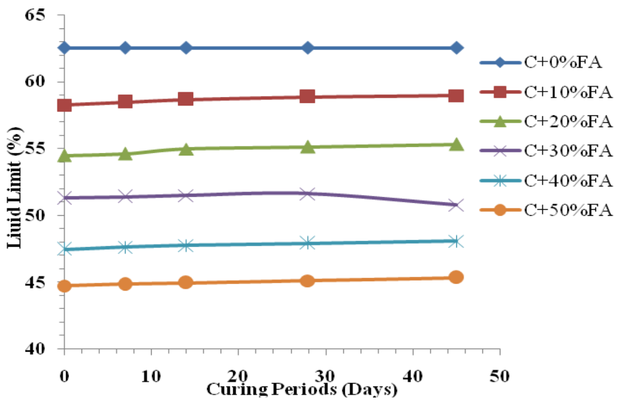

Fig. 1: Change of Liquid Limit of Black Cotton Soil (C) with Different Percentages of Fly Ash

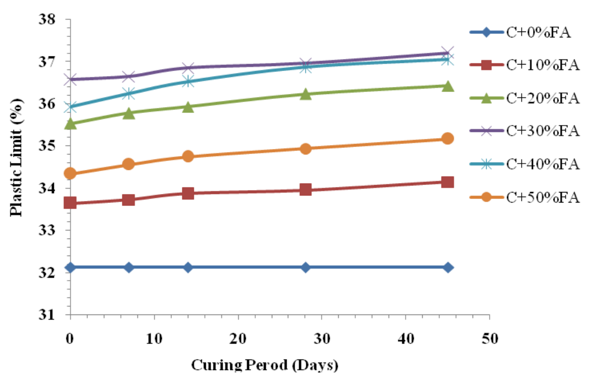

Fig. 2: Change of Plastic Limit of Black Cotton Soil (C) with Different Percentages of Fly Ash

The Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of black cotton soil, reported were 15.50kN/m^3 and 23.50% respectively.

Addition of 10% to 20% fly ash to black cotton soil MDD marginally increases from 15.84 to 16.45kN/m^3 and OMC decreases 21.25% to 17.60% respectively. Further it was noticed that increasing of fly ash to black cotton soil MDD decreases and OMC increases. This may be due to change in soil grain size and rearrangement of structure of the soil grains which resists the compactive efforts. As the compactive effort increases, OMC decreases and MDD rises up to increase of 20% fly ash. The variation of MDD and OMC of black cotton soil stabilized with fly ash presented by Fig. 3, 4 and Table VII. The OMC MDD curve shifted towards the density axis of plot which shows the silty or coarse grained nature of soil.

VII Compaction Result Fly Ash treated Black Cotton Soil

S. No.	Mixtures	Standard Proctor Test		Modified Procter Test	
		Optimum Moisture Content (%)	Maximum Dry Density (kN/m^3)	Optimum Moisture Content (%)	Maximum Dry Density (kN/m^3)
1	C alone	23.50	15.52	17.66	17.57
2	C+10FA	21.25	15.84	16.11	18.32
3	C+20FA	17.60	16.90	15.00	19.25
4	C+30FA	18.33	16.27	15.39	18.75
5	C+40FA	20.05	16.00	16.27	18.00
6	C+50FA	20.51	15.75	16.95	17.50

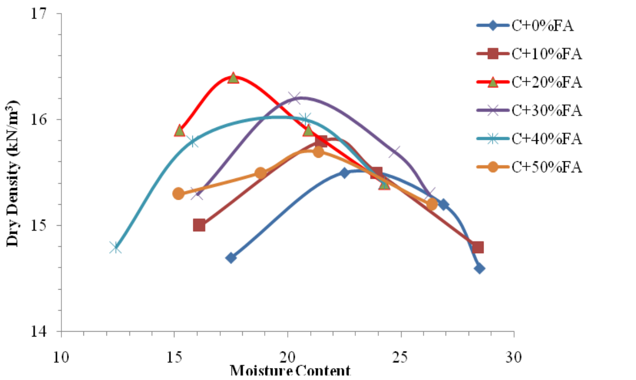

Fig.3 Variation of Dry Density – Water Content of Fly Ash Treated Black Cotton Soil under Proctor Test

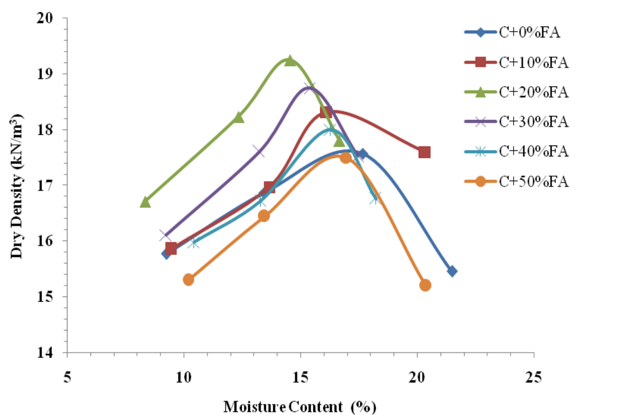

Fig. 4: Variation of Dry Density – Water Content of Fly Ash Treated Black Cotton Soil under Modified Proctor Test

The Unconfined Compressive Strength (UCS) of virgin Black cotton soil was reported as 127.5kN/m^2 on immediate testing while curing not affect the UCS more. The black cotton soil stabilized with 10% to 20% by weight of soil, the UCS improves with increment in the curing period. The highest UCS was reported as 231.27 kN/m^2 at 20% fly ash corresponding to 45 days curing time, exceeding 20% fly ash mixing to black cotton soil the UCS value get decreasing as shown in Table VIII and Fig. 5. The decrease in UCS with the increase in fly ash beyond 20% may be due to non plastic nature of fly ash and low lime content.

VIII Unconfined Compressive Strength (kN/m^2) of Treated Black Cotton Soil

S. No.	Mixtures	Unconfined compressive strength (kN/m^2)				
		Curing period in days				
		0	7	14	28	45
1	C	127.52	127.52	127.68	127.68	126.77
2	C+10FA	121.12	141.94	167.45	186.45	188.48
3	C+20FA	122.23	167.46	196.42	221.50	231.27
4	C+30FA	120.78	155.11	187.36	199.63	200.73
5	C+40FA	112.89	139.33	151.50	163.52	170.71
6	C+50FA	111.56	130.78	136.11	142.56	148.44

The un-soaked and soaked California Bearing Ratio (CBR) of untreated black cotton soil was recorded as 4.87% and 1.08% on immediate testing while curing period not effecting CBR of virgin soil. When black cotton soil blended with different percentage of fly ash (10 to 30%) by weight of black cotton soil, the CBR value grows up to 20% of fly ash increment and 28 days curing period. Ahead of 20% fly ash increment the percentage of CBR get diminishes considerably. Maximum un-soaked and soaked CBR recorded were 12.16% and 5.19% sequentially resembling 20% fly ash and 28 days curing period as mentioned in Table IX. Fig. 6 presents the difference of soaked (dotted line) and un-soaked CBR (solid line) with the curing period. As the curing period increases both soaked and un-soaked CBR values get increases which may be due to the formation of a cementitious compound between black cotton soil and fly ash matrix. The outcomes of CBR were equivalent and have the same exemplary from that stated by Bhuvaneshwari et al. [20]. For fly ash treated black cotton soil, the soaked CBR and UCS initially improved and succeeding reduced with the increasing amount of the fly ash. They published that 15 % of fly ash, improves UCS and soaked CBR of the treated black cotton soil by 74% and 95%, sequentially. The strength increment resulting from the addition of the fly ash to the black cotton soil in present research work is notable, although the percentage gains were approximately same, in contrast with the conclusions taken by Bhuvaneshwari et al. [20]. However, the stabilized black cotton could satisfy the necessity for the performance as sub-grade and sub-base course material.

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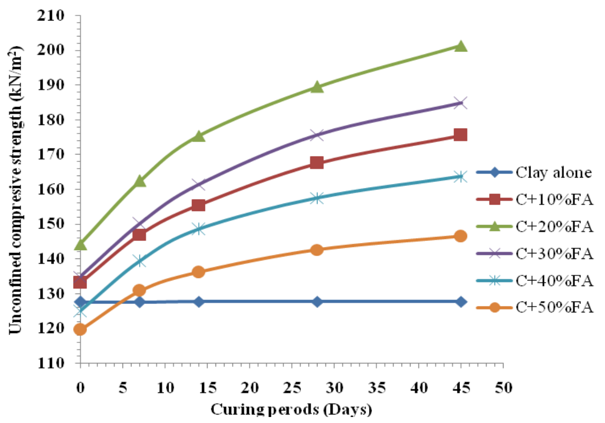


Fig. 5: Change of Unconfined Compressive Strength of Fly Ash Treated Black Cotton Soil with Curing Period

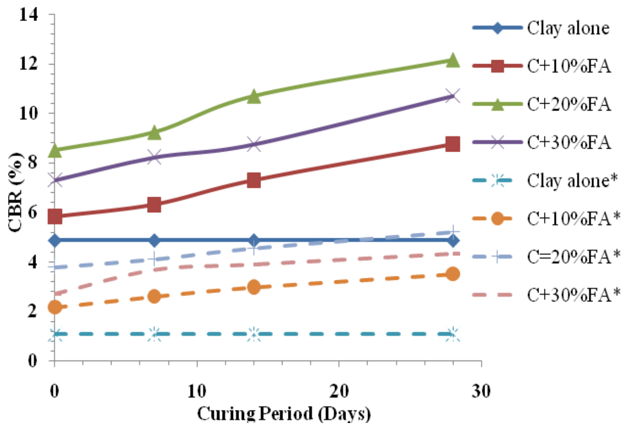


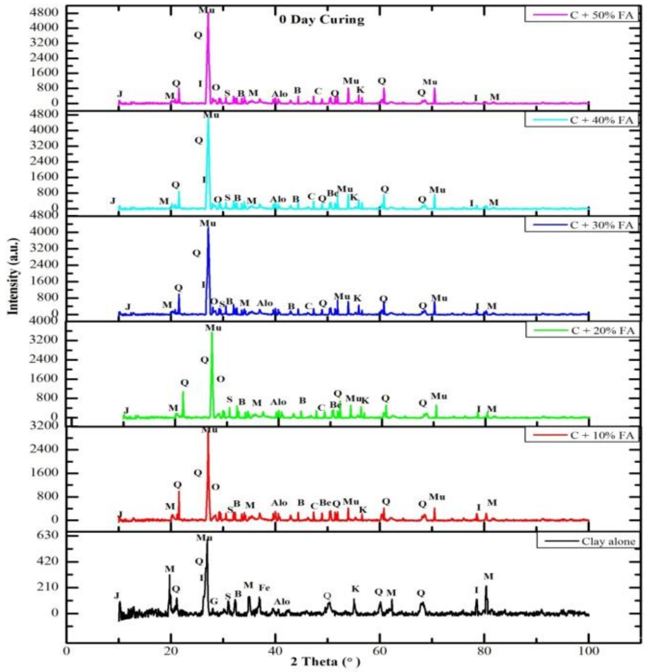
Fig. 6: Change of Soaked and Unsoaked CBR Value under Different Curing Period for Fly Ash Treated Black Cotton Soil

IX CBR (%) Values of Fly Ash Treated Black Cotton Soil

S. No.	Mixtures	CBR (%)							
		0 Days Curing		7 Days Curing		14 Days Curing		28 Days Curing	
		Un soaked	Soaked	Un soaked	Soaked	Un soaked	Soaked	Un soaked	Soaked
1	C	4.86	1.08	4.87	1.08	4.87	1.08	4.87	1.08
2	C+10FA	4.83	1.16	6.32	2.59	7.29	2.97	8.75	3.51
3	C+20FA	4.51	1.78	9.24	4.10	10.70	4.54	12.16	4.89
4	C+30FA	4.29	1.70	8.22	3.67	8.75	3.89	10.7	4.12

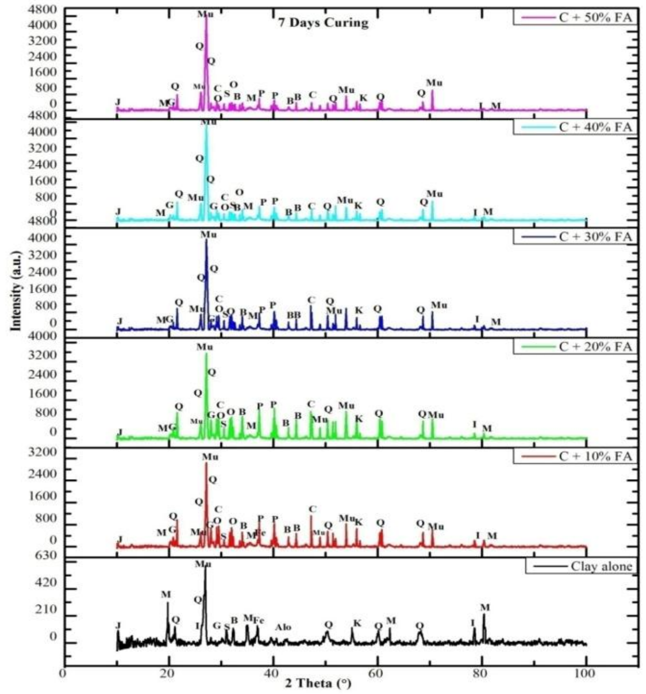
The mineralogical investigation of the fly ash treated black cotton soil was extremely crucial to ascertain the alterations in the mineralogical aspects because of pozzolanic reactions. Certain pozzolanic reactions based on the chemical and the mineralogical constitution of black cotton soil and fly ash [24]. The outcomes of present research work showed that the black cotton soil stabilized with 10, 20, 30, 40 and 50 percentage of fly ash at different curing periods as explained in XRD pattern also in SEM images (Fig. 7 to 14). The black cotton soil was containing montmorillonite clay mineral having pronounced peaks at 9.60, 35.00, 44.803 62.329, and 80.380 degree. In addition to montmorillonite, other mineral like Quartz peaks (SiO_2) at 21.542, 26.583, 50.32, 60.381, 66.528 and 68.476 degree, Jeffite ($Ca_6(Si_2O_7)(H_2O)$) at 10.170 degree, Illite at 25.351 and 78.256 degree, Iron oxide at 36.897 degree, Kaolinite at 55.684 degree, Silimanite (Al_2SiO_5) at 32.291degree, Brownmilerite ($Ca_4Al_2Fe_2O_{10}$) at 33.532 degree, Mullite ($Al_6Si_2O_{13}$) at 26.054, 26.289, 53.967 and 72.497 degree, Gismondine ($Ca_4Al_8(Si_8O_{31.9})(H_2O)_{18}$) at28.004 degree and Aluminium oxide (AlO) at 4.023 degree as shown in Fig 7 to Fig 10. Fig. 7 to Fig. 14 illustrates a micrograph of fly ash stabilized black cotton soil for the various percentage of fly ash and curing periods. The XRD analysis of the samples showed that calcium aluminium oxide, calcium aluminium silicate hydroxide (CASH) at 37.281and 40.153 degrees, calcium silicate hydrate (CSH) at 31.660 and 39.389 degrees, have formed in the samples. Besides formation of the new mineral the intensity of Quartz (SiO_2) at 21.542, 26.583, 50.32, 60.381, 66.528 and 68.476 degree; Brownmilerite ($Ca_4Al_2Fe_2O_{10}$) at 33.532, 44.367 and 47.300 degree and Gismondine ($Ca_4Al_8 (Si_8O_{31.9})(H_2O)_{18}$) at 26.289 and 28.004 degree; Celite ($Ca_3Al_2O_3$) at 29.513 and 47.262 degree, have increases and formation of these minerals takes place at new position of 2θ. The Brownmilerite, Quartz, CASH, CSH and Gismondine cementious compounds formed due to the pozzolanic reaction, may be CaO and FeO content in presence of silica present in both fly ash and expansive soil. The (UCS) and CBR (Soaked) of black cotton soil alone are 127.52 kN/m^2 and 1.08% respectively, addition of optimum (20%) fly ash to expansive soil the UCS increased to 167.46, 196.42 and 221.50 kN/m^2 at 14, 28 and 45 days of curing as illustrated in Table VIII and CBR (Soaked) increased to 4.10%, 4.54%, and 5.19% at 7, 14 and 28 days of curing as illustrated in Table IX respectively. The long-term UCS and CBR of the samples under marginal increment as the curing period increases beyond 28 days. The strength enhances due to hydration and pozzolanic reaction to form cement hydration compound as Brownmilerite, Quartz, CASH, CSH, Celite and Gismondine compounds for 28 days curing and beyond this period the peaks are pronounced at the same position of 2θ. The intensity for the different compounds has increased as the curing periods increases. The highest peaks of different compound imply that hydration and the pozzolanic response has taken place to improve the strength of the stabilized black cotton soil. SEM images of black cotton soil and various percentage of fly ash for 7, 14 and 28 days cured samples taken at a magnification range of 500 and a scale bar of 10**µ**m, this can be recognized that the presence of fly ash have little bonding material has produced agglomerations and the grains seen to be flocculated, materially the spaces have decreased and the mix has attained strength. SEM images taken after 7, 14 and 28 days of cured specimens the microstructure comprises of fly ash treated expansive soil has developed calcium-aluminium-silicate-hydrates

(CASH) gel like mass fills the gap between the soil particles shows that the fly ash have reacted with expansive soil considerably as the fly ash and curing periods increases as shown in Fig. 12 to 15. At the longer curing period, that is at 28 days the SEM micrographs reveal compact gel-like quantity comprising all the composite grains thoroughly and packing up the voids between grains.



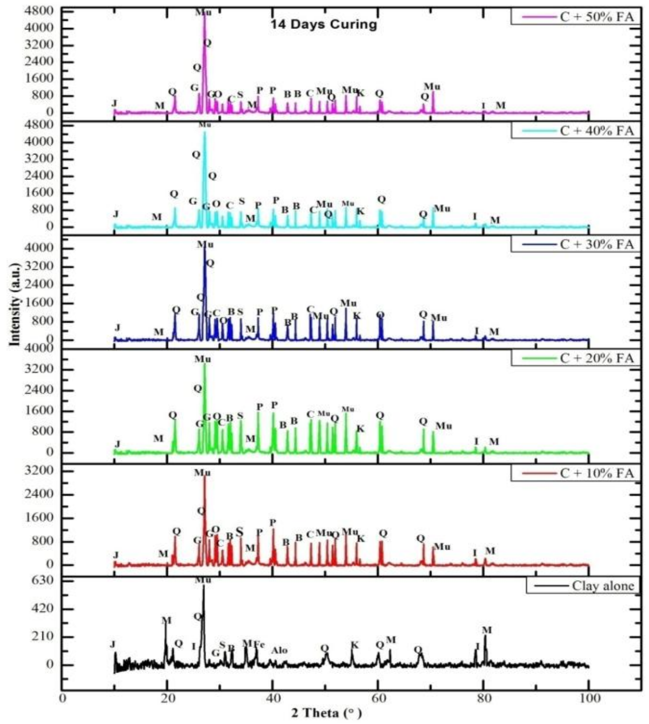
(J – Jaffeite, M – Montmorillonite, Q – Quartz, I – Illite, G – Gismondine, Mu – Mullite, S –Silimanite, B – Brownmillnite, Fe - Iron oxide, Alo – Alumina, P – CASH, K – Kaolinite, O –CSH, P – CASH, C – Celite,).

Fig. 7: XRD Plot of Fly Ash Treated Black Cotton Soil for 0 Days Curing Period



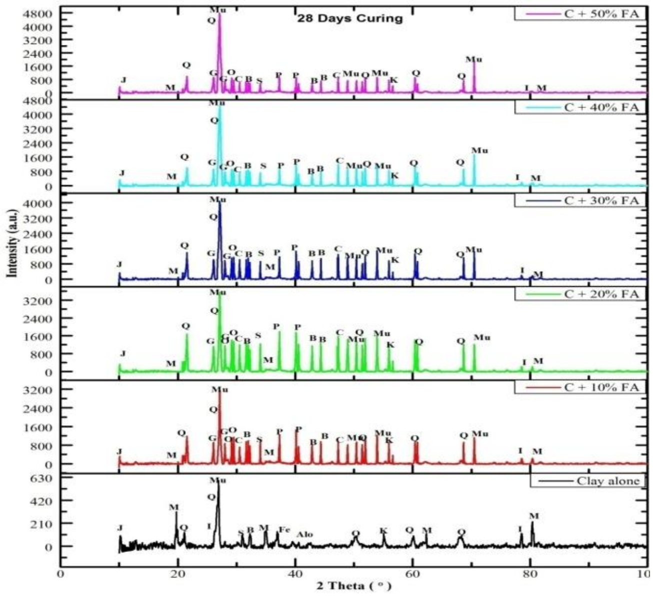
(J – Jaffeite, M – Montmorillonite, Q – Quartz, I – Illite, G – Gismondine, Mu – Mullite, S –Silimanite, B – Brownmillnite, Fe - Iron oxide, Alo – Alumina, P – CASH, K – Kaolinite, O –CSH, P – CASH, C – Celite).

Fig. 8: XRD Plot of Fly Ash Treated Block Cotton Soil for 7 Days Curing Period



(J – Jaffeite, M – Montmorillonite, Q – Quartz, I – Illite, G – Gismondine, Mu – Mullite, S –Silimanite, B – Brownmillnite, Fe - Iron oxide, Alo – Alumina, P – CASH, K – Kaolinite, O –CSH, P – CASH, C – Celite).

Fig. 9: XRD Plot of Fly Ash Treated Black Cotton Soil for 14 Days Curing



(J – Jaffeite, M – Montmorillonite, Q – Quartz, I – Illite, G – Gismondine, Mu – Mullite, S –Silimanite, B – Brownmillnite, Fe - Iron oxide, Alo – Alumina, P – CASH, K – Kaolinite, O –CSH, P – CASH, C – Celite)

Fig. 10: XRD Plot of Fly Ash Treated Expansive Soil for 28 Days Curing Period

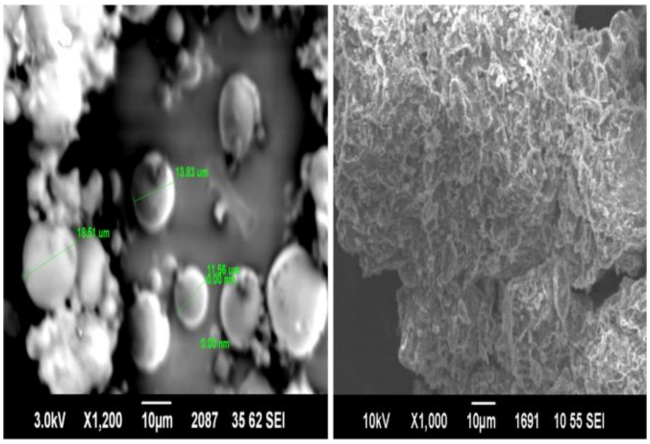


Fig. 11: SEM Image of Virgin Fly Ash (a) and Black Cotton Soil (b)

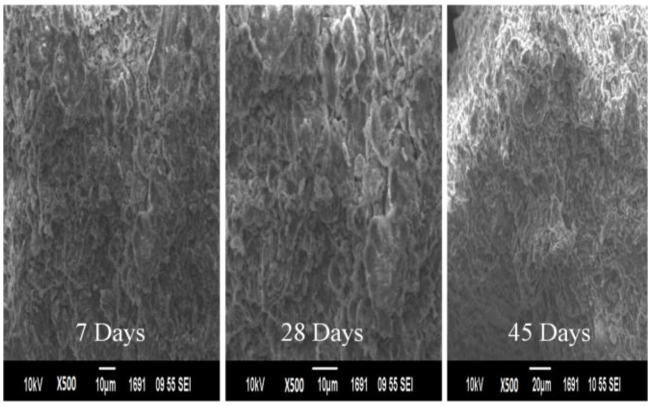


Fig. 12: SEM Image of Black Cotton Soil + 10% Fly Ash for Different Curing Period

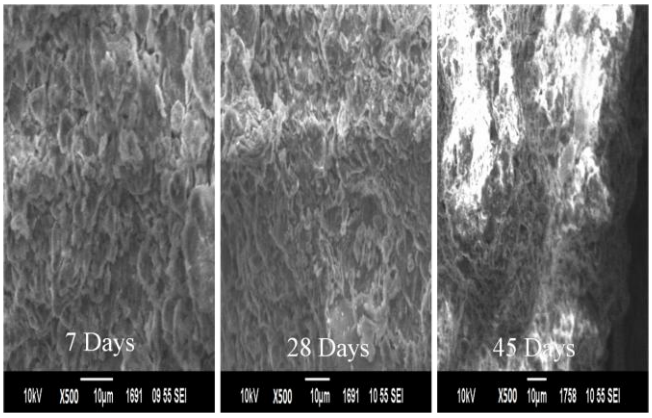


Fig. 13: SEM Image of Black Cotton Soil + 20% Fly Ash for Different Curing Period

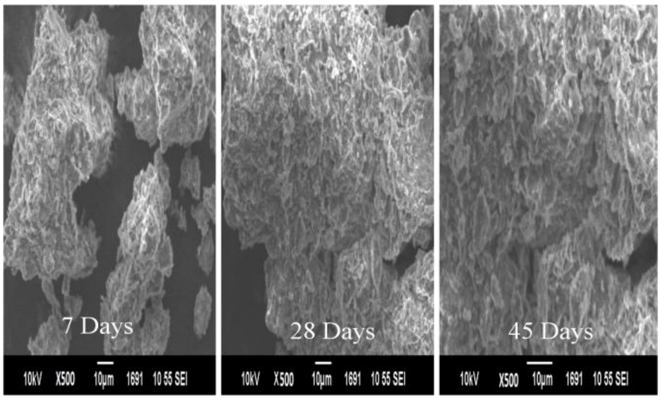


Fig. 14: SEM Image of Black Cotton Soil + 30% Fly Ash for Different Curing Period

V CONCLUSION

The Stabilization of the black cotton soil by the fly ash produced the soil extra workable by reducing its plasticity and improved its strength. Fly ash mitigated the sub-grade feature of the black cotton soil for application as a construction material but such increase in strength property was not adequate to address the soil simply accepted as sub-grade and sub-base materials. The laboratory conclusions of this investigation are valuable because it proves that yet when the soil needs the guidelines for stabilization by fly ash, highway designers are advised to apply valuable attention by examining their impacts on the different geotechnical engineering characteristics. A course of the fly ash stabilized soil with the comparable property as that of this research can be practiced for the construction of moderate vehicle rural paths, and bicycle lanes and walker walkways. Consequently, it is suggested that possible users of fly ash for soil stabilization should have attended the trial experiments to verify their impacts on the soil to be stabilized before utilizing them. The trial tests would recommend ascertaining whether the fly ash can attain the aspired level of soil improvement and the proper portion of additive that would make on before-mentioned improvement. As soils producing index characteristics comparable to that studied, stabilization with a mixture of fly ash and another additive may provide a higher percentage of intensifying their plasticity, strength and another geotechnical property.

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