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"IMPROVIZATION OF BLACK COTTON SOIL USING FLY ASH AS ALAKLI ACTIVATOR"

[1] Mithoon, [2] Dr. Pradeep K.T.V.

[1] M. Tech Scholar, Department of Civil Engineering, IES Group of Colleges, Bhopal, MP, India

[2] HOD, Department of Civil Engineering, IES Group of Colleges, Bhopal, MP, India

ABSTRACT

This research work presents the efficacy of sodium based alkaline activators and class F fly ash as an additive in improving the engineering characteristics of expansive Black cotton soils. Sodium hydroxide concentrations of 10, 12.5 and 15 molar along with 1 Molar solution of sodium silicate were used as activators. The activator to ash ratios was kept between 1 and 2.5 and ash percentages of 20, 30 and 40 %, relatively to the total solids. The effectiveness of this binder is tested by conducting the Unconfined compressive strength (UCS) at curing periods of 3,7 and 28 days and is compared with that of a common fly ash based binder, also the most effective mixtures were analyzed for mineralogy with XRD. Suitability of alkaline activated fly ash mix as a grouting material is also ascertained by studying the rheological properties of the grout such as, setting time, density and viscosity and is compared with that of common cement grouts. Results showed that the fluidity of the grouts correlates very well with UCS, with an increase in the former resulting in a decrease in the latter.

Keyword: *Fly ash; black cotton soil; alkali activator; unconfined compressive strength; etc.*

I. INTRODUCTION

1.1 General

Expansive soils otherwise called swelling soils or shrink swell soils are the terms applied to those soils, which tend to expand and shrivel with the variety in dampness content. Because of which noteworthy trouble in the soil happens, making serious harm the overlying structure. These kinds of soils are commonly found in parched and semi-bone-dry districts of the world and are considered as a likely regular risk, which if not treated well can make expansive harms not exclusively to the structures based upon them yet additionally can cause loss of human life.

Fly ash is a waste material, which is extracted from the pipe gases of a coal terminated heater. These have close similarity with the volcanic remains, which were utilized as water powered concretes in old ages. These volcanic remains were considered as extraordinary compared to other pozzolanas utilized till now on the planet.

1.2 FLY ASH GENERATION AND DISPOSAL

For generation of steams, generally coal is used as a fuel in thermal power plants. In the past coal in the forms of lumps were used to generate steam from the furnaces of boilers, but that method proves to be non-energy efficient. . Firstly the pulverized coal mass is injected into combustion chamber, where it burns efficiently and instantly. The output ash is known as fly ash, which consists of molten minerals.

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When fly ash is not subjected to economizer, it forms 4.3% soluble matter and pozzolanic activity index becomes 94%. When it subjected to economizer, it forms 8.8% soluble matter and pozzolanic activity index becomes 103%. Finally, the fly ashes are removed from the flue gases by mechanical dust

1.3 ALKALI ACTIVATED FLY ASH

Alkaline activation is a chemical process in which a powdery alumina-silicate such as fly ash is mixed with an alkaline activator to produce a paste capable of setting and hardening within a reasonably short period of time. The alkaline activation of fly ash is consequently of great interest in the context of new and environmentally friendly binders with properties similar to or that improved on the characteristics of conventional materials.

In general terms, alkaline activation is a reaction between alumina-silicate materials and alkali or alkali earth substances, namely: ROH, R(OH)2), R2CO3, R2S, Na2SO4, CaSO4.2H2O, R2.(n)SiO2, in which R represents an alkaline ion like sodium (Na) or potassium (K), or an alkaline earth ion like Ca.

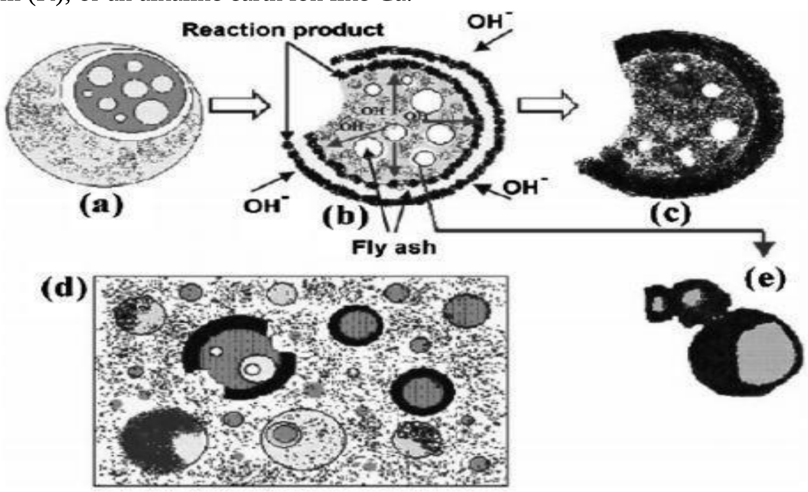

Fig. 1: Descriptive model of the alkaline activation processes of fly ash

II. LITERATUREREVIEW

Siavash Mahavesh (2005) a noteworthy portion of the world's vitality needs is met by coal-terminated force stations by consuming coal as fuel. There are deposits created in these force plants, which are called Coal Combustion Products (CCPs). All around the globe, all in all, the majority of the fly debris (FA) delivered is discarded in a landfill, causing worries for natural offices. This paper is centered around the use of FA just as it has end up being a more feasible soil stabilizer in contrast with base debris, because of its better molecule size. The investigation is worried about the impact of FA on settled sandy soil. Its impact is explored and broke down through some research center tests, for example, molecule size dissemination (PSD) and compaction (delegate). In this paper, a modification of past pertinent examination is illustrated. This area covers some Expansive parts of FA, its maintainability, proceeded by ground improvement and soil adjustment.

Das, Sarat Kumar and Parhi, Partha Sarathi (2008), this examination work presents part of the exploration on viability of sodium based basic activators and class F fly debris as an added substance in improving the designing properties of sweeping soils (Black cotton soils). The concrete business is the second biggest industry for an unnatural weather change. Sodium hydroxide centralizations of 10, 12.5 and 15 molar alongside 1 Molar arrangement of sodium silicate were utilized as activators. The activator to debris proportions (fluids to strong mass apportion) was kept somewhere in the range of 1 and 2.5 and debris rates of 20, 30 and 40%, moderately to the complete solids. The adequacy of this folio is tried by leading the Unconfirmed Compressive Strength (UCS) at relieving times of 3, 7 and 28 days and is contrasted and that of a typical fly debris based fastener; additionally the best blends were broke down for mineralogy with x-beam diffraction (XRD).

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Shriram P Marathe (2015), stabilization is one of the most widely recognized strategies for getting the extensive soils make it appropriate as a building material. Removal of a gigantic measure of modern squanders as fill material on removal locales closer to businesses needs a huge space as well as initiate a tremendous geo condition issue. The creation of soluble base activator by using modern waste materials has become a significant field of exploration as it is conceivable to utilize these materials to deliver a non-costly and naturally solid concrete like settling material. The actuation of waste materials, for example, fly debris in a soluble medium is a substance cycle that permits the client to change shiny structures (incompletely or absolutely undefined or potentially Meta stable) into an exceptionally minimal established adjustment material. Present investigation is centered on the new and eco-accommodating technique received in soil adjustment.

Anant Lal Murmu Anamika Jain (2019), this paper presents the aftereffects of trial work completed to improve the designing properties of a far reaching earth for example dark cotton soil (BCS) by utilizing fly debris geopolymer. Sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) arrangements were blended in various proportions (0.5, 1, 1.5, and 2) and utilized for orchestrating the geopolymer. The settled BCS tests were described in the research facility for different properties viz., Atterberg's cutoff points, free swell proportion, and unconfined compressive quality. The untreated and treated BCS tests were additionally examined for their micro structural and morphological properties by utilizing the SEM (checking electron magnifying lens) pictures and the XRD (X-beam diffract meter) and FTIR (Fourier-change infrared spectroscopy) spectra.

III. EXPERIMENTAL STUDY

3.1. Materials used for study

- **Black Cotton Soil (Expansive Soil) :** In the present investigation, expansive black cotton soil was procured from Khairi, Kanli road, Nagpur, Maharashtra. The black cotton soil was collected by method of disturbed sampling after removing the top soil at 500 mm depth and transported in sacks to the laboratory. Little amount of the sample was sealed in polythene bag for determining its natural moisture content. The soil was air dried, pulverized and sieved with 4.75 mm Indian as required for laboratory test.
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Table 2: Geotechnical properties of expansive soil

Sl. No	Properties	Confirming To Is Code	Value
1	Coefficient of uniformity(Cu)	IS 2720 : Part 4 : 1985	2.43
2	Coefficient of curvature(Cc)	IS 2720 : Part 4 : 1985	0.51
3	Specific gravity (G)	IS 2720 : Part 3 : Sec 1 : 1980	2.64
4	Maximum dry density(MDD)	IS 2720 : Part VII : 1980	1.55 gm/cc
5	Optimum moisture content (OMC)	IS 2720 : Part VII : 1980	23.31%
6	Natural moisture content	IS 2720 : Part 2 : 1973	7.11%
7	Free swell index	IS 2720 : Part XL : 1977	100%
8	Liquid limit	IS 2720 : Part 5 : 1985	72%
9	Plastic limit	IS 2720 : Part 5 : 1985	21%
10	Swelling pressure	IS 2720 : Part XLI : 1977	6 kg/cm^2
11	Classification	IS 1498	CH

- **Fly Ash:** In the present study fly ashes were collected from the captive power plant of National Aluminum Company Ltd, Angul, Odisha. After procuring, the fly ash samples were screened through 2 mm IS sieve, to separate out the vegetative and foreign material. To get a clear homogeneity, the samples are mixed thoroughly and heated in an oven maintained at 105°- 110°C for 24 hours and then is stored in an air tight container

Table 3: Compounds present in Fly ash

Compounds	Composition (%)
SiO_2	41.65
Al_2O_3	22.38
Fe_2O_3	15.04
MgO	4.76
CaO	4.75
K_2O	5.82
Na_2O	4.72

- **Activator Solution:** The alkaline activator solution used was a combination of sodium silicate and sodium hydroxide. The sodium silicate was originally in powder form and is procured Loba Chemie, Thane Maharashtra, having molecular weight of 284.20 gm/mole and specific gravity of 1.5. While the sodium hydroxide was originally in flake form with a molecular weight of 40 gm/mole, and specific gravity of 2.13 at 20º C and 95-99% purity. The sodium hydroxide pellets were procured from Merck specialties Pvt. Ltd. Mumbai, Maharashtra, India.

3.2. Objectives

- To prepare alkali-activated fly ash by using sodium silicate and 10, 12.5 and 15 molar sodium hydroxide solutions.
- To evaluate unconfined compressive strength of fly ash treated soil on an interval of 3, 7 and 28 days (mixed with 20, 30 and 40% fly ash with total solid to water ratio ranging from 0.15 to 0.25)
- To evaluate unconfined compressive strength of alkaline activated fly ash treated soil on an interval of 3, 7 and 28 days (mixed with 20, 30 and 40% fly ash with total solid to activator ratio ranging from 0.15 to 0.25).

To study the rheological Study for assessment of alkali-activated solution as a grouting material.

IV. RESEARCH METHODOLOGY

4.1 Methodology

- To evaluate the effect of the ash/soil ratio (by dry mass) on mechanical strength, three different fly ash percentages, regarding the total solids (soil + ash) weight, were used: 20, 30 and 40 %, corresponding to ash/soil ratios of 0.25, 0.43 and 0.67, with activator/total solids ratios of 0.15, 0.2 and 0.25.
- The soil and the ash were previously homogenized before the activator was added to the mixture. After mixing for 3 min, the samples were cast into 50-mm moulds by tapping the moulds on the lab counter, which were then left in a sealed container.

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- The 15 molar mixtures showed a very high viscosity which made the preparation and handling process more difficult than with the remaining concentrations, to a point where this factor should be considered when designing future studies and/or applications.
- For the fly ash based mixtures, water to solid of 15, 20, 25 and 30% were tested. In terms of fly ash percentage in the mixtures, values of 20, 30 and 40 % of the total dry weight were used.
- The rheological studies include measurement of density and viscosity of both cement and alkali-activated grouts and comparison between the two, with the purpose of determining how much time is available before mixing with the soil.
- The 15 molar mixtures showed a very high viscosity which made the preparation and handling process more difficult than with the remaining concentrations, to a point where this factor should be considered when designing future studies and/or applications.

Table 4: Details of alkali-activated fly ash mixed soil specimens

S. No.	Name of the specimen	Particular of the mix
1	AF-100-20-15	Soil + 20% fly ash by weight of total solids + 10 molar 15% alkali activator by weight of total solids.
2	AF-100-30-15	Soil + 30% fly ash by weight of total solids + 10 molar 15% alkali activator by weight of total solids.
3	AF-100-40-15	Soil + 40% fly ash by weight of total solids + 10 molar 15% alkali activator by weight of total solids.
4	AF-100-20-20	Soil + 20% fly ash by weight of total solids + 10 molar 20% alkali activator by weight of total solids.
5	AF-100-30-20	Soil + 20% fly ash by weight of total solids + 10 molar 20% alkali activator by weight of total solids.
6	AF-100-40-20	Soil + 20% fly ash by weight of total solids + 10 molar 20% alkali activator by weight of total solids.
7	AF-100-20-25	Soil + 20% fly ash by weight of total solids + 10 molar 25% alkali activator by weight of total solids.
8	AF-100-30-25	Soil + 20% fly ash by weight of total solids + 10 molar 25% alkali activator by weight of total solids.
9	AF-100-40-25	Soil + 20% fly ash by weight of total solids + 10 molar 25% alkali activator by weight of total solids.
10	AF-125-20-15	Soil + 20% fly ash by weight of total solids + 12.5 molar 15% alkali activator by weight of total solids.

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11	AF-125-30-15	Soil + 30% fly ash by weight of total solids + 12.5 molar 15% alkali activator by weight of total solids.
12	AF-125-40-15	Soil + 40% fly ash by weight of total solids + 12.5 molar 15% alkali activator by weight of total solids.
13	AF-125-20-20	Soil + 20% fly ash by weight of total solids + 12.5 molar 20% alkali activator by weight of total solids.
14	AF-125-30-20	Soil + 20% fly ash by weight of total solids + 12.5 molar 20% alkali activator by weight of total solids.
15	AF-125-40-20	Soil + 20% fly ash by weight of total solids + 12.5 molar 20% alkali activator by weight of total solids.
16	AF-125-20-25	Soil + 20% fly ash by weight of total solids + 12.5 molar 25% alkali activator by weight of total solids.
17	AF-125-30-25	Soil + 20% fly ash by weight of total solids + 12.5 molar 25% alkali activator by weight of total solids.
18	AF-125-40-25	Soil + 20% fly ash by weight of total solids + 12.5 molar 25% alkali activator by weight of total solids.
19	AF-150-20-15	Soil + 20% fly ash by weight of total solids + 15 molar 15% alkali activator by weight of total solids.
20	AF-150-30-15	Soil + 30% fly ash by weight of total solids + 15 molar 15% alkali activator by weight of total solids.

Table 5: Details of fly ash mixed soil specimens

Sl No	Name of the specimen	Particular of the mix
1	F-15-20	Soil + 20% fly ash by weight of total solids + 15% water by weight of total solids.
2	F-15-30	Soil + 20% fly ash by weight of total solids + 15% water by weight of total solids.

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3	F-15-40	Soil + 20% fly ash by weight of total solids + 15% water by weight of total solids.
4	F-20-20	Soil + 20% fly ash by weight of total solids + 20% water by weight of total solids.
5	F-20-30	Soil + 20% fly ash by weight of total solids + 20% water by weight of total solids.
6	F-20-40	Soil + 20% fly ash by weight of total solids + 20% water by weight of total solids.
7	F-25-20	Soil + 20% fly ash by weight of total solids + 25% water by weight of total solids.
8	F-25-30	Soil + 20% fly ash by weight of total solids + 25% water by weight of total solids.
9	F-25-40	Soil + 20% fly ash by weight of total solids + 25% water by weight of total solids.

V. RESULTS & DISCUSSION

5.1 Results on Stabilization of Expansive Soils with Fly Ash

This chapter presents the results of stabilization of expansive black cotton soil, with fly ash. The increase in strength criteria is ascertained by conducting unconfined compression test on samples, at 3, 7 and 28 days curing. The samples, casted were of 50 mm diameter and 100 mm height, thereby ensuring L/D ratio as 2. These samples contains fly ash in 20, 30 and 40% by weight of dry mass and water to total solid ratio is varied from 15, 20 and 25%. All the samples were covered with cling film, after casting and are kept in a air tight container for 48 hours. Immediately before testing, at the ages of 3, 7 and 28 days, the samples were trimmed to 100 mm long and tested for unconfined compressive strength.

Table 6: UCS results of F-15-20, F-15-30, F-15-40

Curing Time (Days)	Unconfined compressive strength (kPa)		
Specimen Name	F-15-20	F-15-30	F-15-40
3	104.97	98.58	82.6
7	283.22	219.64	144.68
28	363.65	279.93	254.9

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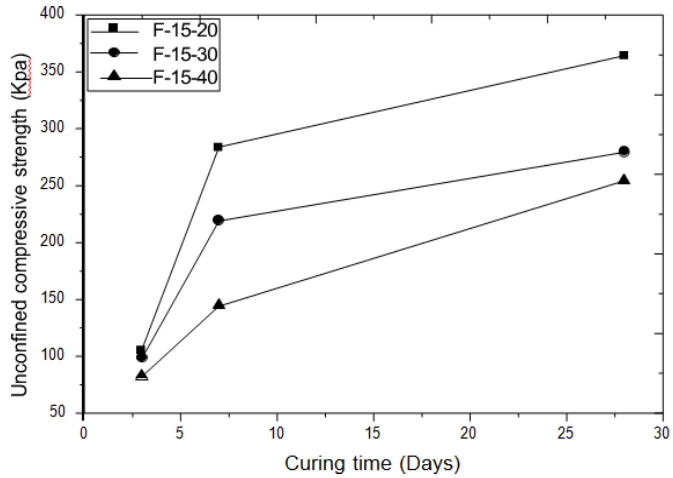

Figure 2: UCS results of F-15-20, F-15-30, F-15-40

It is evident from the Table 4.1, that the mix F-15-20, is giving more strength at 3, 7 and 28 days than the other two. The 3 day strength of F-15-20 is 6 % more than that of F-15- 30 and 27 % more than that of F-15-40. Similarly the 7 day strength of F-15-20 is 29% more than that of F-15-30 and is about 96% more than that of F-15-40. Moreover the 28 day strength of mix F -15-20 is nearly 30% more than that of F-15-30 and is 43 % more than that of F-15-40. The variations of strength of the mixes are shown in Figure 4.2. and it can be stated as the strength of the mix is directly proportional to the curing period and is inversely proportional to the fly ash content in the mix. Thus it can be concluded that for constant water to total solid ratio, the strength increases with the curing period and also with the decreased fly ash content.

Table 7: UCS results of F-20-20, F-20-30, F-20-40

Curing Time (Days)	Unconfined compressive strength (kPa)		
Specimen Name	F-20-20	F-20-30	F-20-40
3	85.69	120.5	91.7
7	113.98	131.5	101.77
28	141.93	156.25	125.94

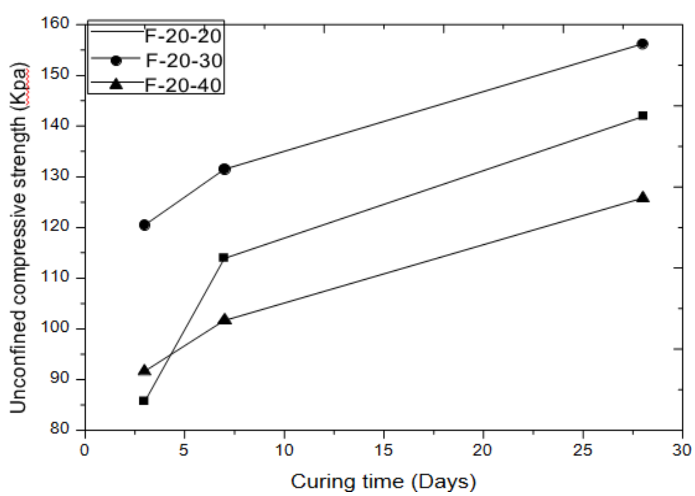

Figure 3: UCS results of F-20-20, F-20-30, F-20-40

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Table 4.2 shows the UCS values of the samples F-20-20, F-20-30, F-20-40, obtained after 3, 7 and 28 days curing. It is evident from the results depicted in table 4.2 that the mix F- 20-30 is giving more strength at 3, 7 and 28 days than the other two. The 3 day strength of F-20-30 is 40 % more than that of F-20-20 and is 31.4 % more than that of F-20-40. Similarly the 7 day strength of F-20-30 is 15.37% more than that of F-20-20 and is about 29.21% more than that of F-20-40. Moreover there is a slight increase in the 28 day strength of mix F-20-30 which is about 10% more than that of F-20-20 and is 24 % more than that of F-20-40. The variations of strength of the mixes are shown in Figure 4.3.

Table 8: UCS results of F-25-20, F-25-30, F-25-40

Curing Time (Days)	Unconfined compressive strength (kPa)		
Specimen Name	F-25-20	F-25-30	F-25-40
3	45.13	41.91	38.38
7	52.69	49.88	47.28
28	115.69	98.63	88.27

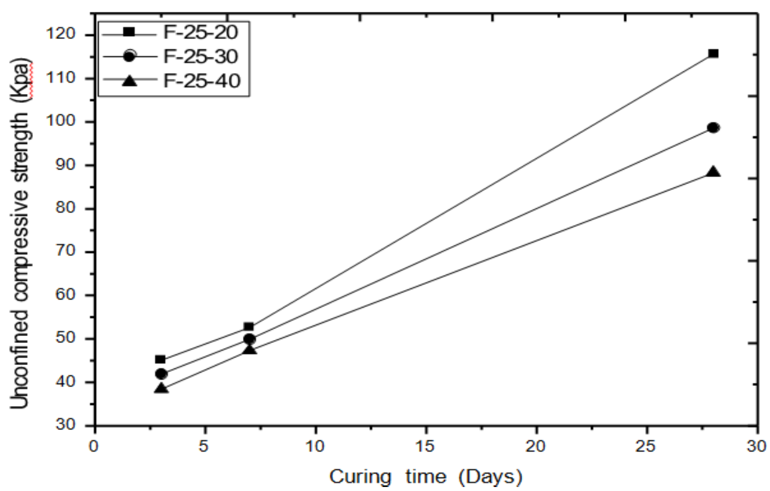

Figure 4: UCS results of F-25-20, F-25-30, F-25-40

There is a slight variation in the 3, 7 and 28 day strength of F-25-20 and F-25-30 which is about 7%, 5% and 17%, but the variation between the 3, 7 and 28 day strength of F-25-20 and F-25-40 is about 18%, 11 % and 31%.

Table 9: UCS results of all Fly ash Samples

Curing time (Days)	Unconfined compressive strength (kPa)								
	F-15-20	F-15-30	F-15-40	F-20-20	F-20-30	F-20-40	F-25-20	F-25-30	F-25-40
3	104.97	98.58	82.6	85.69	120.5	91.7	45.13	41.91	38.38
7	283.22	219.64	144.68	113.98	131.5	101.77	52.69	49.88	47.28
28	363.65	279.93	254.9	141.93	156.25	125.94	115.69	98.63	88.27

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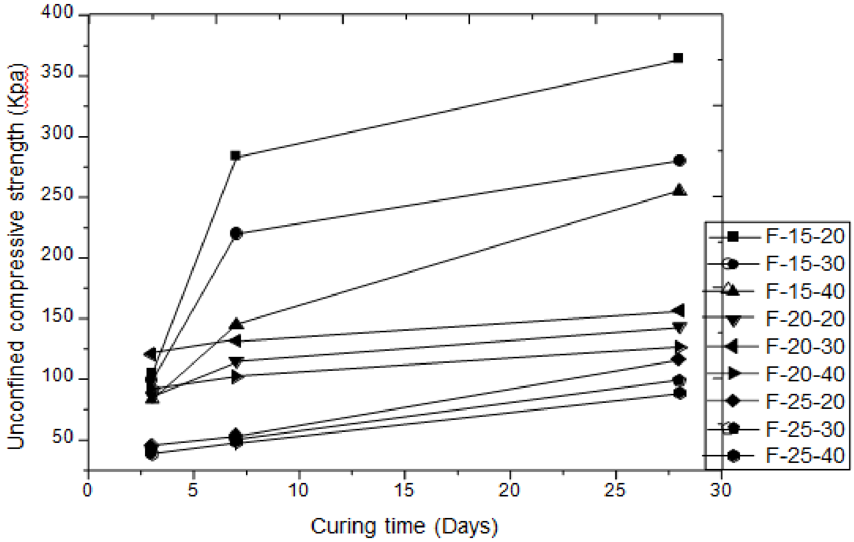

Figure 5: UCS results of all Fly ash Samples

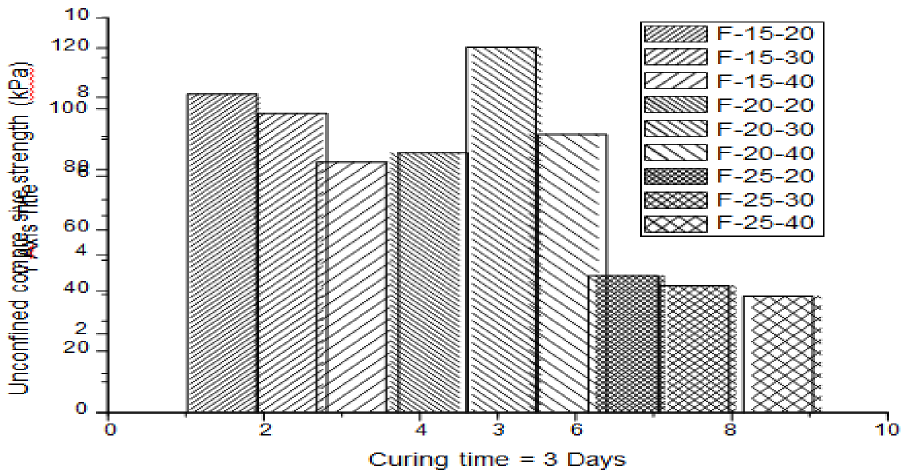

Figure 6: Bar chart showing the UCS results of Fly ash Samples after 3 days of curing

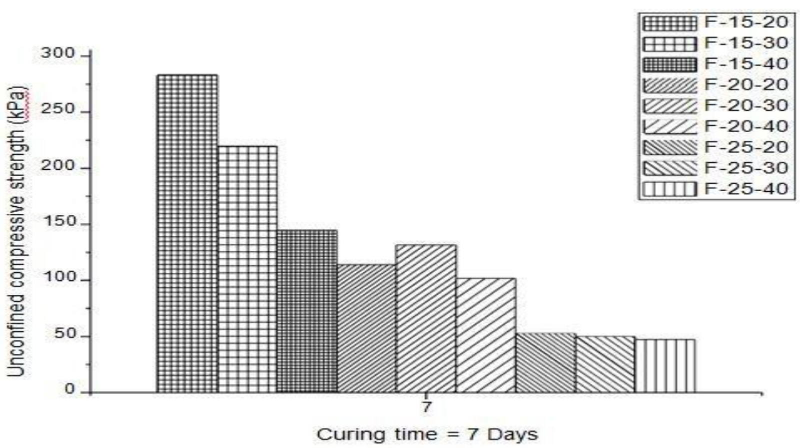

Figure 7: Bar chart showing the UCS results of Fly ash Samples after 7 days of curing

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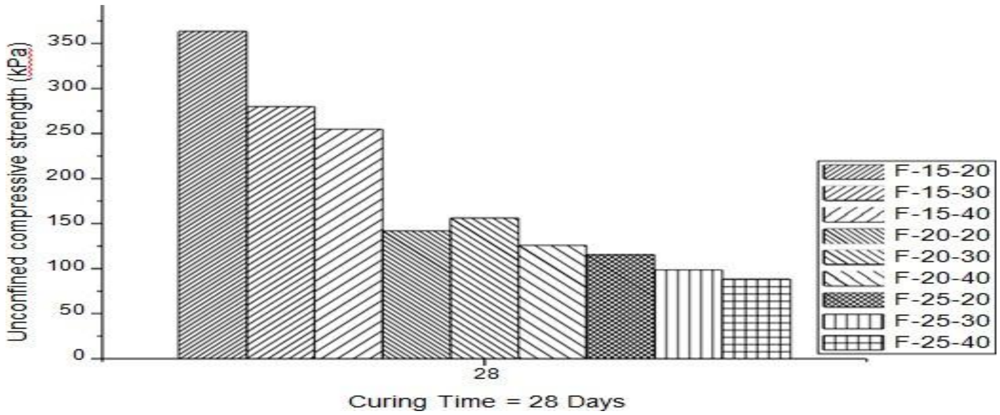

Figure 8: Bar chart showing the UCS results of Fly ash Samples after 28 days of curing

Table 4.4 shows the UCS values of all samples treated with fly ash, obtained after 3, 7 and 28 days curing. It is evident from the results depicted in table 4.4 that the mix F-20- 30 is giving more 3 day strength as compared to other mixes. But the mix F-15-20 is giving more strength at 7 day and 28 day curing as compared to others. Strength of the mix F-25-40 obtained after 3, 7 and 28 days curing is the least among all others. The 3 day strength of F-20-30 is near about 2.2 times more than that of F-25-40. Similarly the strength obtained after 7 day and 28 day curing of the mix F-15-20 is about 5 times and 3 times more than that obtained from mix F-25-40. The variations of strength of the mix obtained with the days of curing are shown in a bar chart graph in figure 4.6, 4.7 and 4.8.

5.2 Results on Stabilization of Expansive Soils with Activated Fly Ash

This chapter presents the results of stabilization of expansive black cotton soil, with alkli- activated fly ash. The increase in strength criteria is ascertained by conducting unconfined compression test on samples, at 3, 7 and 28 days curing.

Table 10: UCS results of AF-100-20-15, AF-100-30-15, AF-100-40-15

Curing time (Days)	**Unconfined compressive strength (kPa)**		
	AF-100-20-15	AF-100-30-15	AF-100-40-15
3	195.46	175.95	140.51
7	253.32	179.24	131.41
28	436.63	195.23	128.9

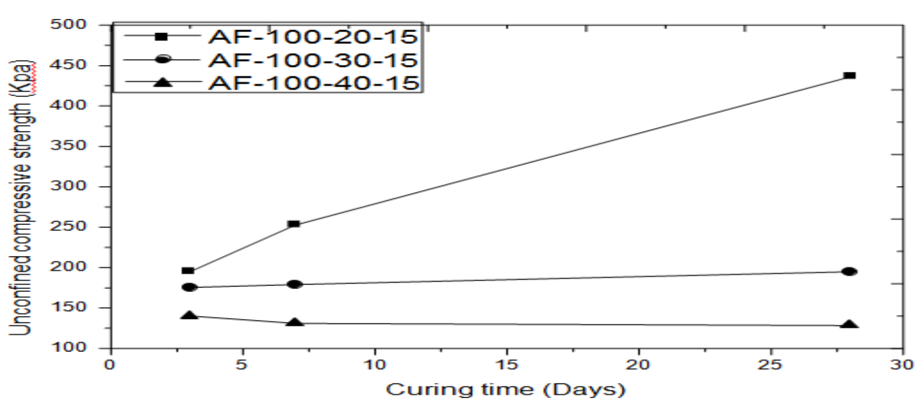

Figure 9: UCS results of AF-100-20-15, AF-100-30-15, AF-100-40-15

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The 3 day strength of AF-100-20-15 is 11 % more than that of AF-100-30-15 and 39 % more than that of AF-100-40-15. Similarly the 7 day strength of AF-100-20-15 is 41% more than that of AF-100-30-15 and is about 92 % more than that of AF-100-40-15. Moreover the 28 day strength of mix AF-100-20-15 is nearly 2.23 times than that of AF-100-30-15 and is 3.38 times more than that of AF-100- 40-15. The variations of strength of the mixes are shown in Figure 5.1. and it can be stated as the strength of the mix is directly proportional to the curing period and is inversely proportional to the fly ash content in the mix. Thus it can be concluded that for a constant activator to total solid ratio, the strength increases with the curing period and also with the decreased fly ash content.

Table 11: UCS results of AF-100-20-20, AF-100-30-20, AF-100-40-20

Curing time (Days)	Unconfined compressive strength (kPa)		
	AF-100-20-20	AF-100-30-20	AF-100-40-20
3	311.58	392.7	322.8
7	350.83	462.64	546.88
28	407.7	580.62	810.02

Table 5.2 shows the UCS values of the samples AF-100-20-20, AF-100-30-20, AF-100- 40- 20, obtained after 3, 7 and 28 days curing. It is evident from the results depicted in table 5.2 that the mix AF-100-30-20 is giving more strength after 3 days curing than the other two, while the strength after 7 and 28 days curing is more in case of mix AF-100- 40-20. This can be probably related to necessary time period required for the nucleation phase to occur, during which the products resulting from the dissolution of the raw silica and alumina accumulate before precipitation. The variations of strength of the mixes are shown in Figure 5.2.

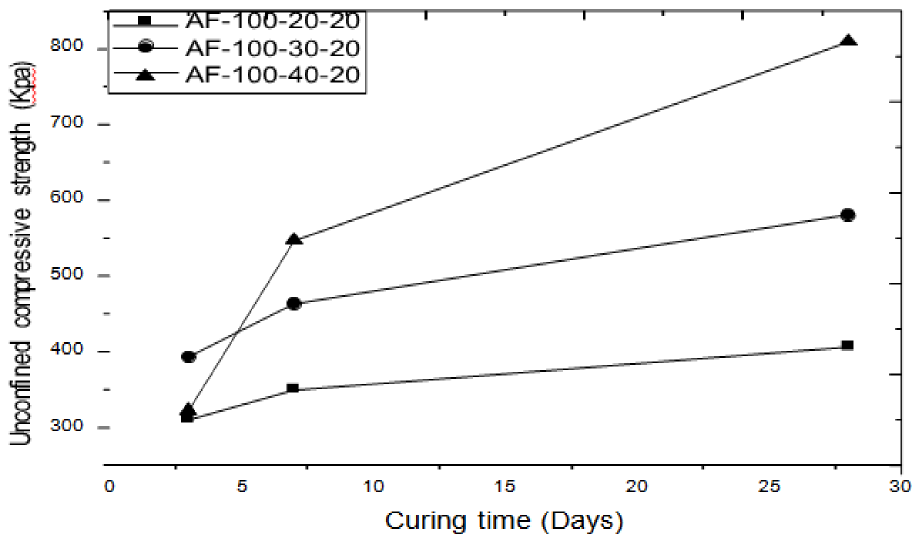

Figure 10: UCS results of AF-100-20-20, AF-100-30-20, AF-100-40-20

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Table 12: UCS results of AF-100-20-25, AF-100-30-25, AF-100-40-25

Curing time (Days)	Unconfined compressive strength (kPa)		
	AF-100-20-25	AF-100-30-25	AF-100-40-25
3	103.97	94.71	85.42
7	130.13	146.92	112.03
28	238.77	215.77	232.77

Table 5.3 shows the UCS values of the samples AF-100-20-25, AF-100-30-25, AF-100- 40- 25, obtained after 3, 7 and 28 days curing. It is evident from the results depicted in table 5.3 that the mix AF-100-20-25 is giving more strength after 3 days and 28 days curing than the other two, while the strength after 7 days curing is more in case of mix AF-100-30-25 The variations of strength of the mixes are shown in Figure 5.3.

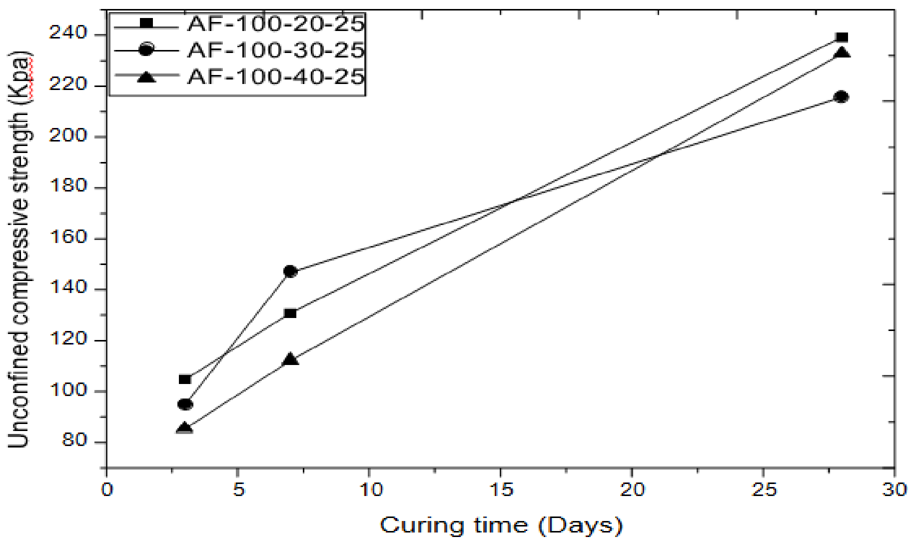

Figure 11: UCS results of AF-100-20-25, AF-100-30-25, AF-100-40-25

Table 13: UCS results of AF-125-20-15, AF-125-30-15, AF-125-40-15

Curing time (Days)	Unconfined compressive strength (kPa)		
	AF-125-20-15	AF-125-30-15	AF-125-40-15
3	114.59	158.87	187.08
7	220.1	152.8	250.27
28	364.32	221.54	399.24

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Table 5.4 shows the UCS values of the mixes, casted from 12.5 molar activator solution. From the table it is evident that the mix AF-125-40-15 is giving more strength than that of others, obtained after 3, 7 and 28 days curing. The variations of strength of the mixes are shown in Figure 5.4.

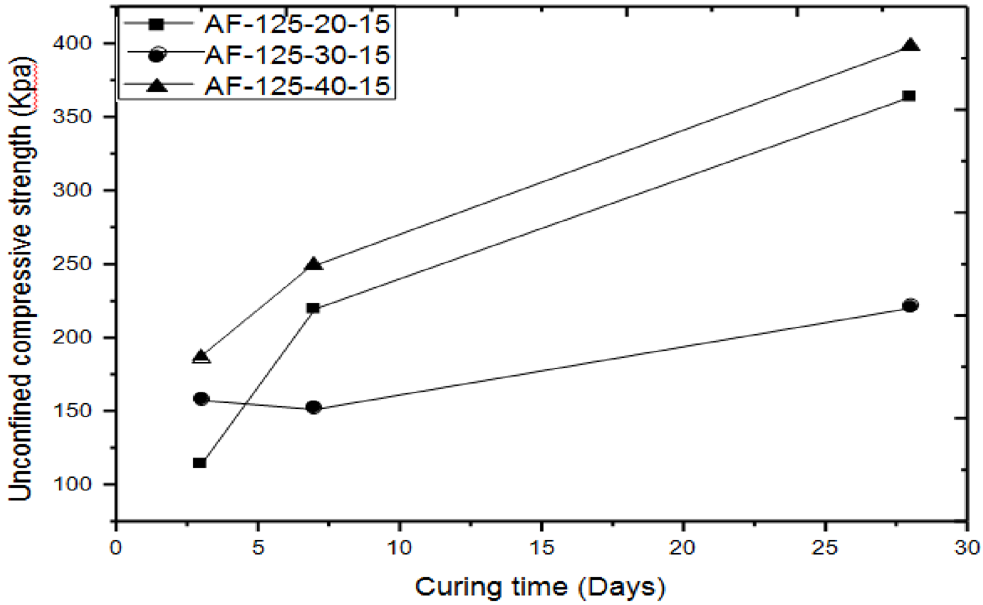

Figure 12: UCS results of AF-125-20-15, AF-125-30-15, AF-125-40-15

Table 14: UCS results of AF-125-20-20, AF-125-30-20, AF-125-40-20

Curing time (Days)	Unconfined compressive strength (kPa)		
	AF-125-20-20	AF-125-30-20	AF-125-40-20
3	307.85	196.93	287.42
7	230.35	293.98	419.2
28	548.78	590.78	977.09

Similarly, Table 5.5 shows the UCS values of the mixes AF-125-20-20, AF-125-30-20, AF- 125-40-20, casted from 15 molar activator solution. From the table it is evident that the mix AF-125-20-20 is giving more strength than that of others, obtained after 3days of curing, while mix AF-125-40-20, is giving more strength than the other two at 7 and 28 days curing. The variations of strength of the mixes are shown in Figure 5.5.

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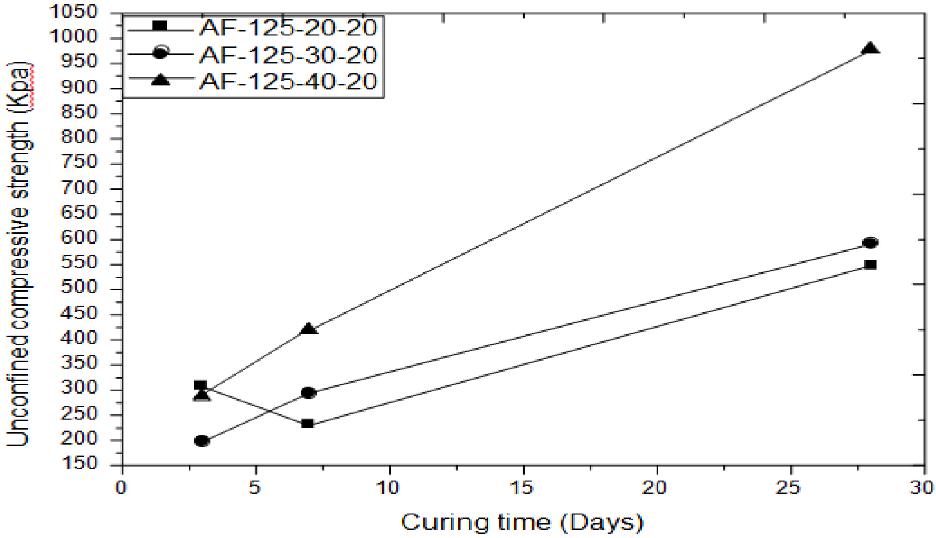

Figure 13: UCS results of AF-125-20-20, AF-125-30-20, AF-125-40-20

Similarly, Table 5.5 shows the UCS values of the mixes AF-125-20-20, AF-125-30-20, AF- 125-40-20, casted from 15 molar activator solution. From the table it is evident that the mix AF-125-20-20 is giving more strength than that of others, obtained after 3days of curing, while mix AF-125-40-20, is giving more strength than the other two at 7 and 28 days curing. The variations of strength of the mixes are shown in Figure 5.5.

Table 15: UCS results of AF-125-20-25, AF-125-30-25, AF-125-40-25

Curing time (Days)	Unconfined compressive strength (kPa)		
	AF-125-20-25	AF-125-30-25	AF-125-40-25
3	128.77	114.93	113.76
7	154.83	179.89	192.29
28	317.55	555.47	852.17

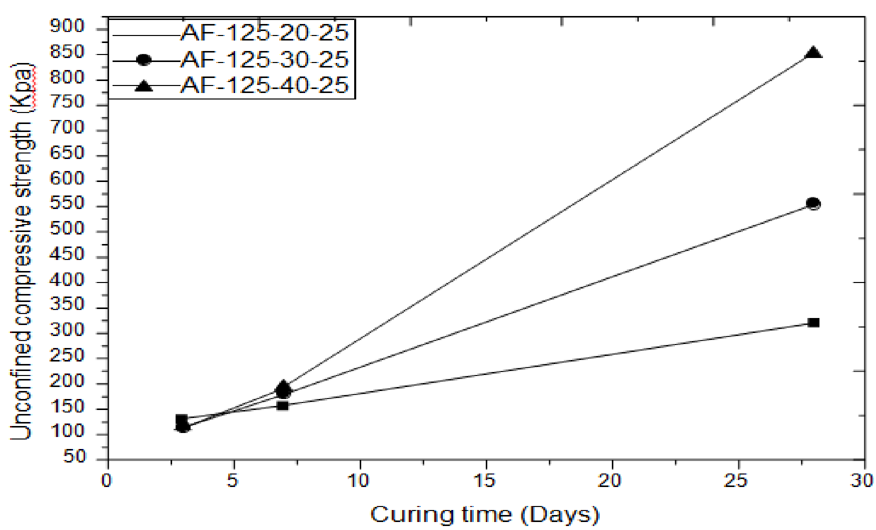

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Figure 14: UCS results of AF-125-20-25, AF-125-30-25, AF-125-40-25

It is evident from the Table 5.6 that the 3 days strength of the mix AF-125-20-25, is more than the rest, while in case of 7 and 28 days strength the mix AF-125-40-25 is giving better results than the rest. The variations of strength of the mixes are shown in Figure 5.6.

Table 16: UCS results AF-150-20-15, AF-150-30-15, AF-150-40-15

Curing time (Days)	Unconfined compressive strength (kPa)		
	AF-150-20-15	AF-150-30-15	AF-150-40-15
3	288.17	247.41	160.75
7	339.7	428.28	503.98
28	579.28	603.32	643.86

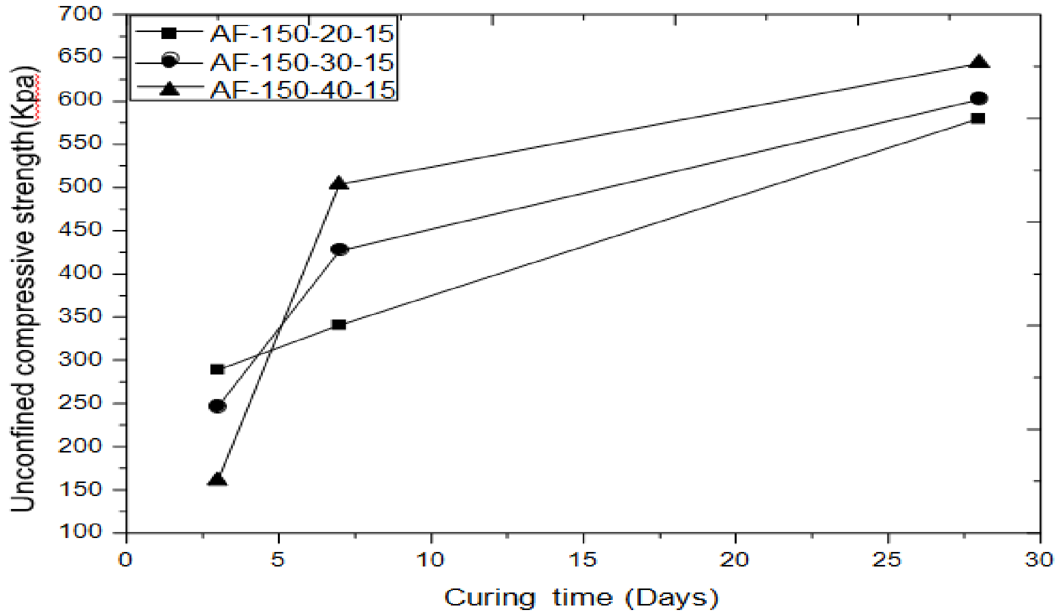

Figure 15: UCS results of AF-150-20-15, AF-150-30-15, AF-150-40-15

Table 5.7 shows the UCS values of the mixes, casted from 15 molar activator solution. From the Table 5.7, it can be concluded that the 3 days UCS is more in case of mix AF- 150-20-15, whose magnitude is about 79 % more than that of mix AF-150-40-15. But in case of strength obtained after 7 and 28 days curing, AF-150-40-15 outperforms all. The variations of strength of the mixes obtained as are shown in Figure 5.7.

Table 17: UCS results AF-150-20-20, AF-150-30-20, AF-150-40-20

Curing time (Days)	Unconfined compressive strength (kPa)		
	AF-150-20-20	AF-150-30-20	AF-150-40-20
3	207.72	239.99	171.61

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7	361.06	450.03	503.98
28	396.93	715.4	643.86

Similarly, Table 5.7 shows the UCS values of the mixes AF-150-20-20, AF-150-30-20, AF- 150-40-20, casted from 15 molar activator solutions. From the table it is evident that the mix AF-150-30-20 outperforms all in the aspect of gaining more strength at 3, 7 and 28 days of curing. The variations of strength of the mixes are shown in Figure 5.7.

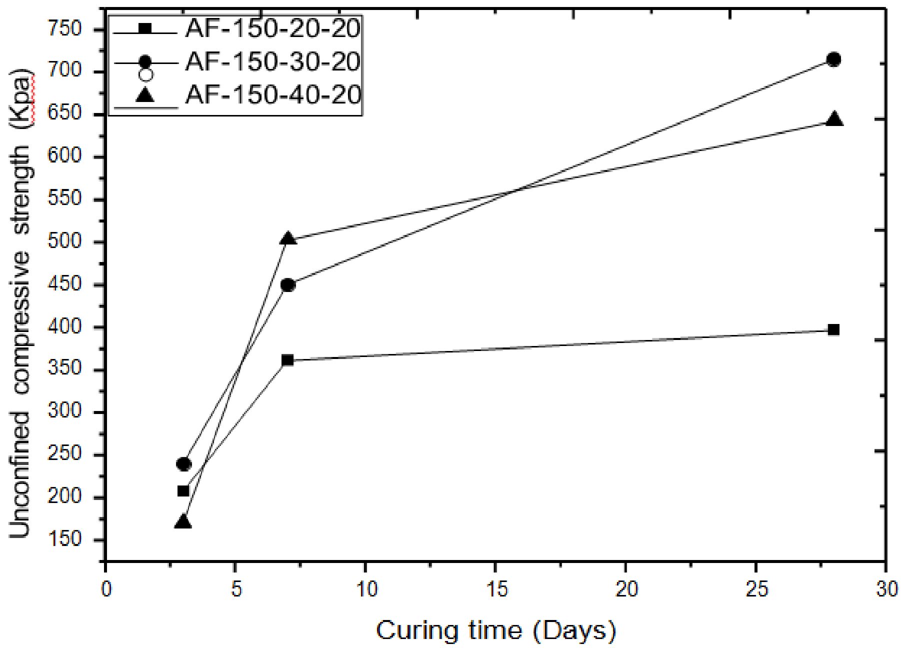

Figure 16: UCS results AF-150-20-20, AF-150-30-20, AF-150-40-20

Table 18: UCS results AF-150-20-25, AF-150-30-25, AF-150-40-25

Curing time (Days)	Unconfined compressive strength (kPa)		
	AF-150-20-25	AF-150-30-25	AF-150-40-25
3	111.24	98.43	75.63
7	138.52	181.89	256.55
28	182.15	465.24	296

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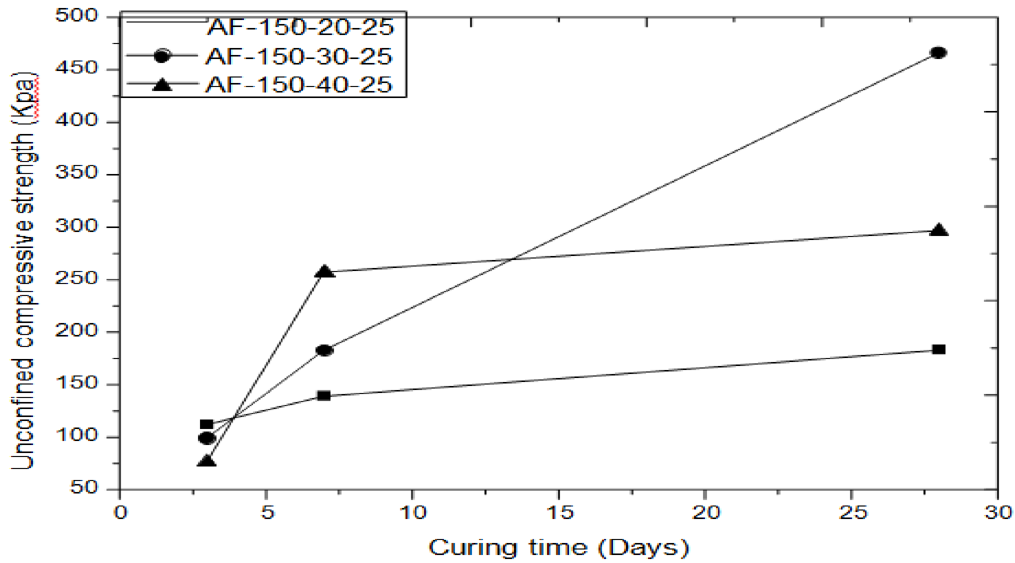

Figure 17: UCS results AF-150-20-25, AF-150-30-25, AF-150-40-25

Similarly, Table 5.8 shows the UCS values of the mixes AF-150-20-20, AF-150-30-20, AF- 150-40-20, after 3, 7 and 28 days of curing. From the table it is evident that the mix AF-150- 20-25 is giving more strength after 3 days of curing as compared to others, mix AF-150-40- 25 is giving more strength after 7 days of curing as compared to mix AF- 150-20-25 and mix AF-150-30-25. In case of 28 days strength mix AF-150-30-25, outperforms all. The variations of strength of the mixes are shown in Figure 5.8.

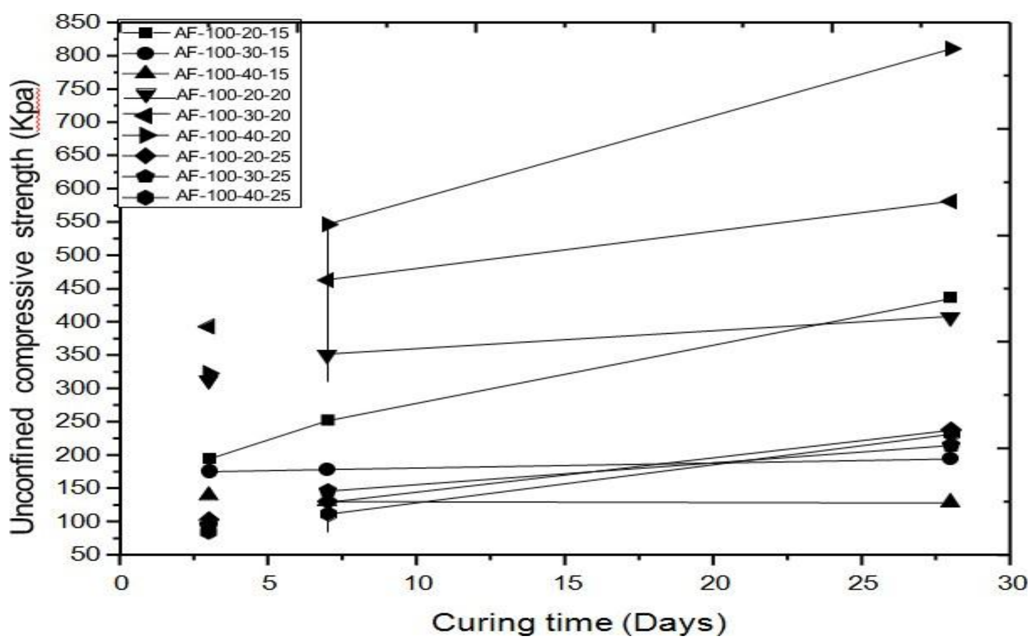

Figure 18: UCS results of all 10 molar sample

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Table 5.9 shows the variation of strength obtained for 10 molar activator content and 20, 30 and 40% fly ash content mixed soil samples, after 3, 7 and 28 days curing periods. The variations are also shown in Figure 5.9. Figure 5.10, 5.11 and 5.12 shows the gain in strength of all 10 molar mixes after 3, 7 and 28 days respectively in bar graph form. From the tables and graphs it is evident that the 3 days strength is more in case of mix AF-100- 30-20, while the 7 & and 28 days strength is more in case of mix AF-100-40-20. The least 3 and 7 days strength is exhibited by mix AF-100-40-25, while mix AF-100-30-25 exhibit least 28 days strength.

Table 19: UCS results of 10 molar sample

Curing time (Days)	Unconfined compressive strength (kPa)								
	AF- 100- 20-15	AF- 100- 30-15	AF-100- 40-15	AF-100- 20-20	AF 100- 30-20	AF 100- 40-20	AF- 100- 20-25	AF- 100- 30-25	AF- 100- 40-25
3	195.46	175.95	140.51	311.58	392.7	322.8	103.97	94.71	85.42
7	253.32	179.24	131.41	350.83	462.64	546.88	130.13	146.92	112.03
28	436.63	195.23	128.9	407.7	580.62	810.02	238.77	215.77	232.77

Table 20: UCS results of 12.5 molar samples

Curing time (Days)	Unconfined compressive strength (kPa)								
	AF- 125- 20-15	AF-125- 30-15	AF-125- 40-15	AF-125- 20-20	AF-125- 30-20	AF-125- 40-20	AF-125- 20-25	AF-125- 30-25	AF- 125- 40-25
3	114.59	158.87	187.08	307.85	196.93	287.42	128.77	114.93	113.76
7	220.1	152.8	250.27	230.25	293.98	419.2	154.83	179.89	192.29
28	364.32	221.54	399.24	548.78	590.78	977.09	317.55	555.47	852.17

Table 21: UCS results of 15 molar samples

Curing time (Days)	Unconfined compressive strength (kPa)								
	AF- 150- 20-15	AF- 150 -30-15	AF- 150- 40-15	AF- 150- 20-20	AF- 150- 30-20	AF- 150- 40-20	AF- 150- 20-25	AF- 150- 30-25	AF- 150- 40-25
3	288.17	247.41	160.75	207.72	239.99	171.61	111.24	98.43	75.63
7	339.7	428.28	503.98	361.06	450.03	503.98	138.52	181.89	256.65
28	579.28	603.32	643.86	396.93	715.4	643.86	182.15	465.24	296

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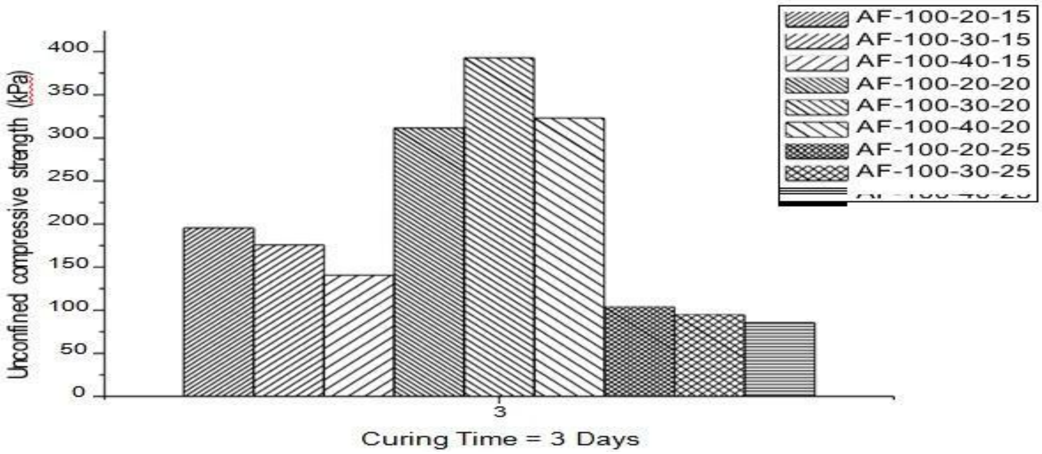

Figure 19: UCS results of 10 molar sample (3 Days curing)

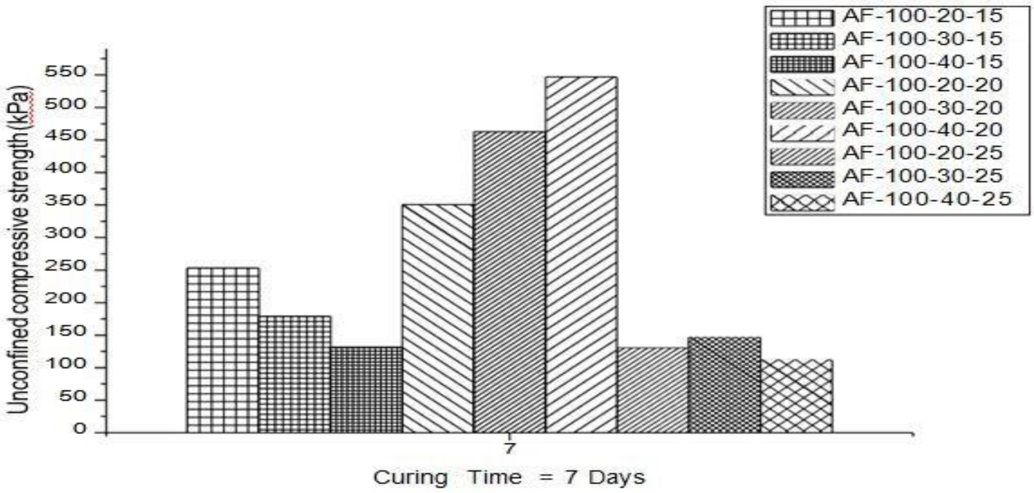

Figure 20: UCS results of 10 molar sample (7 Days curing)

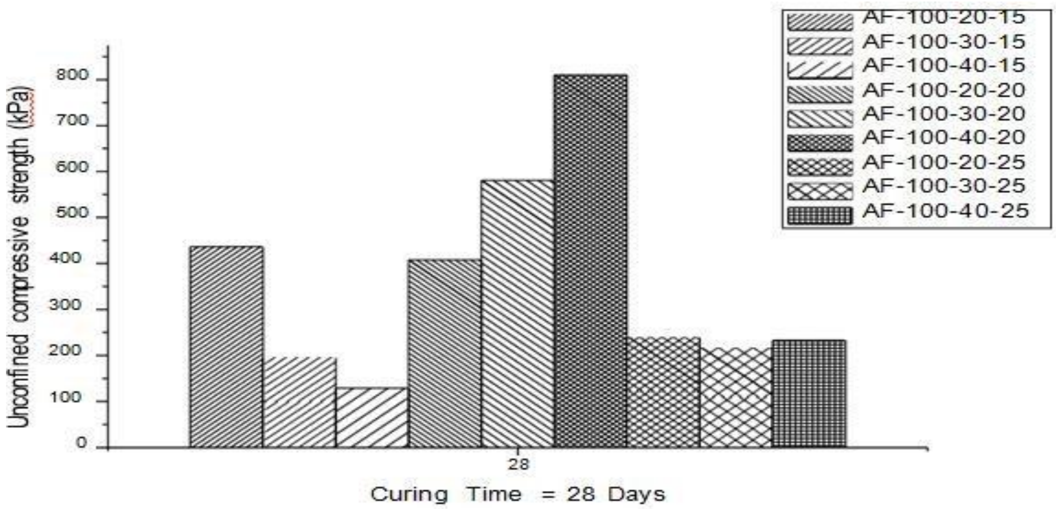

Figure 21: UCS results of 10 molar sample (28 days curing)

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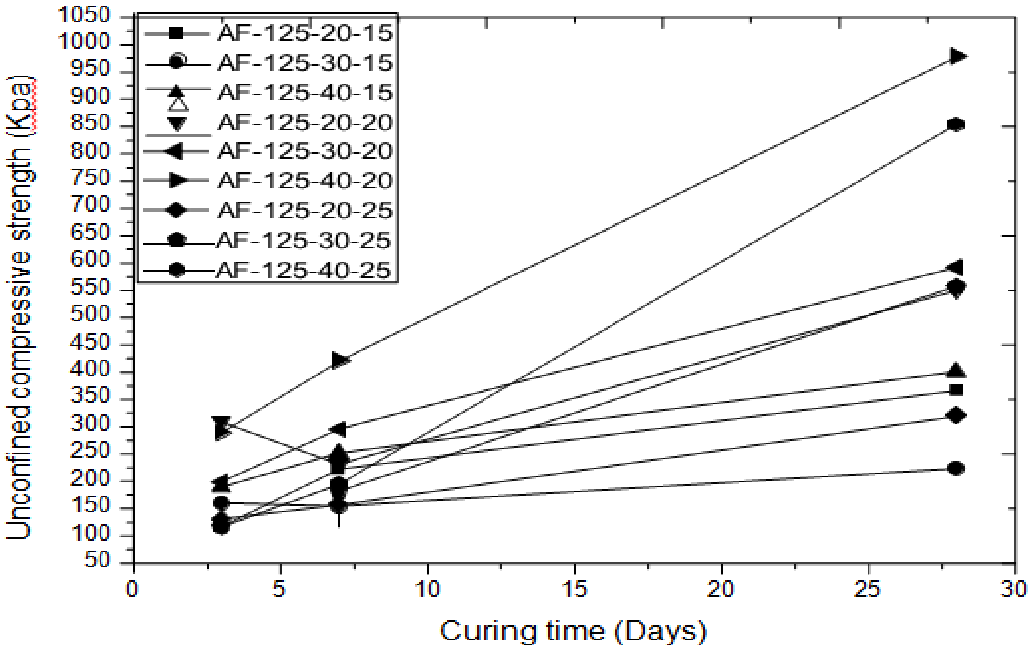

Figure 22: UCS results of all 12.5 molar sample

Table 5.10 shows the variation of strength obtained for 12.5 molar activator content and 20, 30 and 40% fly ash content mixed soil samples, after 3, 7 and 28 days curing periods. The variations are also shown in Figure 5.13. Figure 5.14, 5.15 and 5.16 shows the gain in strength of all 12.5 molar mixes after 3, 7 and 28 days respectively in bar graph form. From the tables and graphs it is evident that the 3 days strength is more in case of mix AF-125-20- 20, while the 7 & and 28 days strength is more in case of mix AF-125-40-20. The least 3 days strength is exhibited by mix AF-125-40-25, while mix AF-125-30-15 exhibit least 7 days strength and mix AF-125-40-15 exhibit least strength after 28 days curing.

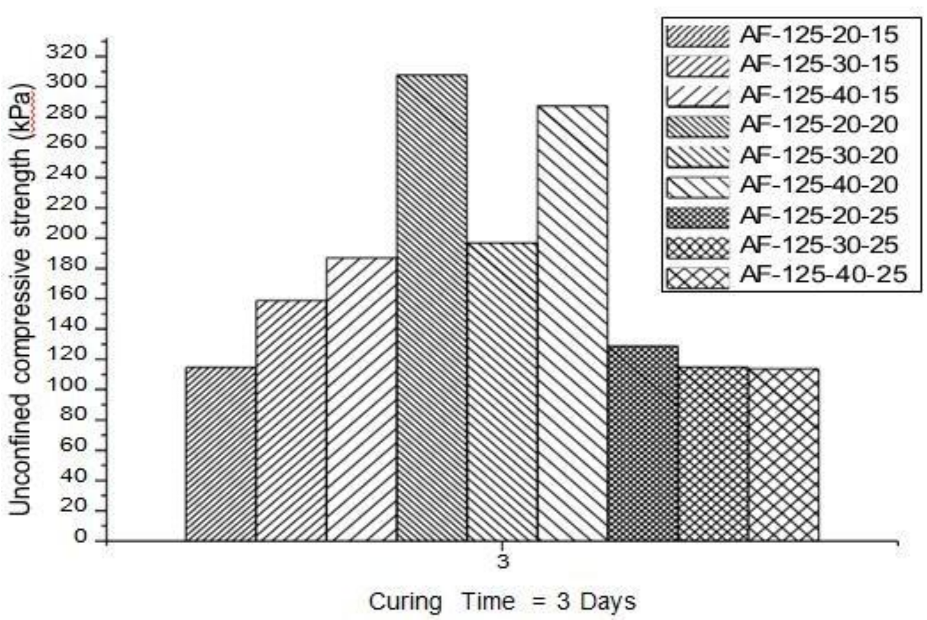

Figure 23: UCS results of 12.5 molar sample (3 Days curing)

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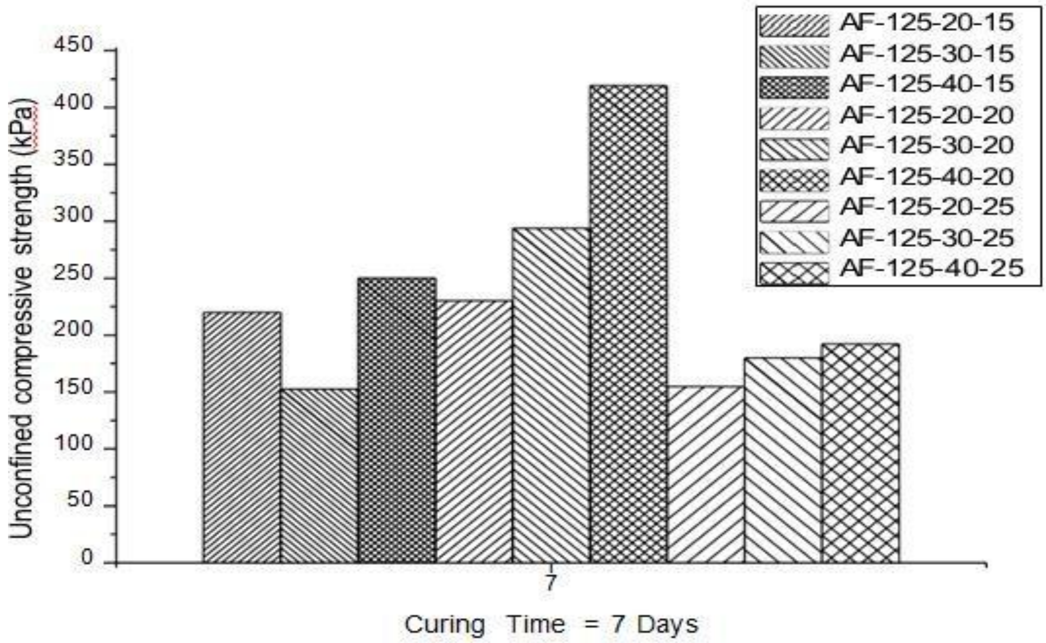

Figure 24: UCS results of 12.5 molar sample (7 Days curing)

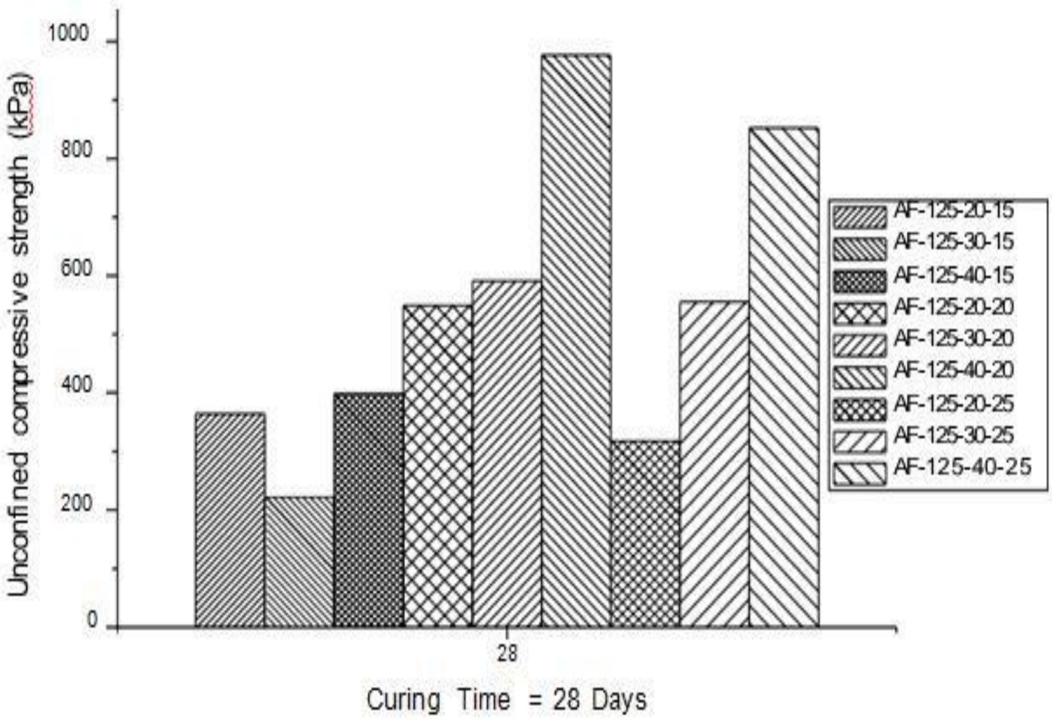

Figure 25: UCS results of 12.5 molar sample (28 Days curing)

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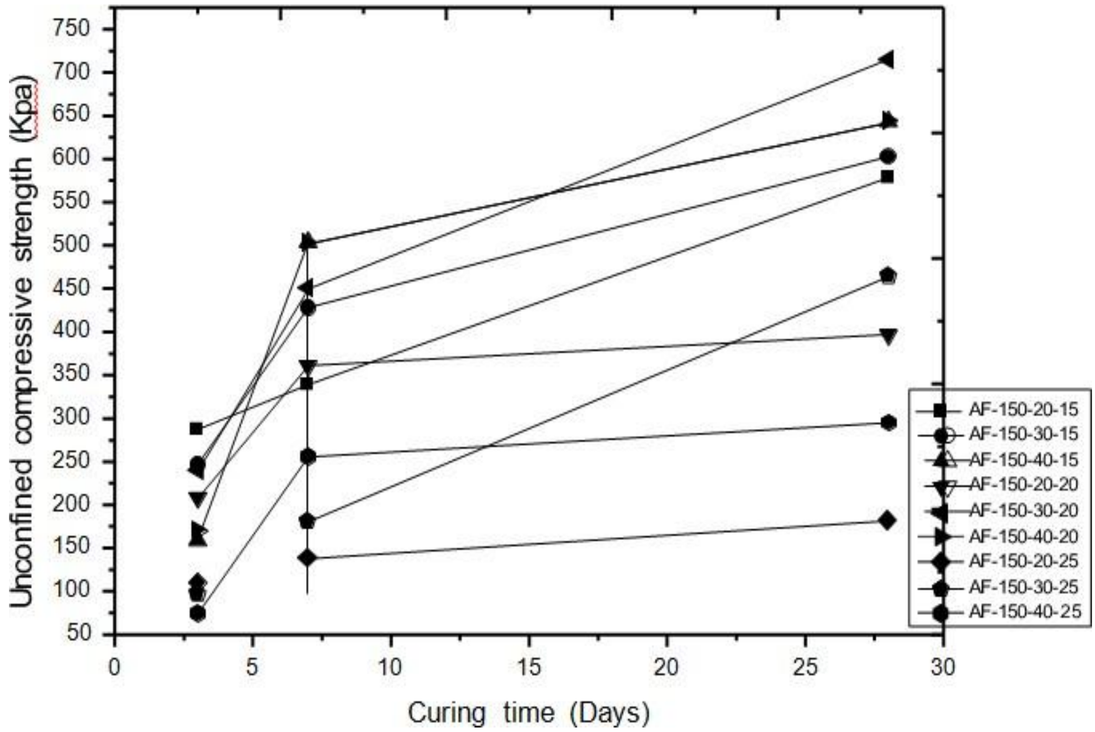

Figure 26: UCS results of all 15 molar Samples

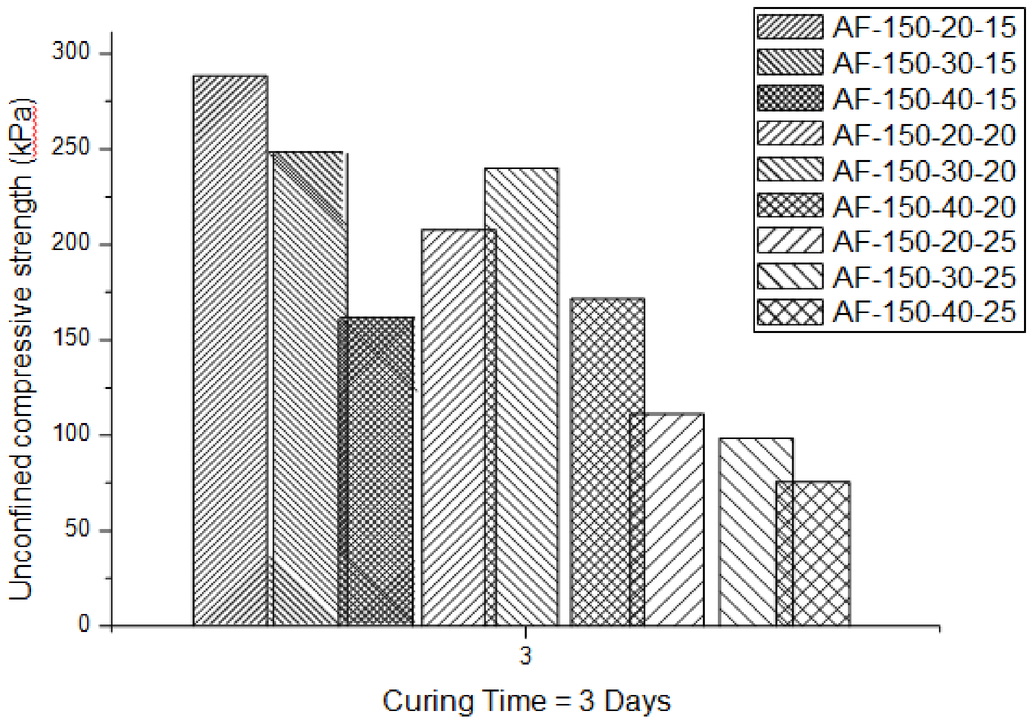

Figure 27: UCS results of 15 molar sample (3 Days curing)

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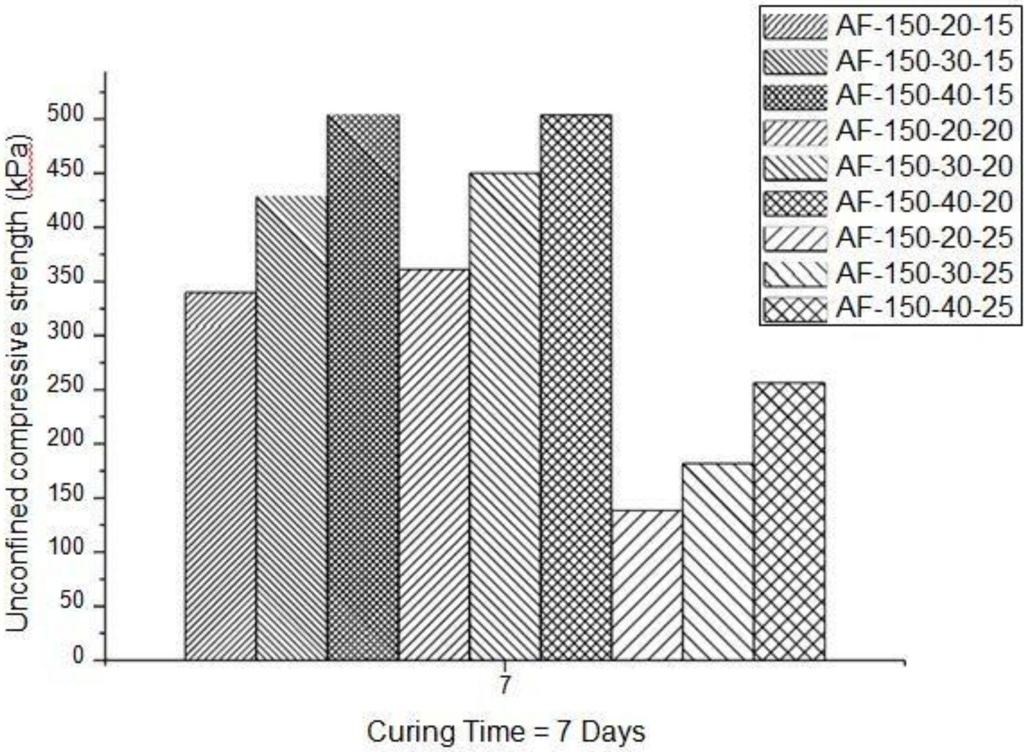

Figure 28: UCS results of 15 molar sample (7 Days curing)

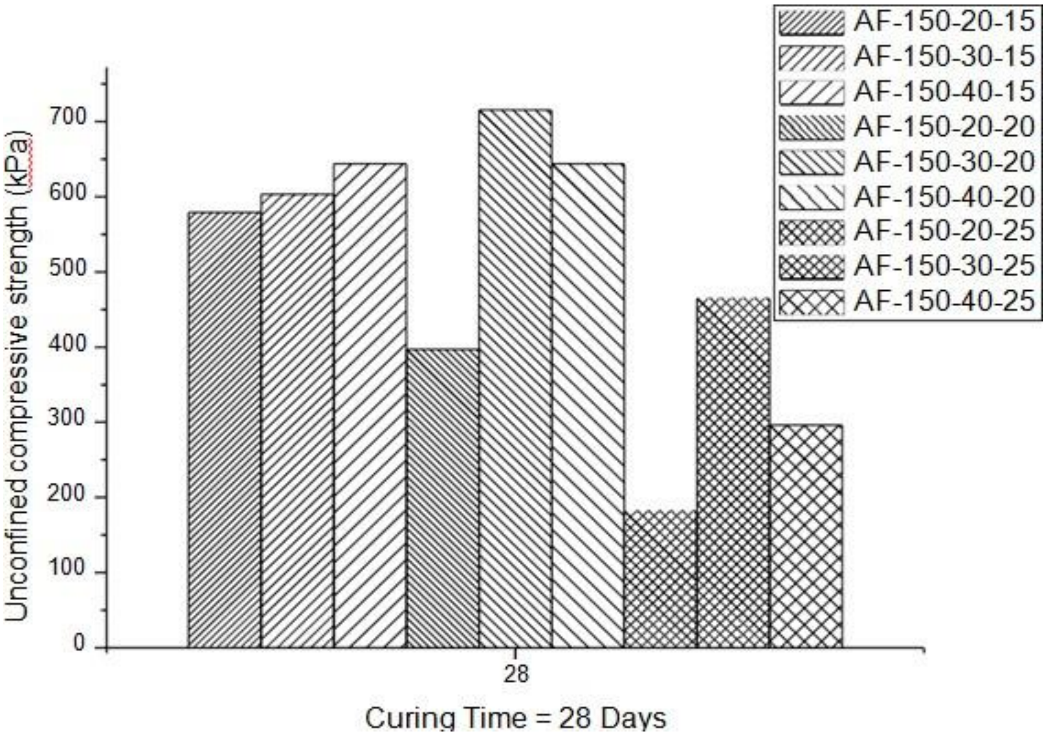

Figure 29: UCS results of 15 molar sample (28 Days curing)

Table 22: UCS results of all AAFA Samples

Name	Qu (kPa)	Name	Qu (kPa)	Name	Qu (kPa)
AF-100-20-15-3D	195.46	AF-100-20-15-7D	253.32	AF-100-20-15-28D	436.63

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AF-100-30-15-3D	175.95	AF-100-30-15-7D	179.24	AF-100-30-15-28D	195.23
AF-100-40-15-3D	140.51	AF-100-40-15-7D	131.41	AF-100-40-15-28D	128.9
AF-100-20-20-3D	311.58	AF-100-20-20-7D	350.83	AF-100-20-20-28D	407.7
AF-100-30-20-3D	392.7	AF-100-30-20-7D	462.64	AF-100-30-20-28D	580.62
AF-100-40-20-3D	322.8	AF-100-40-20-7D	546.88	AF-100-40-20-28D	810.02
AF-100-20-25-3D	103.97	AF-100-20-25-7D	130.13	AF-100-20-25-28D	238.77
AF-100-30-25-3D	94.71	AF-100-30-25-7D	146.92	AF-100-30-25-28D	215.77
AF-100-40-25-3D	85.42	AF-100-40-25-7D	112.03	AF-100-40-25-28D	232.77
AF-125-20-15-3D	114.59	AF-125-20-15-7D	220.1	AF-125-20-15-28D	364.32
AF-125-30-15-3D	158.87	AF-125-30-15-7D	152.8	AF-125-30-15-28D	221.54
AF-125-40-15-3D	187.08	AF-125-40-15-7D	250.27	AF-125-40-15-28D	399.24
AF-125-20-20-3D	307.85	AF-125-20-20-7D	230.25	AF-125-20-20-28D	548.78
AF-125-30-20-3D	196.93	AF-125-30-20-7D	293.98	AF-125-30-20-28D	590.78
AF-125-40-20-3D	287.42	AF-125-40-20-7D	419.2	AF-125-40-20-28D	977.09
AF-125-20-25-3D	128.77	AF-125-20-25-7D	154.83	AF-125-20-25-28D	317.55
AF-125-30-25-3D	114.93	AF-125-30-25-7D	179.89	AF-125-30-25-28D	555.47
AF-125-40-25-3D	113.76	AF-125-40-25-7D	192.29	AF-125-40-25-28D	852.17
AF-150-20-15-3D	288.17	AF-150-20-15-7D	339.7	AF-150-20-15-28D	579.28
AF-150-30-15-3D	247.41	AF-150-30-15-7D	428.28	AF-150-30-15-28D	603.32
AF-150-40-15-3D	160.75	AF-150-40-15-7D	503.98	AF-150-40-15-28D	643.86
AF-150-20-20-3D	207.72	AF-150-20-20-7D	361.06	AF-150-20-20-28D	396.93
AF-150-30-20-3D	239.99	AF-150-30-20-7D	450.98	AF-150-30-20-28D	715.4
AF-150-40-	171.61	AF-150-40-	503.98	AF-150-40-	643.86

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20-3D		20-7D		20-28D	
AF-150-20-25-3D	111.24	AF-150-20-25-7D	138.52	AF-150-20-25-28D	182.15
AF-150-30-25-3D	98.43	AF-150-30-25-7D	181.89	AF-150-30-25-28D	465.24
AF-150-40-25-3D	75.63	AF-150-40-25-7D	256.55	AF-150-40-25-28D	296

The variation of strength obtained for 15 molar activator content and 20, 30 and 40% fly ash content mixed soil samples, after 3, 7 and 28 days curing periods is shown in Table 5.11. The variations are also shown in Figure 5.17. Figure 5.18, 5.19 and 5.20 shows the gain in strength of all 15 molar mixes after 3, 7 and 28 days respectively in bar graph form. From the tables and graphs it is evident that the 3 days strength is more in case of mix AF-120-20-15, while the 7 & and 28 days strength is more in case of mix AF-150- 40-15 and mix AF-150- 40-20. The least 3 days strength is exhibited by mix AF-150-40- 25, while mix AF-125-20-25 exhibit least strength after 7 and 28 days of curing.

Table 5.12 gives the details of the activated mix casted and their corresponding strengths attained after 3, 7 and 28 days of curing. Among all the highest strength obtained after 3 days of curing was attained by the mix AF-150-30-20-3D, while the strength attained by mix AF- 150-40-20-7D after 7 days of curing is more than all others. The mix AF-150-40-20-28D outperforms all in respect of strength attained after 28 days of curing.

VI. CONCLUSION

Based on the obtained results and discussion thereof following conclusions can be made.

- The unconfined compressive strength soil is found to vary with concentration of chemical in the activated fly ash and curing period.
- 10 molar samples are giving better 3 and 7 days strengths than 12.5 and 15 molar samples, which make it economical as compared to 12.5 and 15 molar samples.
- Long term strength is more in case of 12.5 molar samples.
- Maximum 3 day strength attained by activated sample is 392.7 kPa, which is 3.25 times more than that attained by fly ash treated samples.
- Maximum 7 day strength attained by activated sample is 546.88 kPa, which is 2 times more than that attained by fly ash treated samples.
- Maximum 28 day strength attained by activated sample is 977.09 kPa, which is 2.7 times more than that attained by fly ash treated samples.
- There is a strong dependency between the activator/ash ratio and mechanical strength. Results showed that it is advantageous to reduce this ratio since it has a positive effect on strength results, which has also a positive effect on final cost.
- Lowering the viscosity of the grout mixtures to similar values to that of cement grout can have a negative effect on final strength, since it demands an increase in the activator/ash ratio. Therefore, it is recommended that a compromise is made between an optimum viscosity level and the lowest activator/ash ratio possible, whenever the viscosity is a key issue for a particular application

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6.1 Scope for Future Work

- Efforts should be made to reduce the cost of operation, by searching other natural alkaline materials.
- Field application of this method, by using suitable technology.
- Application of AAFA for stabilization of other low strength high compressible clay.

Use of other alkalis like Potassium and Lithium, to study their effect on Fly ash.

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