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STRENGTHENING OF SOFT CLAY USING ALKALI ACTIVATED FLY ASH

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Abstract - This study involves the stabilization of soft clay soil using sodium based Alkali activated (AA) fly ash in order to understand their effectiveness to stabilized soft clay. By using Unconfined Compressive Strength test (UCS), the effectiveness of this AA fly ash is compared with that of ordinary Portland Cement (OPC) at the age of 7 days and 28 days. A sample was soaked in water for a period of 14 days after curing 28 days in order to study the changes in strength of the sample when submerged in water. Sodium hydroxide concentrations of 12 molal were used in the AA specimen with fly ash percentage of 30 % to the total solid (ash + soil). Treatment with AA fly ash significantly increases the strength of the soil and soaking in water further improves the strength to large extent. UCS results of OPC and AA fly ash shows that AA fly was found to provide more strength at all ages except 7 days.

Keywords—soft clay, alkali activated fly ash, Ordinary Portland Cement, unconfined compressive strength

I. INTRODUCTION

The rapid growth in the construction industry has led to the reduction in land resources. Therefore more and more of civil engineering structures are being constructed over weak or soft soil, which leads to the development of various ground improvement techniques such as soil stabilization and soil reinforcement. Soft soil is basically clay which can deform up to large extent at a minimum load and shear stress, thereby; it can be consider a major problem for geotechnical engineers. Soil Stabilization involves adding suitable materials to the soft soil in order to enhance their engineering properties and their strength. Stabilization of soils can help to increase the shear strength of a soft soil or control the shrink-swell properties of a soil, thus improving the load bearing capacity of the soil to support pavements or foundations.

Chemical stabilization by cement or lime is a proven technique for improving the performance of soil in strength as well as other properties *(Ismail et al., 2002; Basha et al., 2005; Kolias et al., 2005; Al-Rawas, 2002)*. However, these chemical additives usually result in a high stiffness and brittle behavior *(Wang et al., 2003; Basha et al., 2005).*The cement is the most commonly used and effective stabilizer particularly for high expansive soil. However, the cement industry releases high amount of greenhouse gas worldwide, which is estimated to be approximately 7 percent of the total greenhouse gas emissions to the earth's atmosphere (*Criado et al. 2007*). Hence, to reduce greenhouse gas emissions, efforts are being made to develop environmentally friendly construction materials.

The alkali activation of waste materials specially fly ash has become an important area of research in many laboratories because it is possible to use these materials to synthesize inexpensive and ecologically sound cement like construction materials *(Palomo et al. 1999*). In another study, alkaline activated materials was found to be more durable and stable and are generally better performing materials than available conventional cements (*Duxson et al. 2005, Pacheco-Torgal et al. 2012, Villa et al. 2010, Xu and Van Deventer 2000, 2003*). The strength of sodium based alkaline activated fly ash treated soil was determined by Unconfined compressive strength (UCS) test and the result at 28 days was almost similar to that of common cement binder (*Cristelo et al. 2013)*. Alkali-activated fly ash can be used effectively as a chemical stabilizer for stabilizing expansive soils and mixer with lower activator/ash show more strength as compared to the mixture containing higher activator/ash ratio *(Partha Sarathi Parhi et al. 2018)* .

The main objective of this study is to stabilize soft clay using sodium base alkali activator and class F fly ash and study their performance using UCS test. UCS test result of the alkali activated (AA) fly ash treated sample will be compared to OPC treated specimen to conclude the benefits of using AA fly ash. The 28 days cured sample will be again be soaked in water to check their strength when expose to water.

II. MATERIALS

Soft Clay

The clay used in the present experimental tests were obtained from Jawaharlal Nehru Institute of Medical Sciences' campus, Porompat, Imphal. The 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. The various geotechnical properties of the soil are shown in Table I.

Table I
Engineering properties of soft clay used in the study

PROPERTIES	VALUE
Specific gravity (G)	2.68
Maximum dry density (MDD)	1.513 g/cc
Optimum moisture content (OMC)	25.25 %
Natural moisture content	52.63%
Liquid limit	61%
Plastic limit	32.32%
Plasticity index	28.68%
ISSCS	CH
Grain size distribution: Gravel Sand Silt Clay	 0 % 0.7 % 63.5 % 35.8 %

Cement

The cement used in the test was Ordinary Portland cement (OPC) of grade 43. Some properties of the cement used are given in Table II.

Table II
Properties of cement used

Test	Result	Unit
Initial Setting Time	180	minute
Final Setting Time	230	minute
Specific surface	390	m^2/kg
Le-Chatelier Experiment	1.5	mm
Compressive Strength 3 Days 7 Days 28 Days	 27.5 38.1 56.0	 MPa MPa MPa

Fly ash

Low calcium fly ash used in the present study was collected from Kolaghat Thermal Power Plant, West Bengal, India. 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 0 C for 24 hours and then is stored in an air tight container, for subsequent use. The received fly ash was tested at SAIF, IIT Mumbai and it had a chemical composition as in Table III.

Table III
Chemical Composition of Fly ash sample

Compounds	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	SO_3	P_2O_5	LOI
Composition (%)	56.01	29.8	3.58	1.75	2.36	0.3	0.73	0.61	Nil	0.44	0.4

Alkali activator solution

The alkaline activator solution used is a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate was originally in solution form and is procured from MPM Processors (P) Ltd, Guwahati, having molecular weight of 284.20 gm/mole. Some properties of sodium silicate solution provided by the manufacturer is given below in Table IV.

Table IV

Properties of Sodium Silicate solution

Compounds	**Composition (%)**
Total solids	45
Ratio of Alkalinity to soluble silica	1:2.2
Water insoluble	0.65
SiO2	30.65
Na2O	14.15

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 97% purity. The sodium hydroxide flakes were procured from Merck life science pvt ltd, Mumbai, India. NaOH solution of 12 molal concentrations was prepared and kept for 24 hours to cool down prior to the mixing with sodium silicate solution. The ratio of sodium silicate to sodium hydroxide solution by mass was kept as 2. This value was chosen not only because the silicate is considerably cheaper than the hydroxide, but also because several studies that have analysed the influence of the activator composition concluded that higher ratios resulted in higher strength levels *(Hardjito et al. 2005, Criado et. al. 2007, Villa et al. 2010).*

III. SAMPLE PREPARATON

The activator solution was prepared first by mixing NaOH solution 12 molal concentrations with sodium silicate solution. The soil and the fly ash were previously homogenized and mixed thoroughly before the activator solution to the mixture. After adding water it was mixed uniformly for 3 minutes and the samples were cast into 38-mm moulds by tapping the moulds on the lab counter. Since the samples were in slurry form they were left for 48 hours to harden as shown in Fig. 2. No density control was used during the preparation of the samples. After 48 hours, the samples were removed from the moulds and wrapped in cling film and kept at desiccator for curing in ambient temperature and humid conditions. After 7 and 28 days curing, the samples were trimmed to 76 mm long weighed and an average unit weight of 18 kN/m^3 was obtained.

Similar mixing procedure was used in the case of OPC and the activator solution is replaced with water. The amount of OPC is same as that of fly ash but the amount of water/solid ratio used is 0.5 as lower water/solid ratio causes difficulty in mixing owing to the high plasticity of soil.

The unconfined compressive strength test was conducted on an Aimil hydraulic testing machine to obtain the strength parameter of the soil samples in accordance to IS 2720-Part 10 (1991). An untreated sample of only soil was prepared by compacting at maximum density at optimum moisture content for comparison with other samples. Every single result obtained was the average of 3 tested samples. The details of the stabilized soil specimens are shown in Table V . The tests were conducted on samples of clay treated with fly ash and cement and cured for periods of 7 and 24 days. Tests were also conducted on samples cued for 28 days and then soaked in water for 14 days to check the effect of soaking on the samples.

TABLE V

Sample details

Soil Name	**Cement %**	**Curing days**	**Soaked days**
SOIL	0	0	0
C-7	30	7	0
C-28	30	28	0
C-42	30	28	14
F-7	30	7	0
F-28	30	7	7
F-42	30	28	14

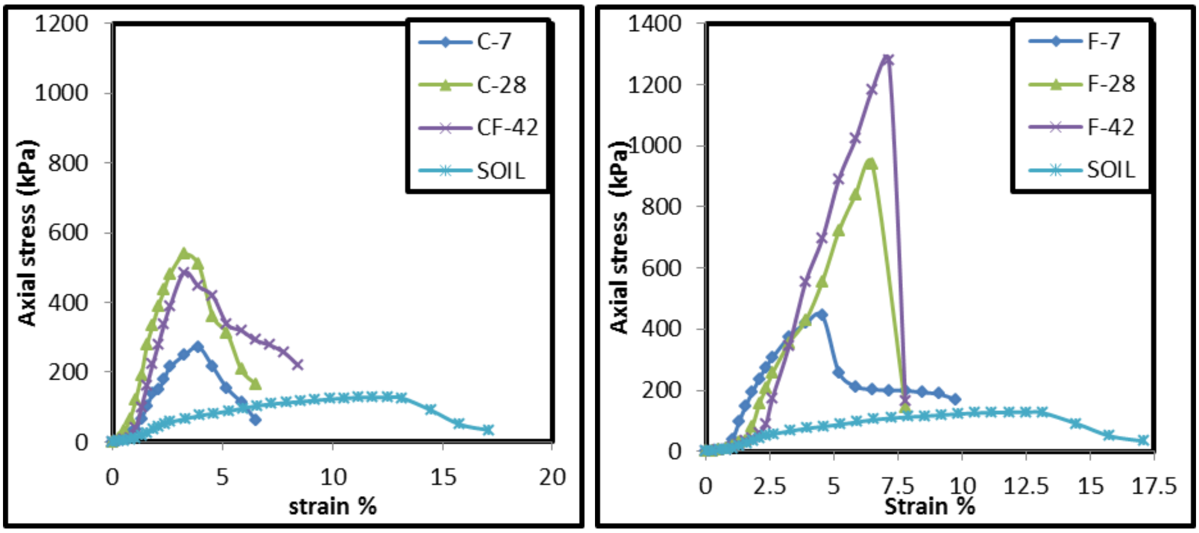
Fig.2 Samples prepared

IV. RESULTS AND DISCUSSION

From Fig. 3 it can be observed that soft clay has very low strength and deform rate is also very high when axial stress is applied. From Fig. 3A, when the soil is treated with OPC, the strength of the soil is improved significantly at just 7 days attaining peak strength more than 2 times the peak strength of the untreated clay sample. The failure pattern of the C-7 indicates that the sample is very hard and brittle as there is sudden rise and fall in the curve. Further increasing the curing period to 28 days, in sample C-28, it gives better peak strength than C-7 which indicates that more curing period can give higher strength. When the 28 days cured sample is again soaked in water for 14 days in sample C-28, to test for strength to find out whether water deteriorates the strength of the OPC treated soil or not, the strength is reduced up to some extent. The reduction of strength in C-42 is about 9.6% of C-28.

Fig 3B shows the stress-strain behaviour of soil stabilized by using Alkali activated (AA) fly ash and it can be seen from the figure that treatment of soil by AA fly is effective as it gains certain amount of strength as strength in F-7 is about 3.5 times of untreated soil sample at 7 days. Increasing the curing period of the sample to 28 days greatly improved the strength reaching peak strength of about 7 times that of untreated clay. When the 28 days cured sample is soaked in water for 14 days, the strength is improved markedly which may be due to some reactions between the AA fly ash and water over the soaking period.

I.



(A) (B)

Fig. 3 Stress-strain curve for (A) OPC treated sample (B) AA fly ash treated sample

On comparing the result between OPC stabilized and AA fly ash stabilized sample, C-7 has lower peak strength than F-7 at 7 days curing and both sample shows brittleness character as there is sudden loss of strength after attaining peak strength. At 28 days curing period, the peak strength is improves for both C-28 and F-28, and F-28 illustrate higher peak strength than C-28, however, the F-28 is found to be highly brittle as sudden loss in strength is observed. In soaking the 28 days cured sample for a period of 14 days, C-42 loses some peak strength but F-42 gain strength which indicates that AA fly ash is more suitable for stabilizing soil as soil are in contact with ground water or rain water most of the time.

Table VI
Peak Strength Comparison

Days	Unconfined Compressive Strength (kPa)		
	SOIL	OPC	AKA FLY ASH
7	127.99	272.16	443.53
28	-	537.85	858.21
42	-	486.10	1280.76

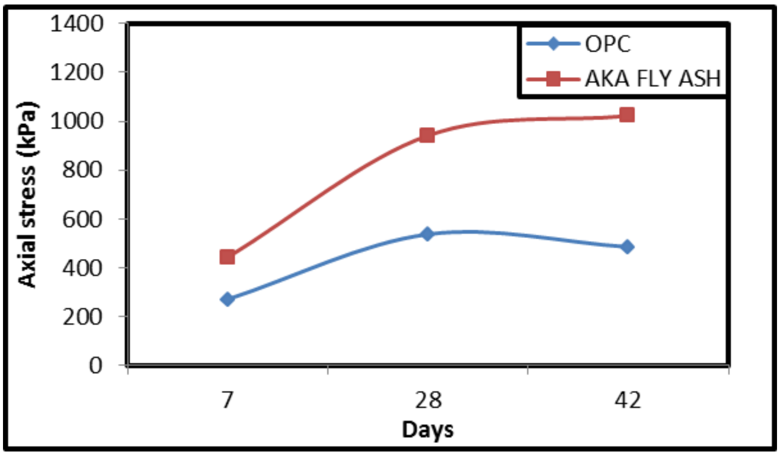


Fig. 4 Unconfined Compressive Strength of AA fly ash and OPC treated soft clay

Fig. 4 gives the unconfined compressive strength of AA fly ash and OPC treated clay samples. Early strength is lower in OPC treated sample as compare AA fly ash treated sample. Increasing the curing period to 28 days increases the peak strength for both OPC and AA fly ash stabilized sample and the strength at 28 days for F-28 is higher than C-28. When the 28 days olds samples are soaked in water for a period of 14 days (42 days in Fig.4), the peak strength is reduced in the case of OPC treated sample, however there is gain in strength in the case of AA fly ash treated sample. The difference in peak strength and its value is given in Table IV. It is observed that AA flyash clay is more effective than OPC treated clay. Moreover, soaking does not seem to affect the strength of AA treated fly ash wheras soaking has adverse3 effect in OPC treated clay sample.

V. CONCLUSIONS

The alkali activated fly can be effectively used to stabilize soft clay as it increases the peak strength of the soil enormously. On comparing the AA fly ash treated soil with OPC treated soil, it gives higher value of strength at both 7 days and 28 days of curing.. Soaking the 28 days cured sample for 14 days reduces the peak strength in the case of OPC treated sample but in the case of AA fly ash treated sample, the peak strength is improved. It can be concluded that the AA fly ash treated soil will face no problem when it comes in contact with ground water or rain water as it increases its strength when fully soaked in water. OPC can be effectively replaced with AA fly ash for soil stabilization purposes and its difficulties lies in applications.

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