EFFECT OF FLY ASH TO IMPROVE ENGINEERING CHARACTERISTICS OF EXPENSIVE SOIL

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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.
Keywords : engineering characteristics, Black cotton soils, class F fly ash, Unconfined compressive strength (UCS), alkaline activated, rheological properties.

I. INTRODUCTION

Expansive soils also known as swelling soils or shrink-swell soils are the terms applied to those soils, which have a tendency to swell and shrink with the variation in moisture content. As a result of which significant distress in the soil occurs, causing severe damage to the overlying structure. During monsoon's, these soils imbibe water, swell, become soft and their capacity to bear water is reduced, while in drier seasons, these soils shrinks and become harder due to evaporation of water. These types of soils are generally found in arid and semi- arid regions of the world and are considered as a potential natural hazard, which if not treated well can cause extensive damages to not only to the structures built upon them but also can cause loss of human life. Soils containing the clay minerals montomorillonite generally exhibit these properties. The annual cost of damage to the civil engineering structures caused by these soils are estimated to be 15000 million in the India, 100000 million in the U.S. and many billions of dollars worldwide.

Fly Ash

Fly ash is a waste material, which is extracted from the flue gases of a coal fired furnace. These have close resemblance with the volcanic ashes, which were used as hydraulic cements in ancient ages. These volcanic ashes were considered as one of the best pozzolans used till now in the world.

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. Hence to optimize the energy from coal mass, the thermal power plants use pulverized coal mass. 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. When the coal ash moves along with the flue gases, the air stream around the molten mass makes the fly ash particle spherical in shape. The economizer is subjected, which recovers the heat from fly ash and stream gases. During this process, the temperature of fly ashes reduced suddenly. If the temperature falls rapidly, the fly ashes are resulting amorphous or glassy material and if the cooling process occurs gradually, the hot fly ashes becomes more crystalline in nature. It shows that the implements of economizer, improves its reactivity process.

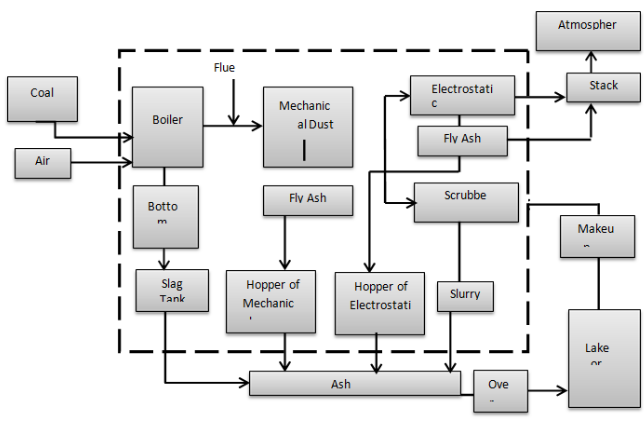

Fig- Schematic view of a typical coal based thermal power plant

Classification of Fly Ash

After Pulverizations, the fuel ash extract from flue gases, by electrostatic precipitator is called fly ash. It is finest particles among Pond ash, Bottom ash and Fly ash. The fly ashes are extracted from, high stack chimney. Fly ash contains non-combustible particulate matter, with some of unburned carbon. Fly ashes are generally contains silt size particles. Based on lime reactivity test, fly ashes are classified in four different types, as follows:

- Cementitious fly ash
- Cementitious and pozzolanic fly ash
- Pozzolanic fly ash
- Non-pozzolanic fly ash

Justification of the Research

In India, almost 20% of the total area is covered by expansive soil, now due to rapid industrialization and huge population growth of our country, there is a scarcity of land, to meet the human needs. And also the cost of rehabilitation and retrofitting of the civil engineering structures founded over these soils are increasing day by day. On the other hand, the safe disposal of fly ash from thermal power industries has been a challenging issue demanding urgent solution because of the decline effect of these materials on the environment and the hazardous risk it pose to the health of humanity. However, production of cement require lime-stone and with the rate with which we are utilising cement, the day is not so far when the lime stone mines will get depicted, and this is a matter of fact that for every 1 kg of cement manufacturing, 1 kg of carbon dioxide is released into the atmosphere, which in turn increases the carbon foot print and also possess serious threat to the global warming. Thus there is a need to find out alternative binder, which is environmental friendly as well as depended like cements. Hence, this research is justifiable in the use of alkali-activated fly ash to stabilize Black Cotton soil.

Objective of thesis

The objective of the current resarch work is to ascertain the suitability of activated fly ash as a soil stabilizing agent.

II. LITERATURE REVIEW

Stabilization is one of the methods of treating the expansive soils to make them fit for construction. Variety of stabilizers may be divided into three groups (Petry 2002): (a) traditional stabilizers (lime, cement etc.), (b) by-product stabilizers (fly ash, quarry dust, phosphor-gypsum, slag etc.) and (c) non-traditional stabilizers (sulfonated oils, potassium compounds, polymer, enzymes, ammonium chlorides etc.). Disposal of large quantities of industrial by products as fills on disposal sites adjacent to industries not only requires large space but also create a lot of geo-environment problems. Attempts are being made by various organizations and researchers to use them in bulk at suitable places. Stabilization of expansive soil is one way of utilization of these by products. Some of the research work conducted by earlier researchers on the above has been described below.

Sharma et al. (1992) studied stabilization of expansive soil using mixture of fly ash, gypsum and blast furnace slag. They found that fly ash, gypsum and blast furnace slag in the proportion of 6: 12: 18 decreased the swelling pressure of the soil from 248 kN/m2 to 17 kN/m2 and increased the unconfined compressive strength by 300%.

Srivastava et al. (1997) studied the change in micro structure and fabric of expansive soil due to addition of fly ash and lime sludge from SEM photograph and found changes in micro structure and fabric when 16% fly ash and 16% lime sludge were added to expansive soil. Srivastava et al. (1999) have also described the results of experiments carried out to study the consolidation and swelling behaviour of expansive soil stabilized with lime sludge and fly ash and the best stabilizing effect was obtained with 16% of fly ash and 16% of lime sludge. Cokca (2001) used up to 25% of Class-C fly ash (18.98 % of CaO) and the treated specimens were cured for 7 days and 28 days.

The quarry dust/ crusher dust obtained during crushing of stone to obtain aggregates causes health hazard in the vicinity and many times considered as an aggregate waste.

Gulsah (2004) investigated the swelling potential of synthetically prepared expansive soil (kaolinite and bentonite mixture), using aggregate waste (quarry dust), rock powder and lime. Aggregate waste and rock powder were added to the soil at 0 to 25% by weight with lime varying from 0 to 9% by combined weight. There was reduction in the swelling potential and the reduction was increased with increasing percent stabilizers and days of curing.

Jain and Jain (2006) studied the effect of addition of stone dust and nylon fiber to Black cotton soil and found that mixing of stone dust by 20% with 3% randomly distributed nylon fibers decreased the swelling pressure by about 48%. The ultimate bearing capacity increased and settlement decreased by inclusion of fiber to stone dust stabilized expansive soil.

III. METHODOLOGY

Expansive Soil

In the present investigation, expansive black cotton soil was procured from a site having coordinates as N 21° 12‘‘ 34.03” and S 79° 09‘‘ 29.09”, 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.

Fly ash

The fly ash is light weight coal combustion by product, which result from the combustion of ground or powdered bituminous coal, sub-bituminous coal or lignite coal. Fly ash is generally separated from the exhaust gases by electrostatic precipitator before the flue gases reach the chimneys of coal-fired power plants. Generally this is together with bottom ash removed from the bottom of the furnace is jointly known as coal ash. The fly ash is highly heterogeneous material where particles of similar size may have different chemistry and mineralogy. There is variation of fly ash properties from different sources, from same source but with time and with collection point (Das and Yudhbir, 2005). Fly ash contains some un- burnt carbon and its main constituents are silica, aluminum oxide and ferrous oxide. In dry disposal system, the fly ash collected at the bottom of the mechanical dust collectors and ESPs. From the dry storage silos also fly ashes are collected in closed wagons or moisture proof bags or metallic bins, if the quality of the fly ash is good. The dry fly ash so collected is then transported to the required locations where it is subjected to further processing before its use in many non-geotechnical applications such as cement industry, brick manufacturing and the like. 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 0 C for 24 hours and then is stored in an air tight container, for subsequent use.

Table 3.2 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.

Methodology Adopted

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 details of the experimental specimens are shown in Table 3.3 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. Since the behaviour of the mixtures was that of a viscous fluid, no density control was used during the preparation of the samples. However, when removed from the moulds, every sample was weighted, and an average unit weight of 20 kN/m^3 was obtained, regardless of the fly ash percentage in the mixture. The 15 molal 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. This effect is related to the SiO2 : Na2O mass ratio of the silicate + hydroxide solution which, for the 15 molar activator, is approximately 1, making the meta silicate solution very unstable and favoring crystallization. This SiO2:Na2O mass ratio was, in the original silicate solution, approximately 2, but the addition of the hydroxide solution reduced it significantly, especially in the 15 molar mixtures. After 48 h, the samples were removed from the moulds and wrapped in cling film and left at ambient temperature and humidity conditions (50–60 % RH and 32-35º C). 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 (UCS) on an Aimil hydraulic testing machine. Every single result obtained was the average of 3 tested samples.

Setting time was ascertained by using Vicat"s apparatus. Each grout was poured in the mould in the view point of calculating its initial and final setting time.

Figure - Experimental Setup of Marsh Funnel Viscomete

IV. RESULT & DISCUSSIONS

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. After 48 h, the samples were removed from the moulds and wrapped in cling film and left at ambient temperature and humidity conditions (50–60 % RH and 32-35º C). 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 (UCS) on an Aimil hydraulic testing machine at constant strain rate of 1.2 mm/min. Every single result obtained was the average of 3 tested samples.

Figure - Photographic image showing test setup of UCS

Table - 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

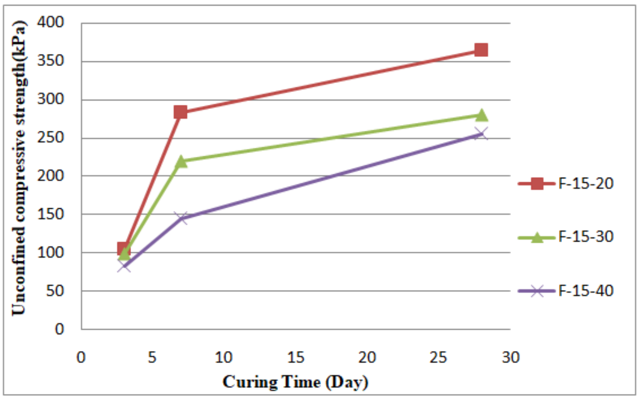

Figure - UCS results of F-15-20, F-15-30, F-15-40

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 a constant water to total solid ratio, the strength increases with the curing period and also with the decreased fly ash content.

Table - UCS results of all Fly ash Samples

Curing Time (Days)	Unconfined Compressive Strength								
	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

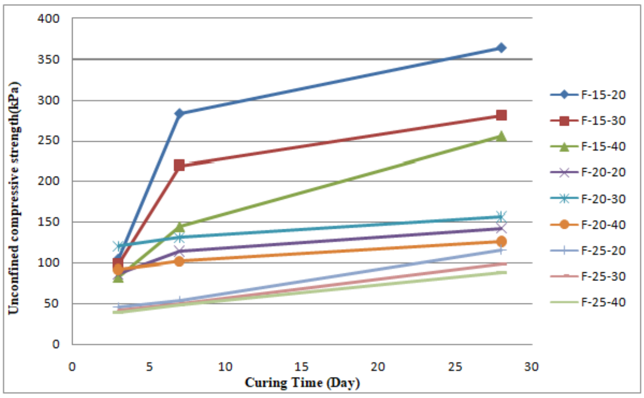

Figure - UCS results of all Fly ash Samples

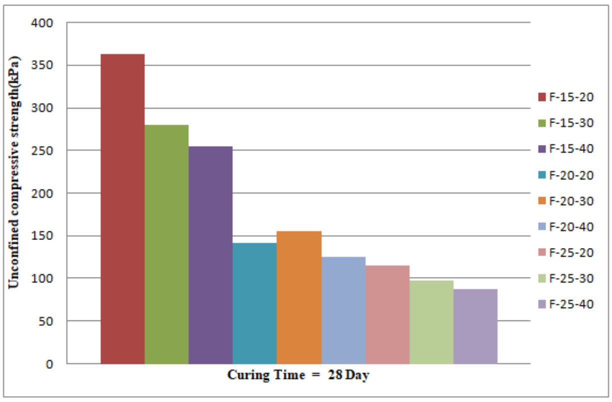

Figure - Bar chart showing the UCS results of Fly ash Samples after 28 days of curing

Table- 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 - 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.

V. CONCLUSIONS

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 molal samples are giving better 3 and 7 days strengths than 12.5 and 15 molal samples, which make it economical as compared to 12.5 and 15 molal samples.
- Long term strength is more in case of 12.5 molal 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.
- Alkali-activated fly ash can be used effectively as a chemical stabiliser for stabilising expansive soils.

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