Effect of Fly Ash and PhosphoGypsum on Properties of Expansive Soils

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Abstract : The results of the laboratory studies undertaken to investigate the effect of PhosphoGypsum (PG) with Fly Ash (FA) on geotechnical properties of clayey soils for soil stabilization purpose are being presented in this paper. The test results on clayey soil treated with different dosages of stabilizer shows that the increase in PG with FA content increases the volume stability as well as the strength of the soil. Observations are made for the changes in the properties of the soils such as Unconfined compressive strength (UCS) test and microstuctural analysis using SEM and EDS results. The study on feasibility of PG and FA for increasing the strength and microstructural development of clayey soils is being carried out thereby proposing an effective solution for the conventional problem of waste management.

Keywords : Fly ash, Phosphogypsum, UCS, SEM, EDS

I. Introduction

Rapid urbanization followed by population growth requires various types of Civil engineering infrastructures and facility services. Because of scarcity of suitable lands it becomes difficult to select an appropriate location for infrastructures. In absence of sound soil that can take load, it is imperative that the engineer has no alternative but to look for methods of strengthening such areas. Soil stabilization is the process of altering some soil properties by different methods, mechanical or chemical, in order to produce an improved soil material which has all the desired engineering properties.

II. Literature Review

Currently there are large volumes of materials considered as wastes or by-products produced by industrial activities. In most cases, these wastes have no possibility of reuse or may be of low economic value for the companies that generate them. The utilization of solid wastes in Civil engineering applications has undergone drastic development over the past. The utilization of blast furnace slag, phosphogypsum, fly ash, red mud, waste tea, etc. are used as construction materials and the environmental impact of such methods have been studied for many years (Cyr et. al., 2004). Lin et al., (2007) demonstrated the improvement of the mechanical properties of a soil when it was treated with a mix of lime and sewage sludge, increasing the strength and reducing the swelling capacity. Wild et al., (1998) improved the strength properties of a soil with sulphates by stabilizing it with lime and GGBS.

It is a well-accepted fact that industrialization and urbanization leads to production of a number of industrial wastes that are of serious environmental concern. Two among them are fly ash (FA) and Phosphogypsum (PG). In this context the study is oriented to use these byproducts for stabilizing clay soils. The beneficial use of fly ash and other waste materials can have an overall economic and environmental benefit. An ideal beneficial use for fly ash and other waste materials is to improve the performance of roadway subgrade and base materials. When mixed with poor-performing soils, the self-cementing properties of Class-C fly ash can be used to improve the engineering properties of subgrades, such as stiffness, strength and durability. Nalbantoglu (2004) used Class - C fly ash as a binder to stabilize an expansive soil, reducing its plasticity and swelling capacity.

In India, about 6 million tons of waste gypsum such as phosphogypsum, flourogypsum etc., are being generated annually [Garg et. al. (1996)]. Phosphogypsum is a by-product in the wet process for manufacture of phosphoric acid by reaction of sulphuric acid on the rock phosphate during the production of ammonium phosphate fertilizer. Some attempts have been made to utilize phosphogypsum for manufacture of fibrous gypsum boards, blocks, gypsum plaster, composite mortars using Portland cement, masonry cement, and super-sulphate cement [Gupta T.N.(1998)]. In other attempts phosphogypsum was also used as a soil conditioner for calcium and sulphur deficient-soils as it has fertilizer value due to the presence of ammonium sulphate [Bhattacharyya et. al., (2004)].

The present study deals with the experimental investigation on unconfined compressive strength characteristics of soil mixed with various percentages of phosphogypsum with a fixed fly ash content of 5%.

III. Materials and Methods

Materials

The materials used for the current research are clay samples (D1 and D2) and two different types of stabilizers [phosphogypsum (PG), and fly ash (FA)]. The clay samples used in this investigation were collected from Tholudur-Vadagaram Pondi road and Perungudi, Chennai. The soil was taken from 0.6 to 1.0m below the top surface with the aim of getting true sample of actual soil strata as the top layer is quite often effected by human activities. Once the soil was collected from the site, roots of the plants were removed in the wet condition. The wet soil was then dried and pulverized.

Methods of Testing

The geotechnical properties of the soil were determined as per IS code of practice. The laboratory tests carried out on the natural soil include particle size distribution, specific gravity, Atterberg limits, standard proctor compaction, CBR and UCS. Both the soils are designated as Inorganic clay of high plasticity (CH) and it was found that sample D1 contained 70% clay, 28% silt and 2% sand and sample D2 contained 66% clay, 32 % silt and 2% sand. The soil D1 and D2 has a free swell index of 120% and 109%, which shows that the soil is susceptible to high degree of expansion. Laboratory test results on untreated soils are shown in Table 1. The Standard Proctor test was conducted on both the soil to obtain the maximum dry density and optimum moisture content as per IS:2720 (Part – VII). Specimens for unconfined compressive strength (UCS) tests were prepared at the optimum moisture contents (OMC) and maximum dry densities (MDD).

Table – 1: Geotechnical Properties of soils

Soil Property	Sample	
	D1	D2
Specific Gravity	2.23	2.37
Liquid Limit (%)	51.5	69
Plastic Limit (%)	20	21.81
Shrinkage Limit (%)	7.71	9.94
Maximum dry density, kN/m^3	15	15.8
Optimum Moisture Content (%)	25.73	18.52

Fly ash collected from Neyveli, Tamil Nadu is used in this study. The oxide composition of soil samples and stabilizers (PG and FA) are shown in Table 2. The fly ash used in this study is classified as Class F type as per the ASTM Standard C618 (sum of the oxides of silica, aluminum and ferrous content is greater than 70 %) and contained 90% of silt size particles. The combined percent composition of silica, alumina and ferric oxide in stabilizers shows the way for a good pozzolonic reaction that helps in the formation of cementitious compounds in the soils.

In this testing programme, the clay samples were mixed with three different percentages of PG (ie, 2, 4, and 6 %) with FA of 5% by weight of dry soil and they were moulded at the optimum moisture content to achieve the targeted density. For all the soil-stabilizer combinations mentioned above, UCS tests were conducted to observe the changes in strength of clay. To maintain the slenderness ratio of 2 in the UCS tests, cylindrical specimens of dimensions 38 mm diameter and 76mm height were prepared using constant volume split mould. Due care was taken to avoid honeycombing of the samples. In order to evaluate the effect of aging on the strength of the mixtures, tests were performed at various curing ages, ie., 14, 28 and 60 days on both the soils (D1 and D2). The curing was accomplished at constant moisture content by tightly wrapping the sample with plastic, placing them in zip-lock bags, and keeping them inside the wet rice husk for allowing the reaction process before the unconfined compression testing in the laboratory. SEM analyses were also performed on this cured sample to study the changes in microstructure of stabilized soil samples at different mix proportions and curing times.

Table – 2 : Oxide composition of soil samples, PG and FA

Chemical constituents	Chemical composition, %			
	Sample D1	Sample D2	PG	FA
Loss on Ignition	13	14.25	16.5	2.74
Silica	53.36	56.84	3.80	36.20
Calcium oxide	3.54	1.11	32.27	18.20
Magnesium oxide	0.73	0.6	---	1.73
Alumina	14.79	14.87	---	27.40
Ferric oxide	7.76	6.95	---	6.83

IV. Test Results and Discussions

Unconfined compression tests were conducted on the untreated and treated soil specimen at a constant strain rate of 1.25mm/min. as per IS:2720 (Part - X). The results of UCS tests carried out on the untreated and soil samples mixed with different percentage of additives are summarized in Table 3. Figure 1 and 2 shows the typical stress versus strain plot from unconfined compression strength (UCS) tests for untreated and treated samples at different curing periods and varying stabilizer contents.

Table – 3 : Unconfined Compressive Strength of untreated and mixture of FA - PG treated soil samples

Additives	UCC Value (kPa)					
	Sample D1			Sample D2		
	Curing Days			Curing Days		
	14	28	60	14	28	60
Soil	75.41			112		
2% PG+ 5%FA	251	286	375	320	380	666
4% PG+ 5%FA	268	304	401	345	406	709
6% PG+ 5%FA	311	356	452	363	424	744

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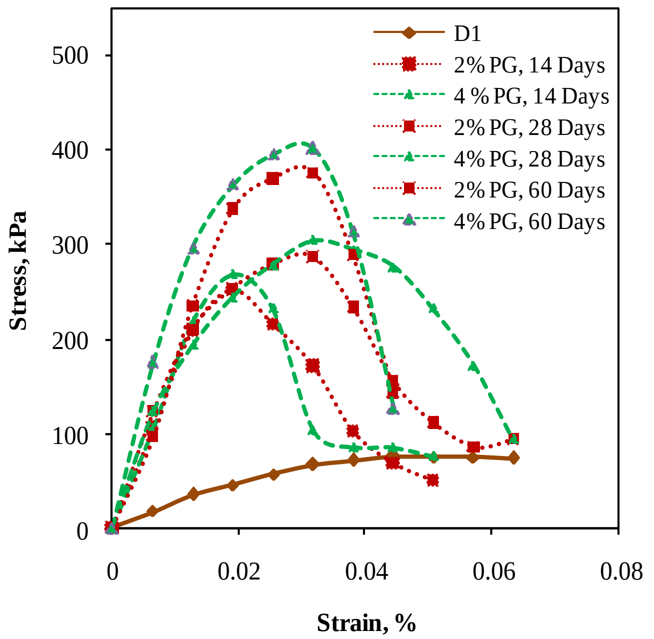

Figure - 1. Stress-strain curves from the unconfined compression test for soils mixed with different percentages PG and 5% of FA.

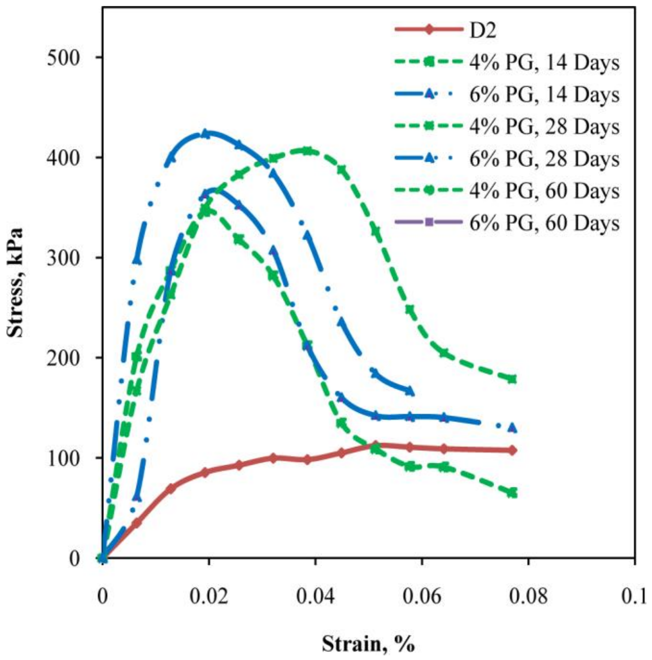

Figure - 2. Stress-strain curves from the unconfined compression test for soils mixed with different percentages PG and FA.

From the results obtained, for a curing period of 14 days the UCS value increased to 2.32 and 1.85 times when 2% PG with 5% FA was added to the soil samples D1 and D2, whereas for the addition of 6% PG with 5% FA on the soil sample D1 and D2, the UCS values are increased in the order of 3.12 and 2.24 times. The effect of curing period on treated soil was also determined by UCS test and it can be seen that the unconfined compressive strength of clay soil treated with PG and FA was improved. The UCS strength developed for treated samples for various curing period are shown in the Figure 3. From the Table 3 and Figure 3, it can be observed that the increase in UCS value for the sample D2 at 14 days and 60 days are 3.13 times and 5.63 times that of untreated soil on addition of 6% PG and 5% Fly ash. It also shows that the strength of soil is increased with increase in curing period. The maximum gain in UCS at 14 days for the samples D1 and D2 were 3.12 and 2.24 times, whereas for the curing period of 60 days the increase was 4.99 and 5.64. The variation in strength indicates that the gain in UCS increases with the increase in curing period for both the soil samples and the increase was more in sample D2 compared D1.

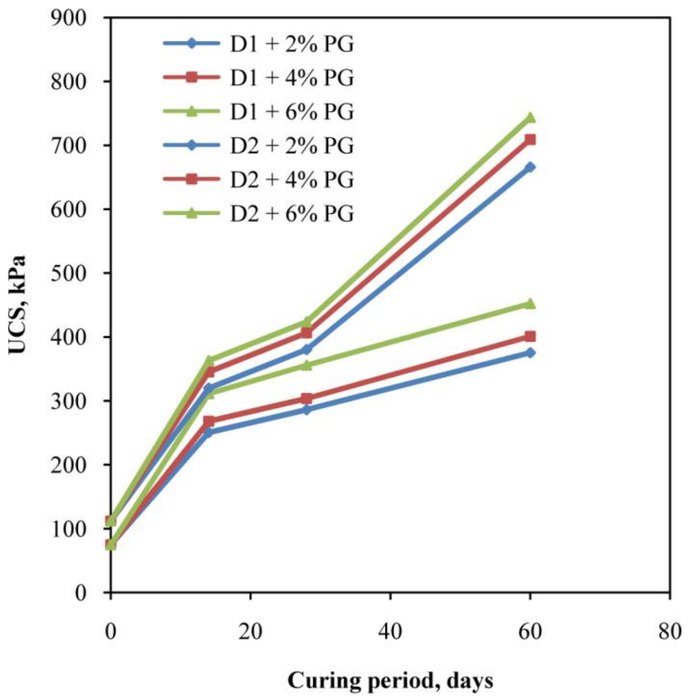

Figure - 3 . Strength development in treated clay samples for different curing periods

Microstructural studies

The SEM and EDS techniques are effective for observations on the microstructural developments of the clay specimens. The fractured surface from prepared clay specimens gives the view of the soil structure and the nature of the products formed during stabilization. The SEM micrographs intimate the evidence of development of a more compact structure after each curing time. The SEM photographs and EDS spectra of samples obtained are shown in the Figures 4 and 5. The EDS helps in analyzing the composition of untreated and treated samples with and without the stabilizers. From the EDS spectra of treated and untreated samples, it is clear that Si and Al are more in treated samples which enhances the cementation property in soil.

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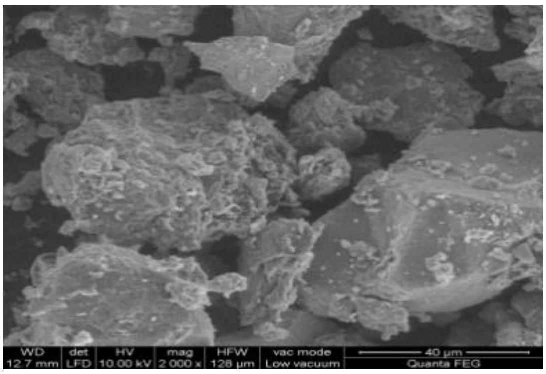
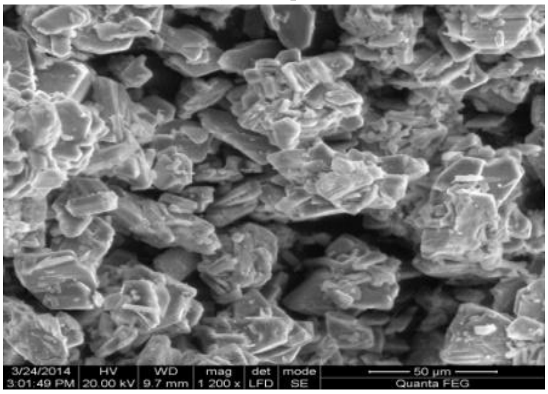
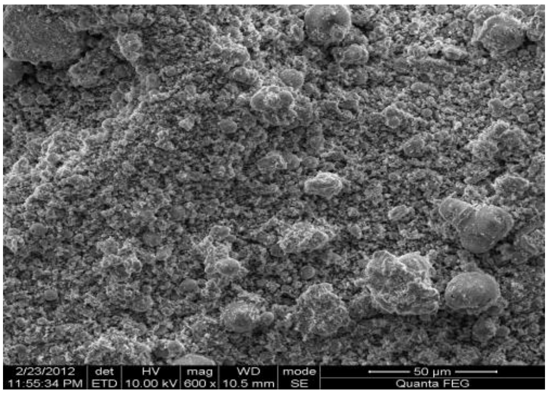


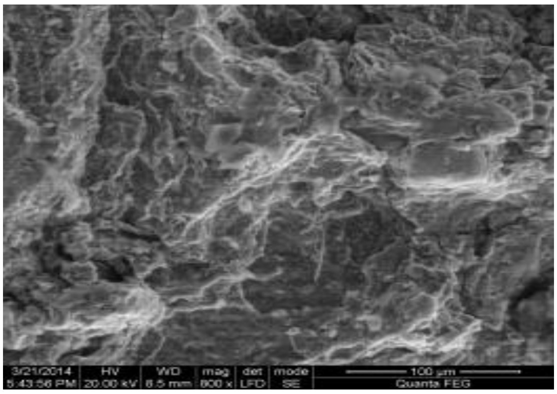
(a). Sample D1



(b). PhosphoGypsum

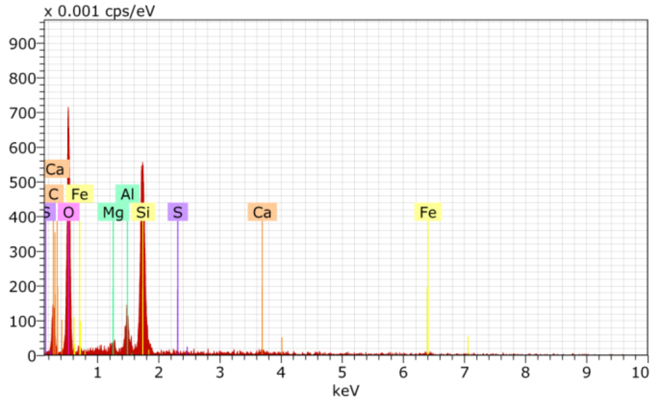


(c). Fly Ash

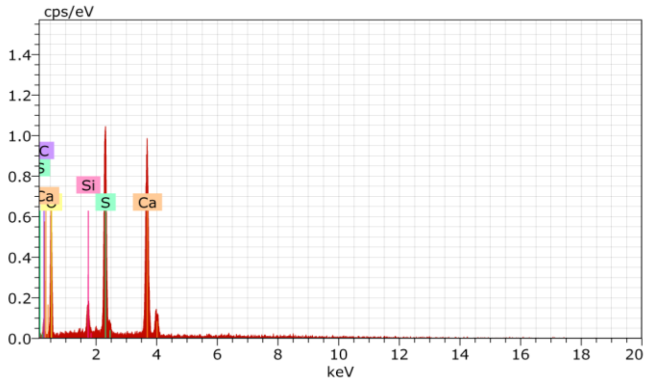


(d). D1 Soil Treated with 4% PG + 5% FA at 14 days curing period

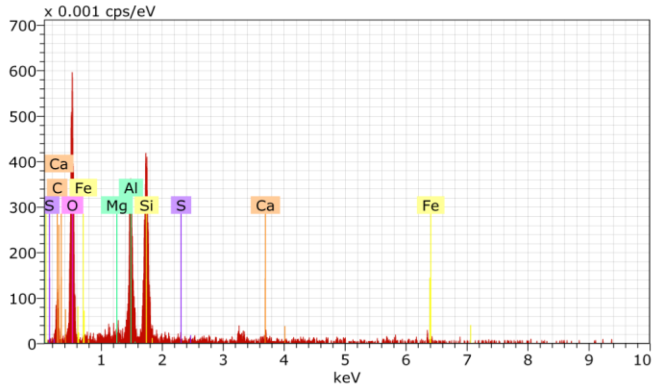
Figure – 4. SEM Micrographs of Untreated Soil, FA, PG and Treated soil



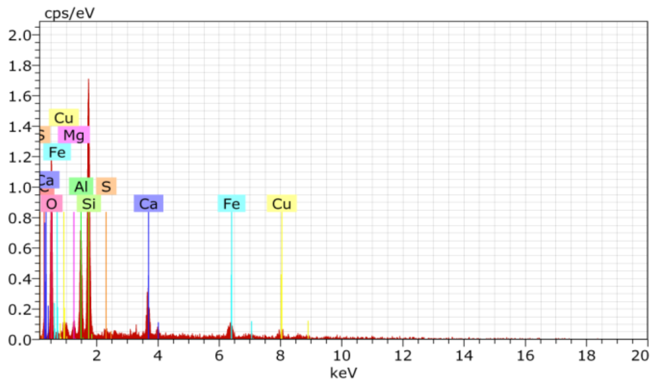
(a). Sample D1



(b). PhosphoGypsum



(c). Fly Ash



(d). D1 Soil Treated with 4% PG + 5% FA at 14 days curing period

Figure – 5. EDS spectra of Untreated Soil, FA, PG and Treated soil

The hydration reaction products formed from the phosphogypsum and fly ash are believed to be the root cause for improvement in microstructure. This growth of cementitious products in the voids between the particles due to hydration increases the strength of stabilized clays. While comparing the untreated and treated specimens, the pore spaces of treated clay samples is less than untreated clay samples because the hydration reactions leads to the formation of larger particles. From the SEM photographs it is clear that a stabilized sample becomes denser than untreated clay samples.

V. Conclusions

The main conclusions from this study are as follows:

1. The result shows that PG and FA are waste products from industries that can be used as additives to clay soil and this would help to solve the conventional problem of their disposals.
2. EDS analysis confirms the presence of montmorillonite mineral in the soil, which is responsible for the expansive characteristics of the soil.
3. The study on addition of 6% PG with 5% FA for atmost 60 days indicates the increase of the unconfined compressive strength of the clay soil and the strength might increase if extended beyond 60 days.
4. The micrograph clearly shows that the fabric of stabilized clay and untreated clay is entirely different. The formation of cementing products is clearly established by the micrograph. Strengths of stabilized clays increase with curing time and admixture contents. The fly ash particles served as nucleation sites for the growth of hydration products with their formation initiating from the surface.

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