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Soil Stabilization with Phosphogypsum and Fly Ash –A Micro Level Study

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Abstract : Socio - economic benefits concerned with the construction of a project deals mainly with the proper utilization of available resources. In this work the geotechnical properties of clayey soils are studied by treating them with industrial waste products like phosphogypsum along with fly ash at varied percentages. Addition of these stabilizers is used to exploit formation of chemical compounds which contributes the strength development of stabilized soils. An improvement in physical and strength properties of soils were observed after stabilizing the soils with varying quantities of stabilizers. An attempt has been made in this work to reduce the problems of clayey soil with appreciable reduction in swell potential. In addition, the micro level analysis using X-ray diffraction and Scanning Electron microscopy was carried out inorder to elucidate the stabilization mechanism. The microstructure of Phosphogypsum-Fly ash stabilized clay mainly focus the arrangement of the soil particle and pore spaces in a soil mass which are dependent on factors such as stabilizer dosages and the different curing periods. During the curing period the volume of pores became smaller and an improvement in microstructure was also found initiating from fly ash particles serving as a component for pozzolanic reaction products which occupy the voids between soil particles. The changes in soil structure due to stabilization were clearly visible in SEM micrographs which show that the clayey soil particles attained closer arrangement after stabilization and prolonged curing period.
Keywords :CBR value, Free swell index, Phosphogypsum, Flyash.

1. Introduction

Soil improvement becomes a significant development in Civil engineering field due to the increasing needs of constructions on soft ground. Varieties of techniques are being practiced in this regard which shows a considerable success in altering the nature of soil to make it fit for construction. Soil stabilization is one of the techniques generally carried out to reduce the plasticity and swelling characteristics, which increases the strength of weak soils. A study conducted on reduction of swell potential of problematic black cotton soil revealed that partial replacement of soil with shredded tyre wastealters the geotechnical properties and swell potential in a way favourable for Civil engineering applications[1].Various locally available stabilizing agents like

Ordinary Portland Cement, Lime and Fly ash can also improving the strength and plasticity behavior of soil and have a wide range of applications in different fields of construction [2,3].

Stabilization using industrial wastes is one of the efficient techniques for improving the strength characteristics of weak soils and proven economical solution. The addition of lime and Class C fly ash, an industrial byproduct of electric power production, produced from burning lignite and sub-bituminous coal, results in the plasticity reduction in highly expansive natural clays [4]. It has been realized that the use of waste products such as rice husk ash and marble dust in stabilization, yields a productive way of handling the wastes in another field for useful application [5].This work is focused on investigating the effect of combination of flyash with phosphogypsum as additives for improving the geotechnical properties of problematic soil which are relevant for evaluating the performance of soils along with micro-level studies like X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectrometer to identify the changes in soil structure due to stabilization.

2. Materials and Testing Procedure

The soils used in the experimental work were brought from a place Tholudur- VadagaramPondi road and Perungudi, Chennai. From particle size distribution it was found thatsoil sample F1 contained 70% clay, 28% silt and 2% sand and soil sample F2 contained 66% clay, 32 % silt and 2% sand. The specific gravity of the soil sample F1 and F2 were 2.23 and 2.37 respectively. Tests for Geotechnical properties of both the soils F1 and F2 were conducted as per the BIS and the test results are shown in the Table 1. From the results obtained, it was identified that both the samples were highly compressible clays.Phospho Gypsum(PG) is a by-product in the wet process for manufacture of ammonium phosphate fertilizer by the action of sulphuric acid on the rock phosphate. The phosphogypsum used in this study had SiO_2 - 3.9%, CaO - 32.27 %, and Loss on ignition of 16.5%.Fly Ash(FA) used in this study was collected from Neyveli, Tamil Nadu. It is classified as Class F type as per the ASTM Standard C618, and it contained SiO_2 - 35.2%, Fe_2O_3 - 6.83%, Al_2O- 27.4% and CaO - 19.2%.

Table 1: Geotechnical properties of the clayey soils

Sample designation	Free swell index	Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)	Maximum dry density, kN/m^3	Optimum Moisture Content (%)	CBR (%)
Soil F1	120	51.5	20	7.71	15	25.73	1.45
Soil F2	109	69	21.81	9.94	15.8	18.52	2.19

The tests for identification of the clayey soils and determination of the geotechnical properties of the soil samples treated with PG and FA were carried out in accordance with the BIS code of practice. To find the effect of stabilization on soil samples, PG varied from 2 to 6 percent with 5 percent FA by dry weight of soil was thoroughly mixed with pulverized clayey soil samples and then mixed with distilled water for preparing specimens to conduct the CBR tests. The effect of admixtures on CBR of soil mixes were studied, after keeping the prepared samples for 3 and 7 days curing time before testing. After testing, the specimens were air dried and pulverized, then free swell index, SEM analysis, EDS and XRD were carried out to determine the swell characteristics and microstructural changes.

4. Results and Discussion

4.1 Strength Characteristics

CBR tests conducted on the soil measure the sub-grade strength as compared to a dense graded aggregate. CBR is an important parameter in pavement design to predict the thickness of the pavement. CBR tests were conducted on untreated soils as well as treated soil as per BIS. CBR samples were initially compacted in the moulds to the corresponding Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) obtained from the Proctor test. Sample in the CBR moulds were placed under a surcharge pressure of 2.5 kPa Then it was placed over wetted rice husk base and covered with wet gunny bags to maintaining room temperature in order toavoid moisture loss from the samples prepared. After curing the samples for desired curing periods, they were soaked for 96 hours. Thereafter, the load was applied on the soil to determine the

CBR value of treated and untreated soil. Figure 1 and 2 shows the variation in CBR of stabilized soil at varying percentages of the admixtures and curing periods for sample F1 and sample F2.

The results of CBR tests on soils F1 and F2 stabilized with 2, 4 and 6% PG with 5% fixed quantity of FA are presented in Table 2. From the Figures 1 and 2, it can be observed that CBR of soil increases to 11.1 % and 12.04 % from 1.45% and 2.19 % when 6% PG with 5% FA was added to soil samples F1 and F2 respectively after 7 days curing. Increase in curing period also increases the CBR values for different percentages of stabilizers. The increment in CBR may be because of the gradual formation of hydration compounds in the soil due to the reaction between the stabilizers and the elements present in the soils.

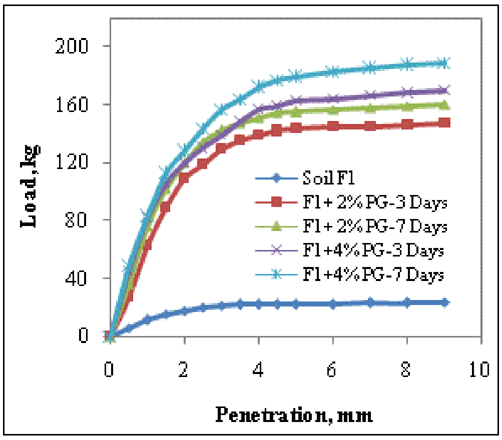

Figure 1 Load – penetration plot for soil F1 mixed with 5%FA and varied percentages of PG.

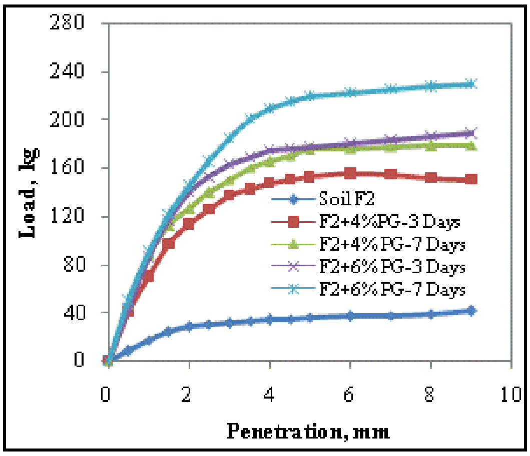

Figure 2 Load – penetration plot for soil F2 mixed with 5%FA and varied percentages of PG.

Table 2: Effect of various percentages of PG-FA mix on CBR values of soils

Admixtures		**CBR (%)**			
		Soil F1		**Soil F2**	
		3 days	**7days**	**3 days**	**7 days**
Soil+0% PG	0% FA	1.45		2.19	
Soil+2% PG	5% FA	8.69	9.78	7.66	8.90
Soil+4% PG	5% FA	9.49	10.51	9.12	10.14
Soil+6% PG	5% FA	10	11.1	11.09	12.04

4.2 Swell Characteristics

The free swell test is one of the most commonly used tests for identifying the swelling potential of soil samples to estimate the expansive nature of soils and it was conducted on both the soils as per IS: 2720 (Part - 40) specification.The variation of free swell index of treated samples with respect to the untreated samples are shown in the Table 3.From the test results, it was observed that, with the increase in proportion of PG with FA, free swell index decreases and that it decreases at nearly constant rate for both the soil samples with changes in the concentration of stabilizers. Similar decreasing trend was observed with the increase in curing periods also. These are indication of gradual formation of hydration compounds in the soil due to the reaction between the stabilizers and the elements present in the soil.

Table 3 : Variation of free swell index of PG-FA stabilized soils

Admixtures		**FREE SWELL INDEX (%)**			
		Sample F1		**Sample F2**	
		3 days	**7days**	**3 days**	**7 days**
Soil+0% PG	0% FA	120		109	
Soil+2% PG	5% FA	110	90	90	80
Soil+4% PG	5% FA	90	80	85	70
Soil+6% PG	5% FA	70	60	60	50

4.3 Microstructural Analysis

In this study, microstructure analyses of selected specimens were also carried out using Scanning Electron Microscopy (SEM) in conjunction with X-Ray Diffraction (XRD). The mass percentage of minerals formed due to stabilization in soil samples can be determined by the images from SEM and XRD analysis.

4.4 Scanning Electron Microscopy (SEM)

In this investigation, an attempt was made to investigate the microstructural changes in PG-FA stabilized clay soils to explain the strength development due to the influential factors, i.e., stabilizer content, clay content and curing time. Two sets of treated samples were prepared ie., for soils F1 and F2 with various admixtures content planned for this study. Figure 3 shows the SEM images andEnergy Dispersive X-ray Spectrometer(EDS) analysis for soil, admixtures and treated soils.

Figure 3a and b shows SEM micrographs and EDS of phosphogypsum and fly ash used to stabilize the untreated soils. SEM and EDS photographs of the untreated samples F1 and F2 compacted at MDD and OMC obtained from standard proctor test are shown in Figure 3c and d. From the micrographs for the untreated samples, the soil appears to be in a blocky arrangement of loosely packed particles. For these untreated samples, the soil structure controls the strength and resistance to deformation, which in turn is governed by compaction energy and water content. Compaction breaks down the large clay clusters into smaller clusters and reduces the pore space. Figure 3e and f shows SEM and EDS results of soils F1 and F2 compacted at their OMC values with 4% PG and 5% FA content for the curing period of 7 days. The water content also affects the stabilization, which helps in the formation of hydration products in treated samples.

The microstructural change with the addition of admixtures and curing time for treated samples promotes the bonding between particles which contributes to the strength development and reduction in pore volume. During the curing period the volume of pores becomes smaller due to the hydration reaction. The images 3e and 3f shows the presence of different clusters affected by chemical reaction. These parts have different micronics sizes due to the reactions. The SEM and EDS analysis revealed the elemental composition in soil after stabilization and prolonged curing period. The mineral composition of stabilizers, soils and treated soil samples are given in Table 4.

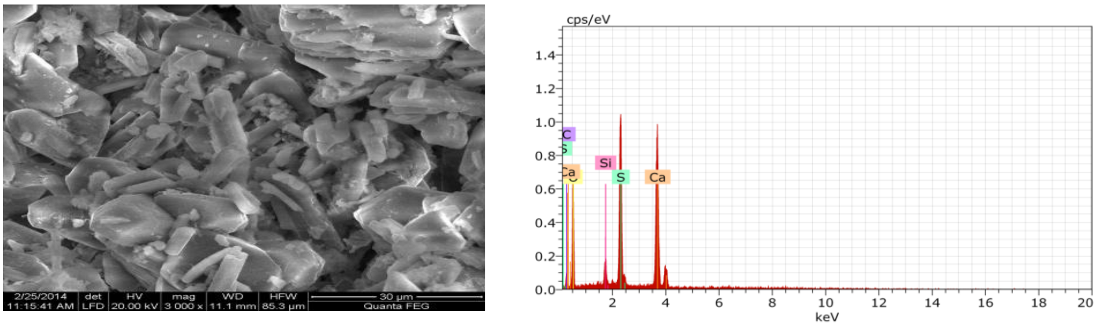

Figure 3(a). SEM and EDS image of Phosphogypsum

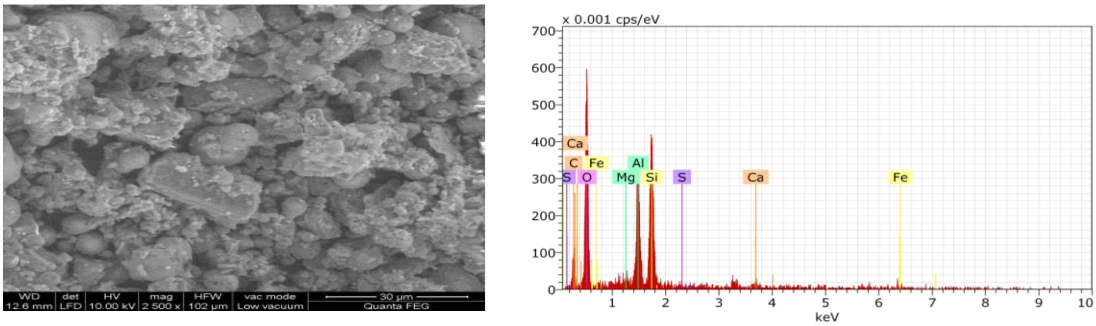

Figure 3(b). SEM and EDS image of Fly ash

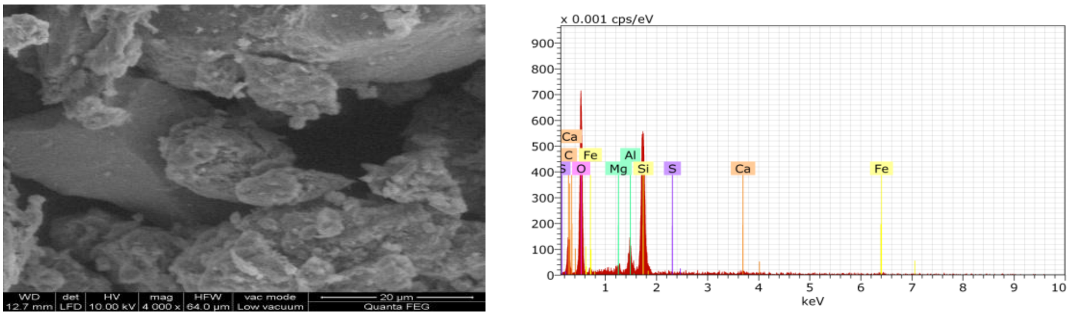

Figure 3(c). SEM and EDS image of Soil F1

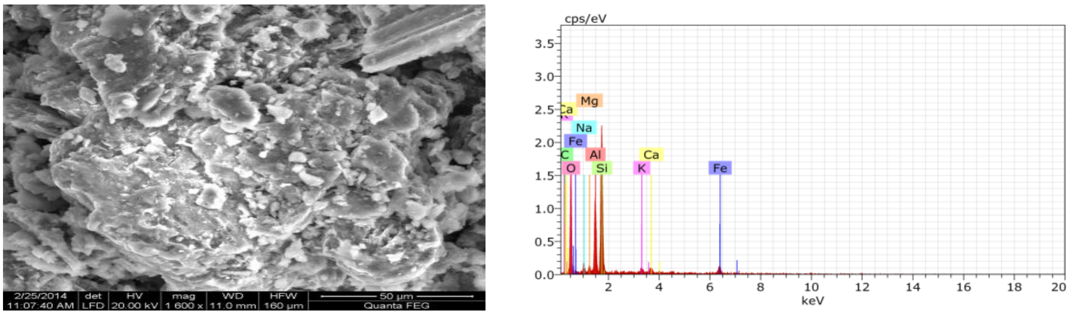

Figure 3(d). SEM and EDS image of Soil F2

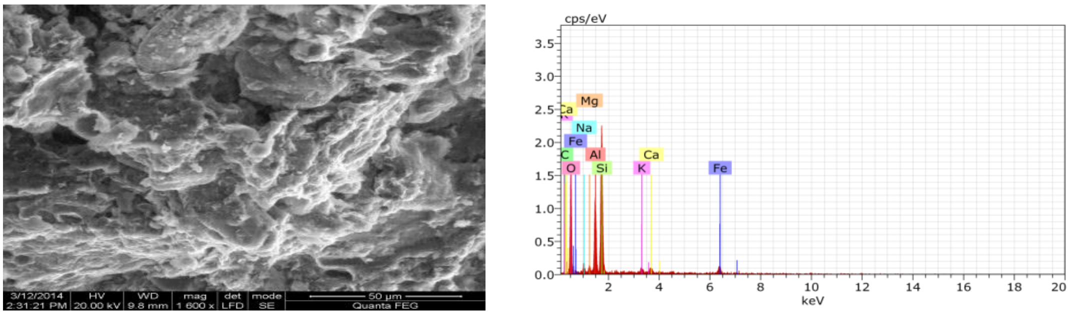

Figure 3(e). SEM and EDS of soil F1 treated with 4% PG + 5% FA at 7 days curing period

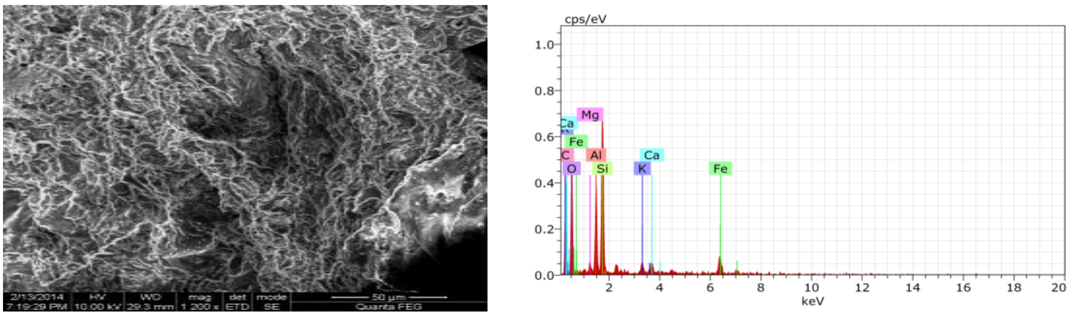

Figure 3(f). SEM and EDS of soilF2 treated with 4% PG + 5% FA at 7 days curing period

Figure 3. SEM and EDS micrographs of stabilizers, soil and treated soil

Table 4: Mineral composition of stabilizers, soils and treated soil samples.

Compound concentration	PG	FA	F1	F2	Soil F1+ 5%FA+ 4%PG	Soil F2+ 5%FA+ 4%PG
O	64.18	50.15	50.25	59.07	64.07	36.57
Si	1.43	16.29	18.77	13.81	6.12	11
C	15.03	21.56	26.85	13.36	18.77	42.89
Al	-	9.12	2.01	8.68	3.29	5.54
Fe	-	1.77	1.31	1.31	1.09	1.76
Ca	9.57	0.63	0.44	0.55	5.79	0.64
Mg	9.79	0.39	0.34	0.87	0.88	0.73
S	-	0.09	0.03	-	-	-

4.5 X-Ray Diffraction

Energy dispersive spectroscopy is used to recognize selected mineral in a thin section sample by its elemental composition and it shows an X-ray mapping of each element. The XRD tests were performed on raw soil, stabilizers and stabilized specimens. Figure4 shows the XRD results for soil, admixtures and treated soils. XRD analysis shows the minerals of hydraulic products formed due to stabilization, leading to a denser and more stable structure of the samples. It was found that the effectiveness of stabilization is dependent on the type of soil, the amount of stabilizer and the curing time.

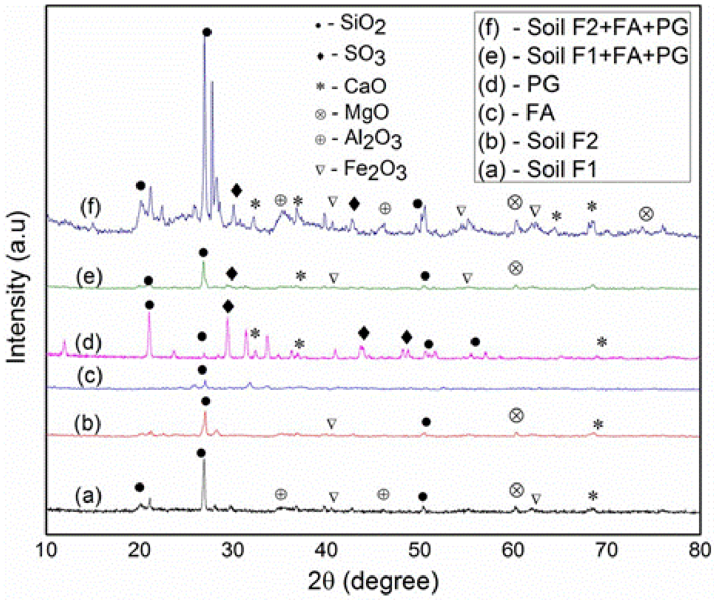

Figure 4.XRD results of stabilizers, soils and treated soil F1 and F2

5. Conclusion

The following conclusions can be drawn on the basis of test results obtained on the expansive soil stabilized with PG and FA.

- Addition of admixture on soil gives a minimum improvement of CBR to a range of 7.5 – 8.5 from 1.4 - 2 for the both the soils used in this study. CBR values also increase with the increase in curing periods.
- Free swell index of treated soil reduced by around 50% on addition of FA and PG in both the soils at the curing period of 7 days.
- The results obtained from strength test were compared with SEM investigations, the addition of relatively small amounts of stabilizers shows noticeable changes in the cementatious formation in soil.
- The changes in mineralogical composition studied by SEM and XRD analyses clearly show the variation in soil structure, due to the chemical reactions initiated by the additives.
- From the study conducted it was found that PG with FA performs satisfactorily as a cheap stabilizing agent for clayey soil.

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