Investigation on Industrial Waste Material for Stabilizing the Expansive Soil

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Abstract. The increasing demand of fertilizer for agricultural field to make the farmable land results in the more generation of byproducts during the manufacturing stages. These byproducts can be utilized by various treatment techniques for the reduction of its contaminants due to its disposal for long time. In this study, the strength characteristics of two expansive clayey soils were studied and it was observed an enhancement in strength by the addition of an industrial waste product, Phosphogypsum as a stabilizing agent at various percentages of 2, 4, 6 and 8 by weight of soil. The attainment in strength characteristics of soil due to the mixing of additive has studied by conducting Unconfined Compressive strength tests at the various time periods of 14, 28 and 60 days. UCS results showed that soil solidification process by the additive exhibited the maximum compressive strength of 50% when the addition of Phosphogypsum reached by 6% at the curing period of 28 days. The improvement in soil characteristics were analysed chemically and it was also studied under microstructural analysis, X-Ray Diffraction methods. Microstructural studies reported a remarkable change in the mineralogy of the treated soil, with the fine phases formed due to the pozzalonic reactions which are responsible for the strength development. Thus the Phosphogypsum waste in the clay as a soil stabilizer suggests a most economical material for the remarkable improvement in the properties of soil and it will be the best options to manage this waste as sustainable material towards the green environment.

1. Introduction
The construction of structures on expansive soil stratas are considered as a challenging concern in civil engineering field, since it is required to prepare as a foundation bed with proper conditions with the adequate capacity to carry the loads. The main outstanding issue in expansive soils is its volumetric instability in presence of moisture content. These types of soils required the modification methods to improve its main characteristics of bearing capacity to attain the suitability for construction activities. Fortunately, there are number of ground improvement techniques are proven, which can modify the unpropitious effects of problematic clay soil to a sound material of better mechanical properties.

Mainly for the expansive clays, soil stabilization is a favorable technique in treating the soil chemically as well as physically since these formations were confirmed with their large volume changing characteristics [1,2]. The traditional stabilizer agents[3-5] gives considerable changes in soil plasticity and swelling characteristics but it shows few negative impacts during its manufacture as well as inclusion in soil. In recent years, the use of waste materials in soil becomes the economical and ecofriendly method in soil stabilization. The addition of industrial and agricultural waste materials such as coal ash[6,7], Flyash
rice husk ash, etc. in soils have been used with success in practice as additives because it suppressed the swelling properties and increased the compressive strength of expansive soils by the flocculation of particles. Besides the use of waste products in modification technique also resulted an effective way of waste disposal. Among the various industrial waste products the Phosphogypsum one which shows the tremendous increase in generation mainly in fertilizer industries. In India, it was reported that 4 to 5 million tons of Phosphogypsum is getting generated annually as a by-product among the various forms of gypsum. This study was to investigate the feasibility of using an industrial waste, Phosphogypsum as a material for soil stabilization and its modification characteristics in soil for a long term period.

2. Materials and methods
The two soils used were collected from a depth of 1m after removing the top soil upto 0.5m depth from two different locations in Chennai. The geotechnical properties of clayey soils used in this experiment study are listed in Table 1.

| Description                  | Soil 1 | Soil 2 |
|------------------------------|--------|--------|
| Free swell index (FSI), %    | 240    | 160    |
| Particle size distribution   |        |        |
| Clay (%)                     | 74     | 66     |
| Silt (%)                     | 26     | 32     |
| Sand (%)                     | 0      | 2      |
| Liquid limit W_L (%)         | 68.5   | 94     |
| Plastic limit W_p (%)        | 24     | 32     |
| Shrinkage limit (%)          | 5.13   | 4.7    |
| Specific Gravity             | 2.66   | 2.8    |
| Unconfined Compressive Stress, kPa | 142    | 115    |

The investigated clayey soils having high Free Swell Index and based on the basic test results, are classified as high-plasticity clays, having high compressibility according to the Unified Soil and Indian Standard Classification Systems. Phosphogypsum (PG) used as the admixture for the soil stabilization in this study was an industrial waste collected from fertilizer industry. The mineral compounds in PG shows the dominating oxide compounds such as CaO -3.8%, SO_3- 44.53 and SiO_2– 3.8% which indicates its capability in clay soil stabilization. Soil samples are mixed with the PG at various percentages of 2, 4, 6 and 8 and kept the specimens for various time periods of 14, 28 and 60 days for finding the strength changes at increasing age. In this study microstructural changes were also traced with the aid of SEM and XRD analyses to analyse the results obtained from strength tests. All specimens were prepared with the compaction method by determining the optimum moisture content and maximum density. The specimens were moulded using the split mould and after the compaction it was taken out and were wrapped with thin plastic covers and stored until curing period is completed.
The investigated clayey soils having high Free Swell Index[12] and based on the basic test results[13,14], are classified as high-plasticity clays, having high compressibility according to the Unified Soil and Indian Standard Classification Systems. PhosphoGypsum (PG) used as the admixture for the soil stabilization in this study was an industrial waste collected from fertilizer industry. The mineral compounds in PG shows the dominating oxide compounds such as CaO -3.8%, SO₃- 44.53 and SiO₂–3.8% which indicates its capability in clay soil stabilization. Soil samples are mixed with the PG at various percentages of 2, 4, 6 and 8 and kept the specimens for various time periods of 14, 28 and 60 days for finding the strength changes at increasing age. In this study alterations in microstructure were also identified with the aid of XRD methods to analyse the results obtained from strength tests. All soil specimens used for the unconfined compression strength tests were prepared with the compaction characteristics as per compaction method[15]. The specimens were moulded using the split mould and after the compaction it was taken out and were wrapped with thin plastic covers and preserved until curing period is completed.

3. Test results and Discussion

3.1 Unconfined Compressive Strength test

The UCS test [16] performed in the untreated and treated soil samples shows an improvement in shear strength from time after stabilization. Figure 1 and 2 shows the stress- strain relationship which indicates as unconfined compressive strength in relation to curing time for soils 1 and 2 respectively.

![Figure 1. Stress-Strain characteristics of treated soil S1 at varying curing periods over treated soil.](image-url)

It was observed that considerably a higher compressive strength is obtained in treated soils with the increase in curing days. The contributions of Phosphogypsum on the strength gain of the treated soil compared with the untreated soils are tabulated in the Table 2. Strength values obtained with PG are higher with the dosage of 6% in both the soils compared with the untreated soils. It was inferred that the PG dosage on strength is mainly due to pozzolanic reactions with the influence of the free reactive elements in admixture[17,18].
The peak strength was identified for the stabilized mixed specimens having 6% PG content in soil. At the curing age of 60th day the UCS values was increased by 237.6 kPa and 177.3kPa for two samples from 142kPa and 115.2kPa respectively.

The effect of combining 2%, 4%, 6% and 8% PG in soil and the unconfined compression strengths with curing time are illustrated in Figure 3 and 4. UCS results of PG in different percentages when used in stabilization of clayey soils shows a marginal development in the strength in comparison with untreated soils. The results show that adding PG of 6% results in an optimum dosage giving more strength compared with the remaining dosages and it gives a percentage increase in strength of 67.3% and 53.9 % for both the soils. UCS values obtained in the earlier period shows the initial modification of soil structure and the long term values marginal increase in strength attained with the pozzalonic reactions imparted by the admixture soil combinations in the presence of moisture content. With regard to the strength
characteristics reported for the soil samples for varying curing periods and admixture content, the 6% PG is the most effective amount in the stabilization of clayey soils.

![Figure 3. Effect of curing days on UCS value for different % of PG for soil sample 1.](image)

**Figure 3.** Effect of curing days on UCS value for different % of PG for soil sample 1.

![Figure 4. Effect of curing days on UCS value for different % of PG for soil sample 2.](image)

**Figure 4.** Effect of curing days on UCS value for different % of PG for soil sample 2.

3.2 Microstructural Analysis
The XRD images of the clayey soils and Phosphogypsum were shown in Figures 5 and 6 respectively. Figure 7 shows the representative X-ray diagram of treated sample 1 and it indicates the change peak values which resulted due to long term pozzolanic reaction with the minerals constituents present in soil and the admixture.
Figure 5. Untreated sample 1.

Figure 6. Phosphogypsum.
After stabilization of soil with PG enhances the strength characteristics with chemical reactions and it results in soil structure modifications. XRD analysis of the soil with PG treatment enables the identification of pozzolanic reactivity and it provides the evidence for the formation of bonded structure with the hydration products. The Phosphogypsum minerals is offering more production of hydraulic compounds like CaO and SiO₂ and the numerous peaks in the XRD graph shows a decrease in reactive compounds due to reaction at the long term age of 60 days compared with untreated soil[19,20].

4. Conclusion
The main conclusions of the test results can be drawn as follows:

The unconfined compression test was performed with the treated soil samples and it is showing an increase in shear strength compared with untreated soil strength with the increase in curing age. The peak strength is observed for the stabilized mixed specimens having 6% PG content in soil. At the curing age of 60th day the UCS values was increased by 237.6 kPa and 177.3kPa for two samples from 142kPa and 115.2kPa respectively. Microstructural study by the X-ray diffractogram technique on samples of untreated and treated samples conformed the changes in the mineral composition of soils with the admixture. The usage of Phosphogypsum waste with the clay as a soil stabilizer proves as a most economical material for soil stabilization and it suggests the effective way of managing the waste as sustainable material.

5. REFERENCES
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