Analysis of Strength Properties of Lime Stabilized Black Cotton Soil with Phosphogypsum

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Abstract. Expansive soils are those soils which pose a very serious problem when they are subjected to moisture variation. Phosphogypsum is one of the industrial waste by-products that can be utilized for the purpose of soil stabilization. In this study, the strength of lime stabilized soil added with Phosphogypsum for immediate,7 and 14 days of curing periods is compared with the strength of Phosphogypsum amended black cotton soil for immediate, 7 and 14 days of curing. From Unconfined compressive strength test, it was found that 6% of Phosphogypsum is the optimum content, that imparts the maximum strength to the soil that when it is used alone. The combination of 3% of lime and 6% of Phosphogypsum gives the maximum strength and the strength obtained is relatively higher than the strength of the black cotton soil stabilized with Phosphogypsum alone.

Keywords: Phosphogypsum, Unconfined compressive strength, Soil stabilization.

1 Introduction

Black cotton soil, a cohesive soil, is considered as a problematic soil for civil engineers. It has characteristics of swelling during rains and shrinking during summer because of the presence of clay mineral montmorillonite. Soil stabilization is the process or technique of improving the engineering properties of the soil. The properties of soil can be improved either by mechanical stabilization or chemical stabilization. Mechanical stabilization is the methodology which involves the improvement in the properties of soil by changing its gradation without the addition of agents. The methodologies include compaction, blasting, dynamic compaction, preloading, sand drains, etc., [10] and chemical stabilization involves the reaction between the stabilizer and the soil minerals in order to achieve the desired effect. The most commonly used materials for soil stabilization include cement, lime, fly ash, blast furnace slag, etc., the soil material which is stabilized is having higher strength and lower permeability and compressibility. Cement and Lime stabilization is the most widely used methods of chemical stabilization. Phosphogypsum is a kind of industrial waste byproduct generated from the production of phosphoric acid by treating phosphate ore with sulphuric acid [6]. Nearly about 4.5 to 5tons of phosphogypsum is generated per ton production of the phosphoric acid. Large volume production of phosphogypsum poses a very serious problem of disposal. If it is disposed of in open yards, it may cause a threat to the environment [9]. The beneficial use of phosphogypsum like it's used as a raw material in the cement manufacturing industry, as a substitute for mineral gypsum as well as for soil stabilization is more effective in solving the problem associated with the disposal of phosphogypsum [1, 2].

2 Materials and Methodology

The materials which are utilized in this study include natural black cotton soil which is needed to be stabilized, lime and phosphogypsum.

2.1 Black Cotton Soil

The black cotton soil used in this study was collected from Raichur district of Karnataka, India. The properties of the soil were tested according to the Bureau of Indian Standards in the laboratory and the results that were obtained are tabulated in table 1

Table 1. Soil properties

Sl. No.	Properties	Values	Standards
1	Liquid Limit	83 %	IS 2720 Part 5
2	Plastic Limit	37%	
3	Plasticity Index	46 %	
4	Shrinkage Limit	8%	IS 2720 Part 6
5	Specific gravity	2.4	IS 2720 Part 3
6	Maximum dry density	14.95 kN/m^3	IS 2720 Part 7
7	Optimum moisture content	27%	
8	UCC strength	20.6 kN/m^2	IS 2720 Part 10

2.2 Lime

The addition of lime quickly improves the condition of soil during construction and can contribute to the early and late strength of the stabilized soil. Addition of lime can cause 3 major improvements in the soil.

- Soil drying – Reduction in soil moisture content
- Soil modification – Reduction in plasticity, improvement in compaction characteristics and gain in early strength.
- Lime stabilization - Increasing long term strength and reduction in swell potential.

The lime used in this study was obtained from the Mysore agency, Bengaluru, Karnataka. The lime composition as provided by the manufacturer was as follows.

Table 2. Properties of lime

Sl no.	Composition	Percentage
1	$Ca(OH)_2$	91.21
2	Silica	0.96
3	Magnesia as MgO	0.94
4	Aluminum as Al_2O_3	In traces
5	Fe_2O_3	In traces
6	Mesh	250

2.3 Phosphogypsum

The Phosphogypsum essentially a "Calcium Sulphate" is generated as a waste by-product from the phosphoric acid manufacturing plants by the reaction of rock phosphate with the sulphuric acid. About 100 to 280 million tons of phosphogypsum is estimated to produce annually worldwide. There is 11 number of phosphoric acid manufacturing units located in 7 states namely Andhra Pradesh, Gujarat, Kerala, Maharashtra, Orissa, Tamil Nadu, and West Bengal. The phosphogypsum generation in India is about 11 million tons per annum [1].

The phosphogypsum used in this study was collected from Vaikash Exim, Tuticorin, Tamil Nadu. It's a grey coloured, fine-grained material and its chemical composition as provided by the manufacturer is as follows.

Table 3. Composition of Phosphogypsum

Sl.no.	Composition	Percentage
1	Moisture	10 -15
2	CaO	32.8
3	SO_3	45.8
4	Total phosphate as P_2O_5	0.30
5	Water soluble phosphate as P_2O_5	0.08
6	Flouride	0.46
7	Water of Hydration	19.50
8	MgO	0.10
9	Na_20	0.10
10	K_2O	0.04
11	Fe_2O_3	0.01
12	Al_2O_3	0.0
13	SiO_2	1.20
14	Cl	0.004
15	Organic matter	0.15

2.4 Methodologies

The soil which was collected from the site was subjected to cleaning, air drying, and pulverization and then it was sieved through designated sieves as per the requirement of the test. The three different trial percentages of phosphogypsum i.e., 3%, 6%, and 9% were selected. Each of this percentage of phosphogypsum was mixed with the soil and the tests were carried out as per the Bureau of Indian Standards. The compaction test was conducted according to the Bureau of Indian Standards for the combination of Soil + Phosphogypsum and Soil + Lime + Phosphogypsum. The optimum phosphogypsum content was determined by conducting unconfined compressive strength on three different percentages of phosphogypsum like 3%, 6% and 9% and the phosphogypsum content which gives the maximum UCC strength is selected as the optimum phosphogypsum content. The optimum phosphogypsum content in enhancing the maximum UCC strength obtained was 6 % [4].

Similarly, the optimum lime content was determined by conducting unconfined compressive strength test on three different percentages of lime like 3%, 6%, and 9% and 3% of lime is obtained as optimum lime content in imparting the maximum UCC strength. The expansive soil was mixed with each of these 3 different percentages of phosphogypsum by dry weight of the soil and the specimens for UCC test were prepared according to the maximum dry density and optimum moisture content obtained in the compaction test. The specimens were casted in a steel mold of 38mm diameter and 76mm of height [6].

The samples which were prepared were kept for immediate testing, 7 and 14 days of curing in airtight sealed polythene bags in order to prevent the loss of moisture. The specimens kept for curing were subjected to unconfined compressive strength test at their specific curing days. The specimens were made by using the combination of optimum lime content stabilized soil i.e., 3%lime admixed soil to each percentage of phosphogypsum like 3%, 6%, and 9%. The specimens were prepared according to their maximum dry density and optimum moisture content obtained in the compaction test. The specimens prepared were kept for immediate testing, 7 and 14 days of curing. The samples which were kept for curing were tested at their specified curing days. The UCC test was conducted at the strain rate of 1.25mm/minute. To determine the performance of the additives, the results of the unconfined compressive strength tests of lime stabilized soil admixed with phosphogypsum is compared with the soil stabilized with the phosphogypsum alone.

3 Results and Discussion

The results of the unconfined compressive strength test conducted for the specimens at their different curing periods and phosphogypsum content were discussed in this section. The effect of phosphogypsum and the combination of lime and phosphogypsum on the unconfined compressive strength of the soil is as shown in the figure1 and figure 2 respectively.

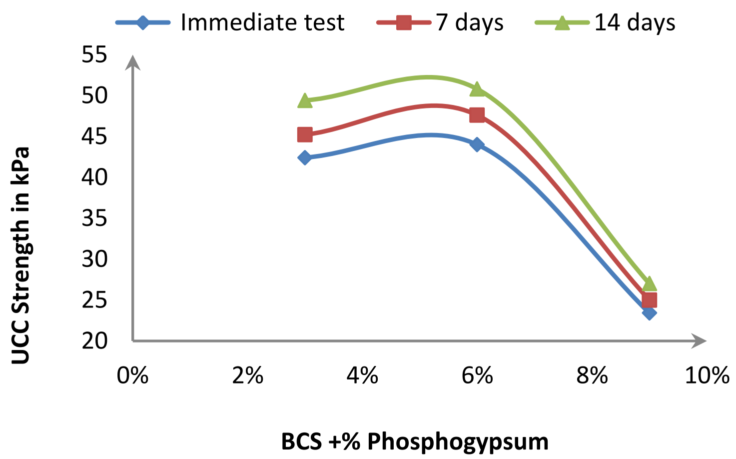

Fig. 1. Variation of UCS of soil with different percentages of phosphogypsum

Figure 1 shows the variation of UCC strength of soil stabilized with different percentages of phosphogypsum. From the test we can observe that the addition of phosphogypsum increases the strength up to 6%, thereafter which there is a reduction in the strength of the soil. The UCC strength of the soil to be stabilized is 20.6 kPa. The strength increases from 20.6 kPa to 49.4 kPa for 3% of phosphogypsum and for 6% of phosphogypsum it increases from 49.4 kPa to 50.8 kPa, thereafter which the UCC strength decreases to 27 kPa for 9% of Phosphogypsum for 14 days of curing. The similar trend of change in the strength is observed for 7 days and immediate testing.

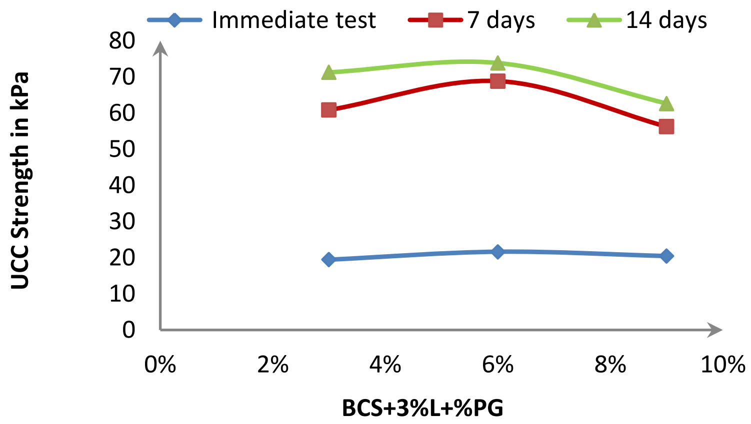

Fig. 2. Variation of UCS of 3% lime stabilized soil with 3 different percentage of phosphogypsum.

Similarly, from the figure2, it can be seen that the maximum unconfined compressive strength is obtained for the combination of 3% lime stabilized black cotton soil with 6% of phosphogypsum and is of the magnitude 21.6 kPa,68.8 kPa and 73.8kPa respectively for immediate testing, 7days and 14 days of curing. However, the strength achieved is more in the case of lime stabilized soil with phosphogypsum when compared to the soil stabilized with the phosphogypsum alone at their optimum content. The magnitude of UCC strength achieved in the former case is 73.8 kPa and in the latter case 50.8kPa respectively at 14 days of curing.

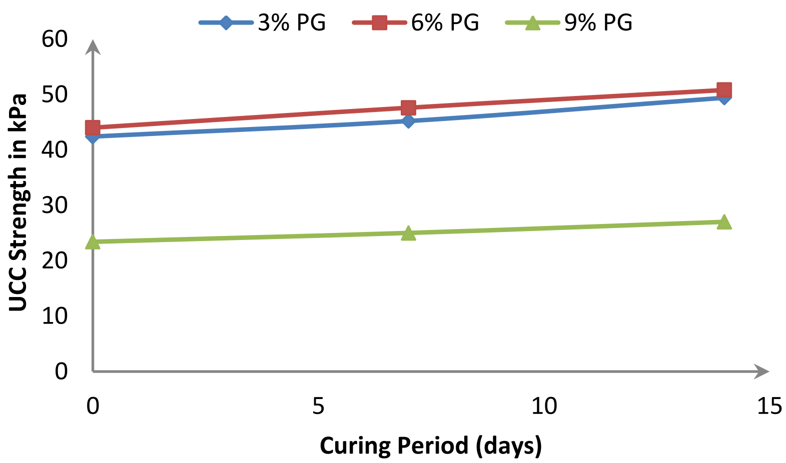

Fig. 3. Variation of UCC strength of phosphogypsum amended soil with the increase in curing periods.

Figure 3 shows the variation of UCC strength of the phosphogypsum amended soil with different curing periods. The strength increases from 20.6 kPa to 44 kPa on immediate testing, from 44 kPa to 47.6 kPa for 0 to 7 days of curing and from 47.6 kPa to 50.8 kPa for 7 to 14 days of curing for 6% of phosphogypsum content. The increase in strength is almost similar for the soil stabilized with 3% of phosphogypsum when compared with the soil stabilized with 6% of phosphogypsum with the increase in curing period. However, the increase in the strength of the soil is observed with the increase in curing periods irrespective of the phosphogypsum content with the increase in curing period.

Figure 4 shows the variation of UCC strength of 3% lime stabilized soil amended with different percentages of phosphogypsum with the increase in curing periods. The graph shows a similar trend of increase in the strength of the soil as that of the phosphogypsum stabilized soil. The strength increases from 20.6 to 21.6 on immediate testing, from 21.6 to 68.8 for 0 to 7 days of curing and from 68.8 to 73.8 for 7 to 14 days of curing respectively for optimum lime content stabilized soil amended with 6% of phosphogypsum.

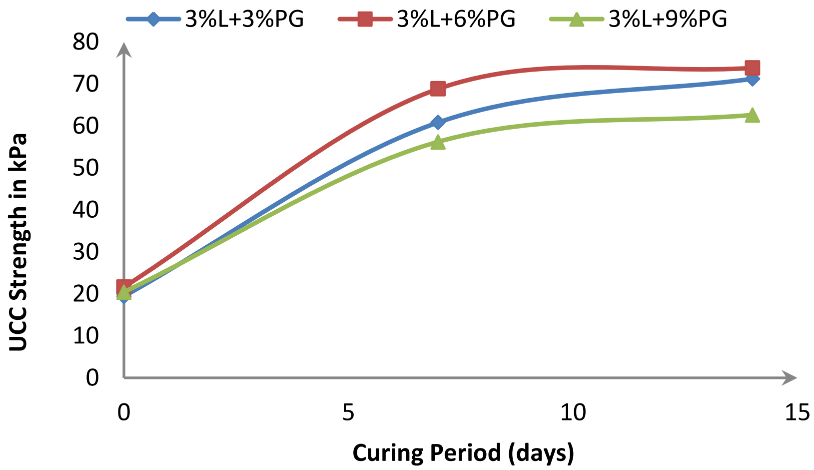

Fig. 4. Variation of UCC strength of 3% lime stabilized soil admixed with different % of phosphogypsum with the increase in the curing period.

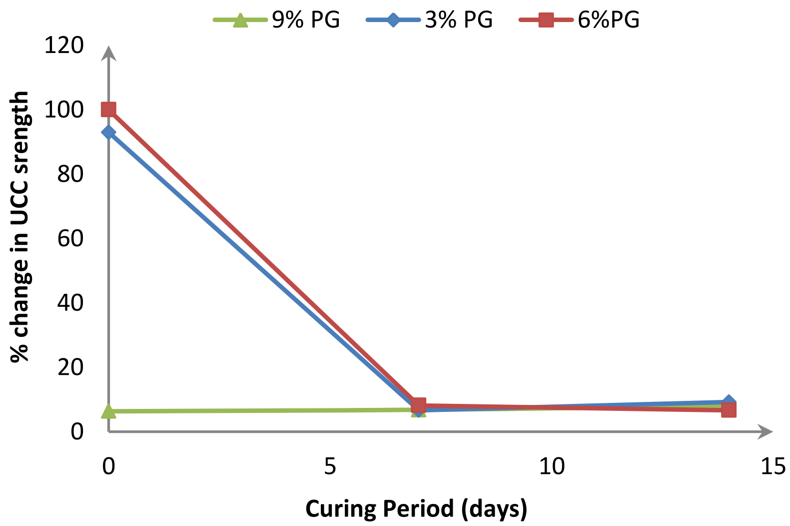

Fig. 5. Variation in the % change in UCC strength with the increase in the curing period for the phosphogypsum amended soil.

Figure 5 and 6 shows the variation of % change in the UCC strength for phosphogypsum amended soil and the lime stabilized soil admixed with phosphogypsum with the increase in curing periods respectively. The percentage increase in the strength for immediate testing for phosphogypsum admixed soil is more. Whereas, the percentage increase in strength decreases with the increase in curing period. The UCC strength is increased by 100% on immediate testing, after which, the % increase in strength decreases to 8% and 6% respectively for 7 days and 14 days of curing for 6% of Phosphogypsum content which is optimum in imparting maximum strength. The similar trend of % change in strength is observed for 3% of phosphogypsum content. However, the % increase in strength remains relatively constant that is almost remain 7% for 9% of phosphogypsum content with the increase in curing period.

From the figure 6, it can be seen that the % change in strength increases from 0 to 7 days of curing by 225% for both 3% and 6% of phosphogypsum admixed lime stabilized soil whereas the % increase in UCC strength decreases to 7% and 17% from 7 to 14 days of curing period for 3% and 6% Phosphogypsum admixed lime stabilized soil. The similar trend of % change in strength is observed for 9% of phosphogypsum admixed lime stabilized soil. The % increase strength is more for initial curing period and hence from this, we can conclude that phosphogypsum is responsible for the early strength gain of the soil.

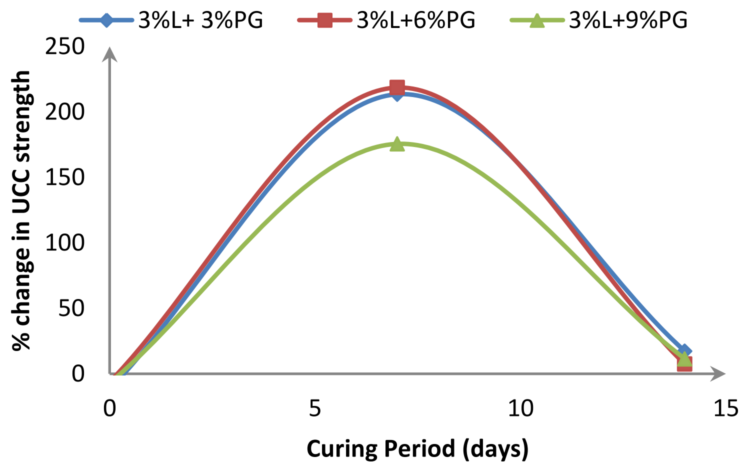

Fig. 6. Variation in the % change in UCC strength with the increase in the curing period for the phosphogypsum admixed lime stabilized soil.

3.1 Mechanism of Increase in the Strength of Phosphogypsum Admixed Soil and Lime Stabilized Soil with Phosphogypsum

The earlier strength development in phosphogypsum stabilized soil can be attributed to the increase in the supply of calcium ions by phosphogypsum and hence the accelerated pozzolanic reactions occur [3]. Formation of ettringite may also be the one of the reasons for the early strength gain by the phosphogypsum amended soil. High pH environment is found to be favorable for the formation of ettringite and in this case that is enabled by the presence of lime. Phosphogypsum is consumed by forming ettringite with the increase in the curing period. The formations of ettringite fill up the pores, which is in turn responsible for the increase in the strength of the soil. However if once, the phosphogypsum content goes beyond the optimum content may result in large cluster formation of ettringite and that may lead to the decrease in the strength of the soil.

4 Conclusions

The study here centered towards understanding and comparing the effect of phosphogypsum on black cotton soil with the effect of phosphogypsum on the lime stabilized black cotton soil. From the test results, the following points can be concluded.

- The addition of phosphogypsum to the lime stabilized soil resulted in high early strength gain when compared to the early strength gain of Phosphogypsum admixed soil.
- The strength achieved by the soil at optimum content of Phosphogypsum and lime amended soil is more when compared to the strength achieved by optimum content of Phosphogypsum amended soil.
- The strength of both lime stabilized soil with Phosphogypsum and the Phosphogypsum stabilized soil increases with the increase in the curing period. However, the percentage increase in strength is more in the former case than the latter one respectively.
- Phosphogypsum is one of the industrial waste materials that can be utilized effectively in construction of pavement rather than dumping.

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