Experimental Study on the Impact of Type of Sulphate in Lime Stabilised Clays

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ABSTRACT

Marine clays are distinguished by high compressibility and low shear strength. It has been reported that lime stabilisation is very much potent, and can be used as an ideal ground improvement technique in the case of marine clays. Cochin marine clays are sometimes abundant in primary and secondary sources of sulphates of sodium, lithium, potassium and calcium. Different types of sulphates may have different impact on lime stabilised clays. Present study investigates the effect of different types of sulphates in lime treated marine clays. Marine clay samples were collected by auger boring and all the physical properties were determined. Sulphate content in clay was also found. Clay samples were treated with 6% of lime and 4% of sodium sulphate, lithium sulphate and potassium sulphate and were kept for various curing periods of zero days, 1 week, 1 month, 3 months and 6 months. Atterberg limits, free swell index, unconfined compressive strength and pH of all samples were determined. It was found that the plasticity and swelling characteristics of lime treated clay were influenced by the addition of sulphates. It was also found that all the three types of sulphates had detrimental effect on the gain in strength of lime stabilised soil. But the effect varies significantly with the type of sulphate present in the clay. This necessitates the importance of determination of the type sulphate present in the marine clay, before planning the soil stabilisation using lime.

Keywords: Cochin marine clay, lime stabilisation, sulphates, Atterberg limits, unconfined compressive strength

1 INTRODUCTION

Marine clays found in the low land and coastal region of Kerala have poor shear strength and high compressibility. Construction activities in such soil without any stabilisation technique would result in failure of the structure. Therefore, it is essential to understand the problems associated with these soils in the early stages of project planning. Soil stabilisation with different additives is one of the methods for improvement of problematic soil. Addition of lime is found to be an effective method for improving the geotechnical properties of weak clayey soils.

Kochi a metro city and the business capital of Kerala has more than 247 industries. Marine clays found in this region are sometimes enriched with the presence of primary and secondary sources of sulphates. It has been established that the use of industrial wastes like colliery spoil for pavement or other construction works may be contaminated with sodium and magnesium sulphates (Obika et.al., 1990). Sodium sulphate (thenardite, $NaSO_4.10H_2O$), potassium sulphate (arcanite, K_2SO_4), calcium sulphate (gypsum or selenite, $CaSO_4.2H_2O$) and magnesium sulphate (epsomite, $MgSO.7H_2O$) are commonly present in the surface sediments, especially in the

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limited rainfall areas (Grim, 1968; Wild et al., 1999). Different types of sulphates such as Na_2SO_4, Li_2SO_4, K_2SO_4, $CaSO_4$ and $MgSO_4$ may be present in soil and these may have different impact on lime stabilized clays. Some of these sulphates may produce drastic effect, while the others may only produce negligible effects. Therefore, it is essential to understand the impact of various sulphates at the early stages of lime stabilisation process. This will increase the efficiency of chemical stabilisation.

Only limited studies were conducted on lime stabilized sulphate bearing marine clays. Also, no comparative studies were made between effects of different sulphates in lime stabilised Cochin marine clays. Hence the present study, aims to compare the effect of different types of sulphates in lime treated marine clays. Before the application of lime stabilisation technique, it is necessary to understand the nature of sulphates present in the soils, soil–lime-sulphate reactions, mechanisms involved in ettringite formation and its related problems.

1.1 Soil-lime-sulphate reactions

Lime is the most effective stabilising agent for marine clays, Jose et al, (1987). The main three stages of lime-soil reaction are cation exchange, flocculation and aggregation (time and temperature dependent). When sulfate-rich soils are treated with calcium based lime and cement stabilisers for soil improvements, the sulfates in soils react with the calcium of stabilisers and alumina of clayey soils to form a crystalline mineral, ettringite. This mineral, upon hydration, undergoes a large amount of heave in the soils. In presence of sulphate these soils react with lime produce calcium silicate trisulphate hydrate(ettringite) and calcium-silicate-hydroxide-sulphate-carbonate-hydrated material (thaumasite). Ettringite form fibrous crystals and damages the soil structure through mineral expansion during its precipitation. (Sherwood, 1962; Mehta and Klein,1966; Mitchell, 1986; Hunter, 1988). These sulphate minerals expand considerably when subjected to hydration process. Both hydration reactions and crystal growth will result in a significant amount of heaving in the sulfate-rich soils**.** Sulphate-containing clay soils cause swelling with the application of lime. It causes a reduction in long term strength.

Threshold level of sulphate is a key parameter used in evaluating the impact of different problems associated with lime treatment**.** According to study conducted by Ferris et al. (1991), the quantity of ettringite formation depends on the sulphate content in soil. The greater the soluble sulphates, the greater the potential for the growth of ettringite. Petry (1989) suggests that sulfate levels of 2,000 mg/kg (0.2%) have the potential to cause swelling in lime stabilized materials and levels of 10,000 mg/kg (1.0%) have the potential to cause serious damage to lime-stabilized materials. Based on experiments conducted on 11 samples of marine clay from different regions of the Country, the maximum sulphate content was reported as 4.10% (Rajasekaran et al.,1999).

2 Materials and Methods used for Experimental Investigations

2.1 Materials used

Sample of marine clay for present study was collected from Kadavanthra, Kochi, State of Kerala, India. The sample was taken from a depth of 7 to 8 meters by auger boring. The samples were mixed well to obtain a homogeneous mass and were kept in polyethylene bags, sealed and stored without loss of moisture. The physical properties of soil sample were determined and are presented in Table1. Particle size analysis was done and soil is classified as CH. The particle size distribution curve is shown in Fig.1

Table 1: Basic properties of Cochin Marine clay

Sl.No:	Physical properties	Value
1	Natural moisture content (%)	84
2	Specific gravity	2.6
3	Liquid limit (%)	127
4	Plastic Limit (%)	57
5	Shrinkage Limit (%)	16
6	Plasticity Index (%)	70
7	Free Swell Index (cc/g)	4.2
8	Grain size distribution Clay size (%) (<0.002mm) Silt size (%) (>0.002mm <0.075mm) Sand size (%) (>0.075mm <4.75mm)	 50 35 15
13	Soil Classification	CH
14	Unconfined Compressive Strength at NMC (kN/m^2)	7.22
15	pH value	7.3
16	Sulphate (by precipitation method) (%)	0.18
	Sulphate (by volumetric method) (%)	0.16

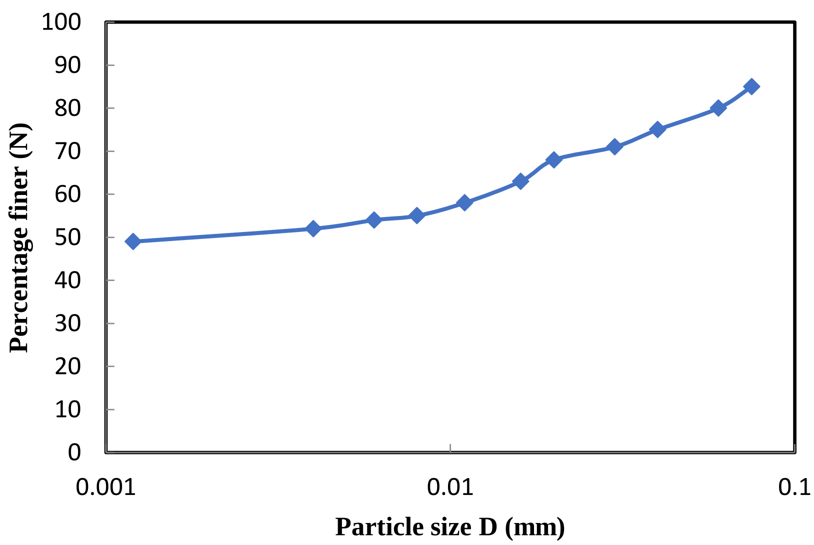

Fig 1: Particle size distribution of Cochin Marine clay

Lime used for the test was prepared by hydrating quick lime into powder form and sieving through 425 micron IS Sieve. The optimum lime was determined using Eades and Grim test (ASTM D 6276). Samples were prepared by adding 0%, 1%, 2% etc upto 8% lime to marine clay and pH values were found for all the samples. The optimum lime was found to be 6% corresponding to a pH value of 12.4 (Fig 2). Sulphates selected for the present study are Sodium sulphate (Na_2SO_4), Lithium sulphate (Li_2SO_4) and Potassium sulphate (K_2SO_4), which are the common naturally occurring sources of sulphates. These sulphates were selected based on their relative positions in the activity series and solubility chart. Effects of various sulphates on lime stabilised clay were studied by adding these sulphates at a rate of 4% by dry weight of the clay.

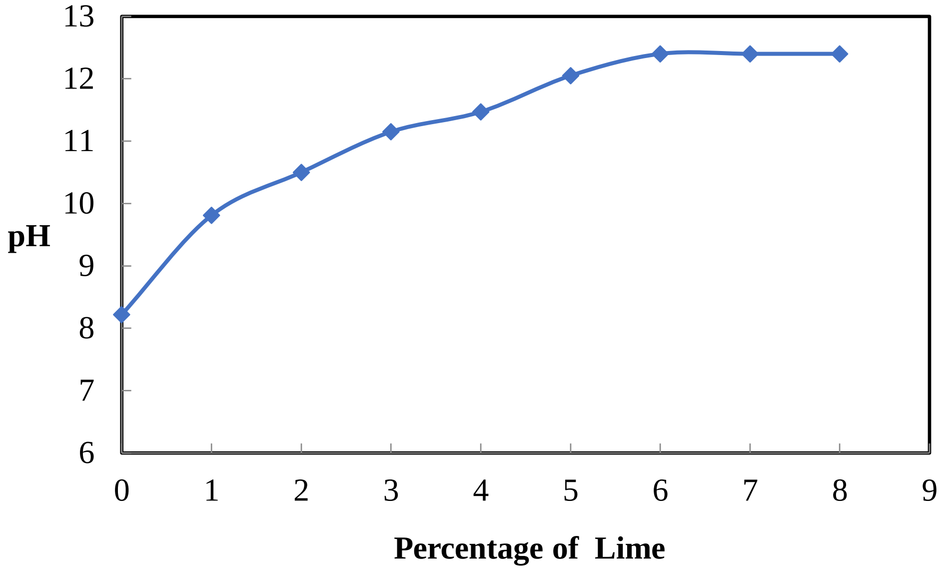

Fig 2: Determination of optimum percentage of lime

2.2 SAMPLE PREPARATION AND TEST METHODS

Soil samples were prepared by adding 6% lime and 4% of sulphates and were cured for curing periods such as zero days, 1week, 1month, 3months and 6months. Sample details are shown in table 2.

Table 2: Sample details

Sl No	Type and Percentage of additive	Sample Name
1	**Lime -6%**	**Clay+ Lime**
2	**Lime-6%, Na_2SO_4-4%**	**Clay+ Lime +Na_2SO_4**
3	**Lime -6%, Li_2SO_4- 4%**	**Clay+ Lime +Li_2SO_4**
4	**Lime -6%, K_2SO_4 – 4%**	**Clay+ Lime +K_2SO_4**

2.2.1 Sulphate content determination

Soluble sulphates present in water is measured in parts per million (ppm) and often expressed either in ppm or percent. 10,000ppm is equivalent to 1.0%. The sulphate content of clay sample was determined by precipitation method and volumetric method (Pillai et al.,2011). The precipitation method depends upon preparing an aqueous extract of the soil and the precipitation of sulphate as barium sulphate. Volumetric method depends upon the formation of insoluble barium sulphate. In both methods sulphate content is expressed in percentage by mass. The sulphate content obtained by precipitation method was 0.18% (1800ppm) and by volumetric method was 0.16% (1600ppm) as given in Table 1.

2.2.2 Atterberg limits test

The liquid limit and plastic limit of lime treated clays were determined as per IS 2720 (Part 5) for fine grained soils. Liquid limit was determined using Casagrande apparatus and plastic limit was determined using thread rolling method. Since the Atterberg limits of marine clays changes with drying, tests for liquid limit and plastic limit were done on the moist soil itself. The shrinkage limits were obtained as per the IS: 2720 (Part 6).

2.2.3 Free swell index test

Sridharan et al. (1985) pointed out that determination of free swell index as per IS 2720 (Part 40) gave a negative value for soils containing kaolinite. This is because kaolnite occupies a higher sediment volume in kerosene than in water. Hence the method proposed by Sridharan et al. was used for the determination of free swell index, in this study. For this purpose, a moist sample of equivalent dry weight of 10g (both treated and untreated clay) was taken in a 100 ml graduated cylinder containing about 40 ml of distilled water. The suspensions were stirred repeatedly and then made up to 100 ml mark with addition of distilled water and was thoroughly mixed with a glass rod. The soil was allowed to settle. The sediment volume per unit weight of dry soil is expressed as free swell index in cc/g. Accordingly, Free swell index $=V_d/10$ cc/g
Where, V_d is the volume of 10 g of soil specimen read from the 100 ml graduated cylinder containing distilled water. As per this equation free swell index is defined as the volume occupied by a unit weight of soil in water without any external constraint.

2.2.4 Unconfined compression test

Unconfined compression tests were carried out as per IS 2720 Part 10. Lime treated samples were prepared by adding lime content of 6% by dry weight of clay. About 4% sulphate (Na_2SO_4, Li_2SO_4 and K_2SO_4) as percentage of dry weight of soil were added to clay and thoroughly mixed. UCC test samples of size 38mm dia and 76 mm height were prepared and sealed in polyethylene bags and cured under humid conditions. Unconfined compression tests were then conducted on the cured samples.

3 RESULTS AND DISCUSSIONS

The results obtained by conducting various experimental investigations on Cochin marine clay are given below.

3.1 Clay treated with lime and different types of Sulphates

3.1.1 Atterberg limits

Plasticity characteristics primarily depend on the water holding capacity of the soil and are measured through index properties such as liquid limit, plastic limit, and plasticity index. Cation exchange is an important reaction and mainly responsible for the changes occurring in the plasticity characteristics of soil. Na+ and other cations adsorbed to the clay mineral surfaces are exchanged with Ca ++ ions. The presence of sulphates in lime treated soil influences both coagulation and cementation reactions which affect the plasticity characteristics of the soil.

3.1.2 Liquid Limit

Changes in liquid limit values of lime stabilised marine clay with different sulphates are shown in Fig. 3.
Initial value of liquid limit was 127%. Results show that the liquid limit increases immediately with addition of lime. This may be due to the formation of cementitious compounds and increased water holding capacity. The penetration of cations into the soil system neutralises the negative charge of clay particles and change the flocculated structure of soil to dispersed structure. This phenomenon causes the decrease in rate of water flow and an increase in liquid limit of clay. With increase in curing period, liquid limit shows a decreasing trend. This is due to when hydrated lime is added to clay drying occurs through the chemical reactions like flocculation, change in pH, cation exchange reactions and carbonation which affects the Atterberg limits. For lime treated

clay with different sulphates liquid limit increases immediately after the addition of sulphates. After a particular curing period the liquid limit was found to decrease.

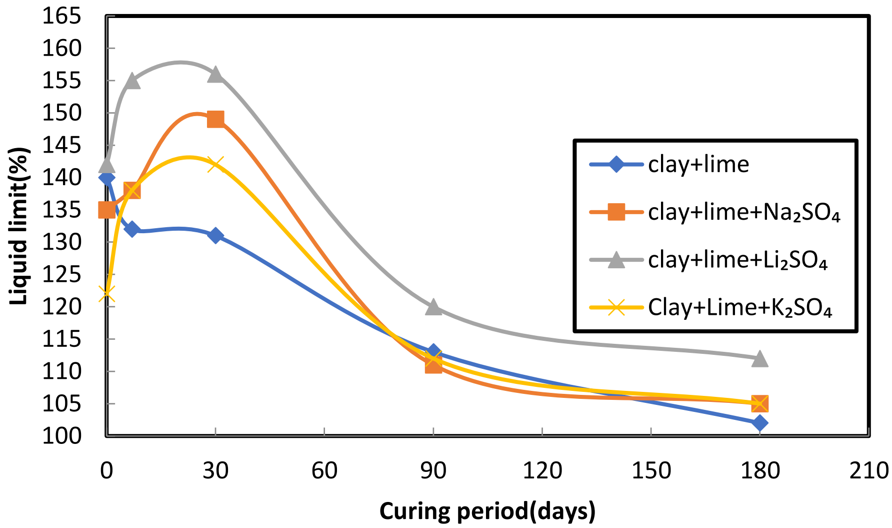

Fig 3: Effect of different type of sulphates on the Liquid limit of lime stabilised marine clay

3.1.3 Plastic limit

Initial value of plastic limit for untreated clay was 57%. Plastic limit value of soil-lime system and soil-lime-sulphate system decreases immediately with the addition of additives. When curing period increases, plastic limit value decreases slightly as shown in Fig. 4. The decrease in plastic limit value may be due to the aggregation and cementation of particles into larger size clusters.

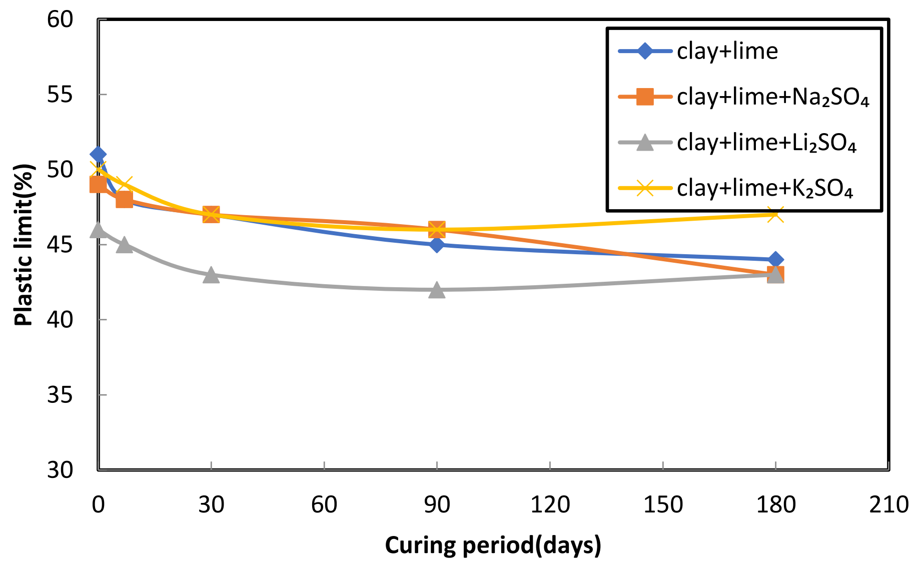

Fig 4: Effect of different type of sulphates on the Plastic limit of lime stabilised marine clay

3.1.4 Shrinkage limit

The shrinkage limit value for the clay at its natural state was 16%. Shrinkage limit of clay samples added with lime is shown in fig.5.Treatment with lime increases the shrinkage limit value immediately. This is on account

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of the decrease in double layer thickness and increase in attractive forces at the inter particle level. Presence of sulphates also yields higher value immediately. Also, from the figure we can infer that, on curing, the shrinkage limit values continuously decreases. This may be due to further reduction in shear strength and increased concentration of deleterious compounds formed.

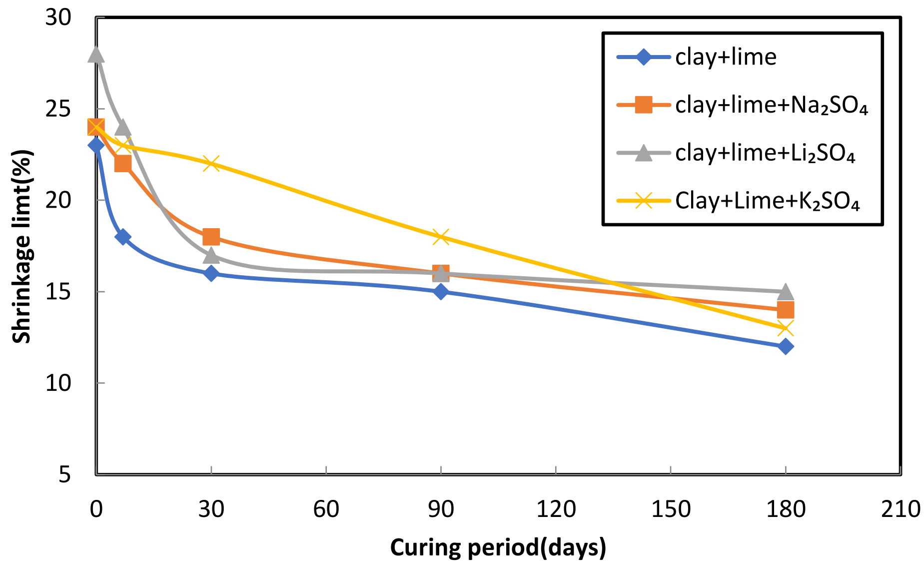

Fig 5: Effect of different type of sulphates on the Shrinkage limit of lime stabilised marine clay

3.2 Plasticity Index

Plasticity index of original marine clay sample was 70%. Variation of plasticity index of lime treated soil with the addition of different sulphates is shown in Fig. 6.

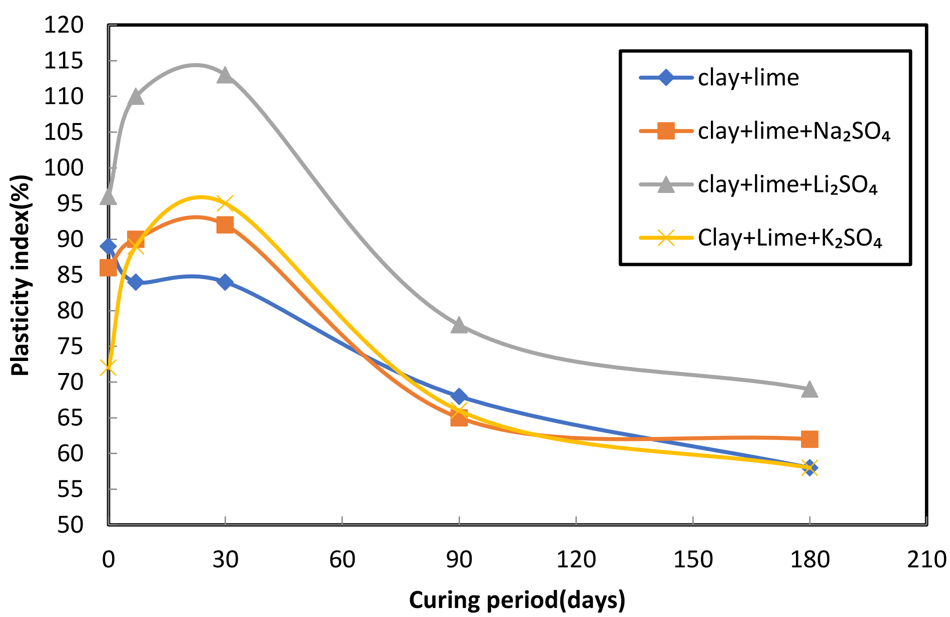

Fig 6: Effect of different type of sulphates on the Plasticity index of lime stabilised marine clay

Treatment of soil with lime reduces plasticity index and workability of soil increases as the cement reacts with the clay surface. The reaction is mineralogy dependent, but almost all plastic soils show a plasticity index reduction and workability increases. Plasticity index of lime treated soil in presence of sulphates increases immediately and the value decreases with curing.

3.3 Free Swell Index

Results show that free swell index of lime stabilised clay decreases with increase in curing period as shown in Fig. 7. This is due to the formation of cementitious compounds. For clay treated with lime and different sulphates, free swell index increases first and then decreases with increase in curing period. Again, after a particular curing period free swell index value increases. The increase in free swell value after a particular curing period may be due to the formation of expansive mineral ettringite and the sulphate induced heave.

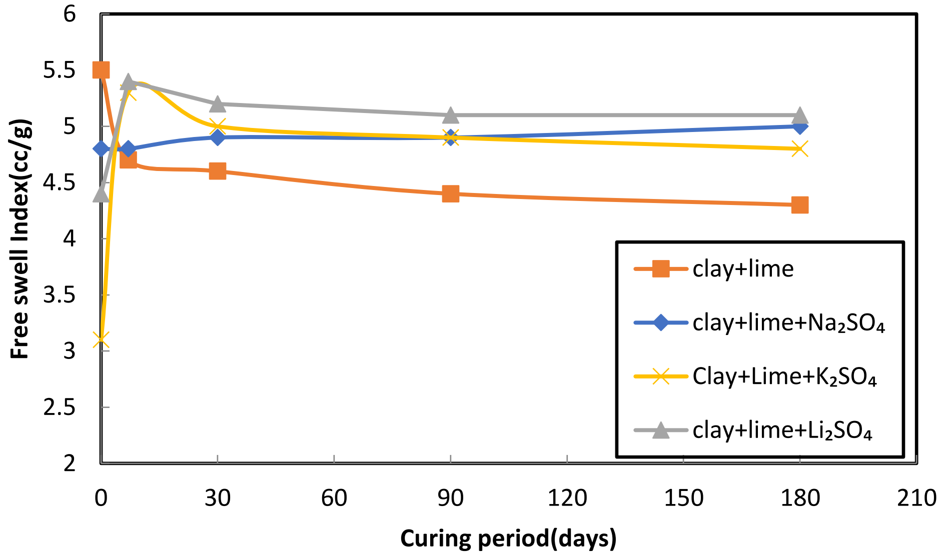

Fig 7: Effect of different type of sulphates on the Free swell index of lime stabilised marine clay

3.4 Unconfined compressive strength

The comparative strength gain of lime stabilized clay with and without different sulphates is shown in figure.8. For lime treated clay, strength shows an increasing trend with increase in curing period. The increase in strength is mainly due to the cement hydration that leads to the formation of pozzolanic products. After a curing period of 90 days, strength was found to decrease. This is due presence of sulphates which were already present in marine clay.

For lime treated clay containing sodium sulphate, lithium sulphate and potassium sulphate, the strength increases upto a particular curing period and after that it decreases. Decrease in strength of sulphates of sodium, lithium and potassium may be due to the swelling of the complex mineral ettringite or due to the obstruction caused by the sulphate in pozzolanic reaction. Among the sulphates, lithium sulphate causes a strength reduction after a curing period of one week and more adversely affects the strength of sol-lime-sulphate system.

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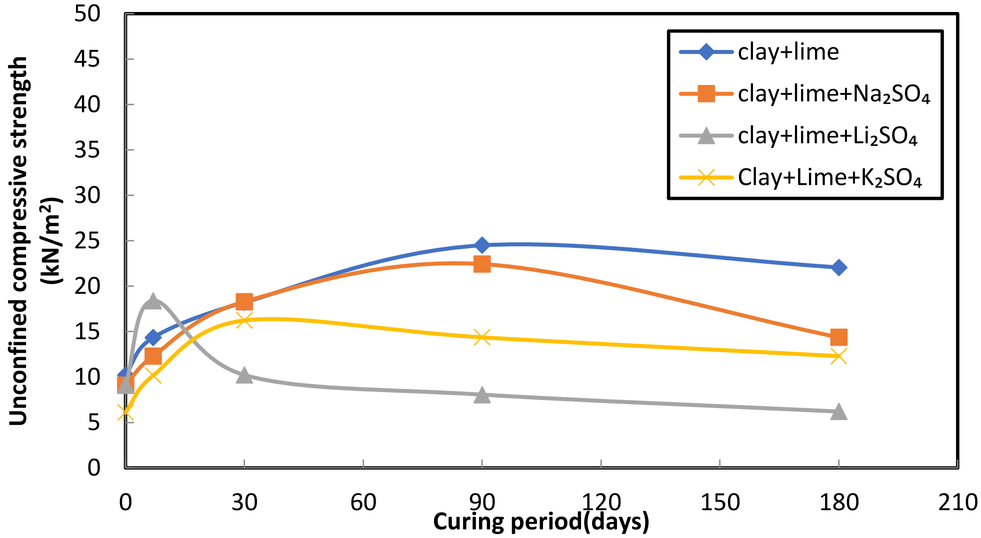

Fig 8: Effect of different type of sulphates on the UCS of lime stabilised marine clay

4 CONCLUSIONS

Based on the detailed study conducted on samples of Cochin marine clay, the following conclusions are arrived:

- Liquid limit of sulphate bearing clays increases immediately after the addition of lime and the decreases with increase in curing period.
- Plastic limit value of soil-lime system and soil-lime-sulphate system decreases immediately after the addition of lime and sulphates and with increase in curing period plastic limit decreases slightly.
- Plasticity index of lime treated soil in presence of sulphates increases immediately and the value decreases with curing.
- For clay treated with lime and different sulphates, free swell index increases first and then decreases with increase in curing period.
- Strength gain of lime treated marine clay shows that the natural sulphate content of 0.18% has only marginal effect.
- Among the sulphates, sodium sulphate and lithium sulphate have more detrimental effect on the strength attainment of lime stabilized soil by obstructing the pozzolanic reaction compared to potassium sulphate.

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