Undrained Strength Characteristics of Fibre Reinforced Expansive Soils

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ABSTRACT

Expansive soils are those whose volume changes take place while it comes in contact with water. It expands during rainy season due to intake of water and shrinks during summer season. Expansive soils owe their characteristics due to the presence of swelling clay minerals. Expansive soils cover nearly 20% of landmass in India and include almost the entire Deccan plateau, western Madhya Pradesh, parts of Gujarat, Uttar Pradesh, Andhra Pradesh, Karnataka and Maharashtra. The properties that describe the expansive behaviour of soils are free swell index, swell potential and swell pressure. This behaviour has an impounding effect on the bearing capacity and strength of foundation lying on such a soil. Some of the stabilization techniques which are currently being used are physical alternations, sand cushioning, belled piers, under reamed piers, granular pile anchors, chemical stabilization, and fibre reinforcement techniques. This paper focuses on improvement in the strength characteristics of stabilized Chittur soil. The commonly used stabilizer for expansive soils is lime. This paper looks upon alternative materials such as fly ash and polypropylene fibres in order to reduce the lime content. It was concluded from the trials that an optimum combination of 1.5% lime, 10% fly ash and 0.2% polypropylene fibres contribute to a 200% increase in the unconfined compressive strength of the Chittur soil.

Keywords: Expansive soils, fibre reinforcement

1 Introduction

Expansive soils are clayey soils that have the tendency to swell when the moisture content is increased or shrink when their moisture content is decreased and they owe their characteristics due to the presence of swelling clay minerals. Expansive soil covers many areas in the world and it covers nearly 20% of land mass in India and includes almost the entire Deccan plateau, Western Madhya Pradesh, parts of Gujarat, Utter Pradesh, Andhra Pradesh, Karnataka and Maharashtra. Expansive soils are problematic because they have poor engineering properties and hence, they cause damages to civil engineering infrastructures. The process of stabilization is applied to make the deficient expansive soil useful. Main properties of expansive soil are swelling properties like free swell index, swell potential and swelling pressure which directly affect the bearing capacity and strength of foundation lying on such a soil. Swelling soil contain high percentage of swelling clay particles that are capable of absorbing large quantities of water. Soil volume may expand 10 percent or more as the clay becomes wet.

Damages caused by expansive soil includes cracked foundation, masonry walls floors and ceilings, uneven floors, doors and windows getting jammed, heaving and cracking of sidewalks and roads, broken pipes and water line etc. Hence expansive soil stabilization and study of its swell consolidation characteristics have significant role in the present context.

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2 Literature Review

A study was conducted by Sindhu et al (2010) on stabilization of black cotton soil using fly ash. The paper dealt with the techniques to stabilize the black cotton soil for the construction of road using fly ash. The addition of fly ash showed a decrease in liquid limit, plastic limit and plasticity index and improved the CBR value of soil. There is also 70% and 53% reduction in swell index and swell pressure respectively when 30% fly ash is added and it was recognized as the optimum content of fly ash required.

Kumar et al (2007) conducted an experimental program named Influence of fly ash, lime and polyester fibres on compaction and strength properties of expansive soil to study the effects of polyester fibre inclusions and lime stabilization on the geotechnical characteristics of fly ash soil mixtures. Lime and fly ash contents varied from 1 to 10% and 1 to 20% respectively. Test specimens were subjected to compaction tests, unconfined compressive strength tests and split tensile strength tests. Optimum values of lime and fly ash content may be taken as 8 and 15% respectively.

Pasupalak and Sinha (2017) used polyester fibres with triangular cross section to improve the characteristics of expansive soil collected from Odisha, India. Soil was collected at a depth of 2m from the ground level. One dimensional swell consolidation test was conducted using oedometer to study swell characteristics. The fibre length varied by 3, 6, 9 and 12 mm and the fibre content varied from 0.05 to 0.2%. It was observed that minimum heave and swell pressure decreased with increasing fibre content for a given length of fibre. The cause for this decrement in swelling properties was due to the interlocking and interfacial friction with hydrophobic nature of polyester fibres and the optimum content depended on homogeneity of mix and aggregation of fibres.

Dang and Khabbaz (2007) conducted a study on the compaction and compressible properties of expansive soil reinforced with bagasse fibre and lime. The compaction test revealed that dry density decreased with increase in fibre content. However, the pre consolidation pressure increased with fibre contents only up to 1%.

Expansive soils stabilized with fly ash were another such study conducted by Zha et al (2008). In this study, the potential use and the effectiveness of expansive soils stabilization using fly ash and fly ash-lime as admixtures are evaluated. Expansive soils were sampled at a depth of about 2-3m in Hefei city, China. Fly ash contents were varied by 0%, 3%, 6%, 9%, 12% and 15% and lime contents by 0%, 1%, 2% and 3%. The test results showed that the plasticity index, free swell, swell potential and swelling pressure decreased with an increase in fly ash or fly ash-lime content.

Similarly, Mir (2015) discussed fly ash and lime as effective means to provide an economic and powerful method of soil strength improvement. Black cotton soil collected from Karnataka state of India was used for the investigation.

3 Scope of the study

The black cotton soils are identified in alluvial plains, terraces and undulating plains of Chittur taluk in Palakkad district in patches. The elevation of the area ranges from 100 to 300m above MSL with gentle to moderate slope. These soils are developed on Khondalite suite of rocks traversed by lenticular bands of crystalline limestone and calc-granulites. These soils are very deep, black and calcareous. The texture of the soil ranges from clay loam to clay. They possess high shrink-swell capacity and hence exhibit the characteristic cracking during dry periods. A variety of crops such as cotton, coconut, sugarcane, chilly, pulses and vegetables are grown here.

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This project focuses on the strength characteristics of lime and fly ash treated expansive soil. Polypropylene fibre is used as reinforcement for the increased tensile strength of the soil. The tests are conducted on expansive soil from Chittur. Chittur is a green town in Palakkad district of Kerala. Unconfined compression tests were conducted on different combinations of lime ash, fly ash and polypropylene fibre to study the stabilization effects. Further, the effect of curing was also investigated. A site visit was initially done and information which was useful for this project was collected. The soils of the region exhibits shrink swell behavior with fluctuating water table. . The depth of clayey soil in Chittur is about 14m. This soil has a free swell index of 78%.

4 Materials for study

4.1 Soil

The properties of the soil are determined by standard test procedures and are tabulated in table 1. Fig 1and 2 shows the results of UCS test and swell potential of natural soil.

Table 1: Index properties of soil

Liquid limit	51%
Plastic limit	22%
Plasticity index	29%
Free swell index	78%
Shrinkage limit	14%
Specific gravity	2.27
Field density	1.74g/cm^3
Natural moisture content	24%
Soil Contents	Gravel Content – 8.99% Silt Content- 13.32% Clay Content- 77.69%
Compaction	OMC- 21.74% Maximum Dry Density- 1.64g/cm^3
Unconfined compressive strength	0.164 Kg/cm^2

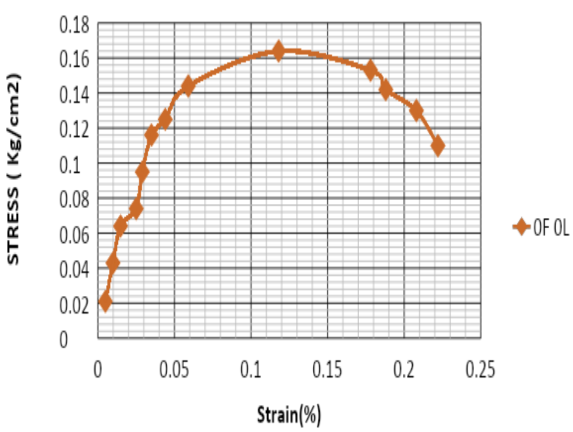


Fig 1. UCS on natural soil

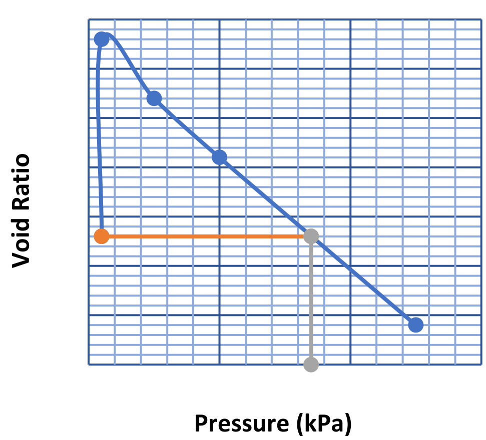


Fig 2. Swell potential of natural soil

4.2 Reinforcement

For this study polypropylene fibre having 20mm is used. They are mixed uniformly in the soil at varying percentages (0.25%, 0.5% and 0.75%) by dry weight of soil.

4.3 Lime and flyash

Lime (Ca $[OH]_2$) and flyash are the addictives used in this study for stabilizing and improving the properties of black cotton soil in addition to fibre. Lime-Soil stabilization is the process of adding lime to the soil to improve its properties like density, bearing capacity etc. When clayey soil is treated with lime, cation exchange takes place between them which increases plastic limit and reduces plasticity index, reduces the moisture holding capacity, swell reduction which finally results in increased stability of soil. Fly ash is a fine powder which is a byproduct from burning pulverized coal in electric generation power plants. fly ash particles generally consist of hollow spheres of silicon, aluminum, and iron oxides and unoxidized carbon all of which make both classes of fly ash, pozzolans-siliceous or siliceous and aluminous materials. It was observed that the fly ash reduced the liquid limit and plasticity index, and enhanced the California bearing ratio (CBR) and unconfined compressive strength of soils.

5 Results and Discussion

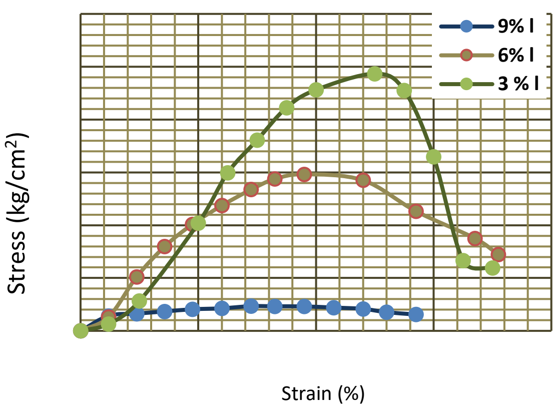
Tests are carried out in accordance with the standard procedure to study the effect of lime fibre and flyash on black cotton soil and how much the properties have improved.

5.1 Unconfined Compressive Strength (UCS) Test

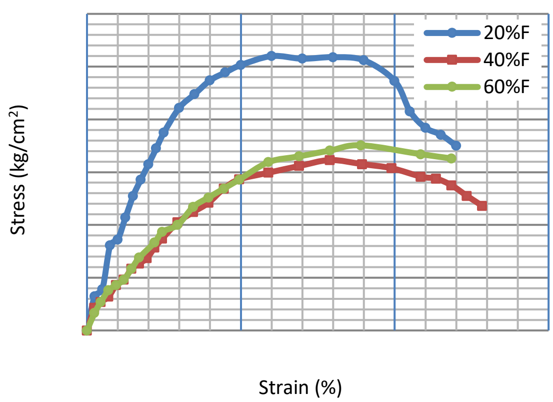
5.1.1 UCS on Lime-Flyash Soil

Here using lime flyash and fibre as addictive to enhance the stability of the soil. Chosen percentages of lime and fly ash were 3%, 6%& 9% and 20% 40% &60% respectively. After natural soil, UCS tests were conducted on soil samples with combinations of lime and flyash. Initially 0% flyash and varying percentages of lime (0%F&3%L, 0%F&6%L, 0%F&9%L*)* were tested. The graph so obtained is shown in the fig 3a and corresponding water content on table 2. The highest value of UCS is obtained for 0%F&6%L, which has value of 1.679Kg/cm². For 0%F&3%L UCS value obtained is 1.465 Kg/cm². Here lime content is almost reduced to half (from 6% to 3%), but the final result has small reduction. So, 0%F&3%L is more effective than 0%F&6%L. The least UCS value in this set is found for 0%F&9%L (0.233Kg/cm²). Next set of UCS tests were conducted on 0%lime and varying percentages of flyash (0%L&20%F, 0%L%&40%F, 0%&60%F). Stress strain graphs obtained is shown in the fig 3b. The highest UCS value is obtained for 0%L&20%F, which is 0.52Kg/cm². The second maximum for 0%L&60%F (0.35Kg/cm²) and least for 0%L&60%F (0.32Kg/cm²).It is found that, even though there is small changes, UCS values for this set are more or less similar. Then 20% flyash and varying percentages of lime (20%F&3%L, 20%F&6%L, 20%F&9%L) specimens were tested. Result showing that maximum UCS for this set is for 20%F&9%L (0.433Kg/cm²), then for 20%F&6% L(0.246Kg/cm²) and least for 20%F&3%L(0.202Kg/cm²). Fig 3c shows the test results. Next combination is 40%flyash and varying percentages of lime (40%F&3%L, 40%F&6%L, 40%F&9%L). In this set of experiment highest UCS value is obtained for 40%F&3%L(0.31Kg/cm²) then comes 40%F&9%L(0.244Kg/cm²) and finally 40%F&6%L(0.234Kg/cm²). The stress-strain curve is shown in fig 3d. Next set of combination is 60% flyash and varying percentages of lime (60%F&3%L, 60%F&6%L, 60%F&9%L). Test results were shown in fig 3e. The combination giving highest UCS value is 60%F&3&L(0.68Kg/cm²). For 60%F%&9%L has the second highest value (0.62Kg/cm²) and then comes 60%F&6%L(0.48Kg/cm²).

By analyzing UCS results of all the above set of samples, the one with 0%F&6%L has the highest value of UCS. But 0%F&3%L is more economical as there is only a little reduction in strength compared to 0%F&6%L. So, 0%F&3%L combination is observed a most effective one. But it is important to check whether lower percentages of lime and flyash combinations can give more beneficial results. So a lime content of 1.5% (which is half of 3%lime) is selected. In the case of flyash we have used a range of 20%-40% earlier. In fact, that flyash content were little bit huge and it has no significant effect on strength of soil. So, this time we have used flyash percentages below 20% (i.e., 5%, 10% &15%). Then UCS tests were carried out on these new set of combinations of lime and flyash (1.5%L&0%F, 1.5%L&5%F, 1.5%L&10%F, 1.5%L&15%F). UCS results of these 4 combinations are provided in fig 3f. A combination of 1.5%L&0%F gives a UCS value of 0.663Kg/cm², which almost half the strength of 3%L&0%F. But it is observed that there is an improvement in unconfined compressive strength as the flyash content increased to 5%. That is, 1.5%L&5%F giving a UCS of 0.799Kg/cm².UCS value is again improved to 1.215Kg/cm² for a combination of 1.5L&10%F, which is almost similar to UCS of 3%L&0%F combination (1.465Kg/cm²).Further increase in flyash resulting to a reduced unconfined compressive strength. That is, a combination of 1.5%L&15%F giving a UCS of 0.948Kg/cm². So, the optimum combination of lime and flyash is selected as 1.5%L&10%F. This optimum combination is comparatively economical and eco-friendly too, as the content of lime, which a relatively costlier material, used is very small percentage and also incorporated an industrial waste material like flyash.

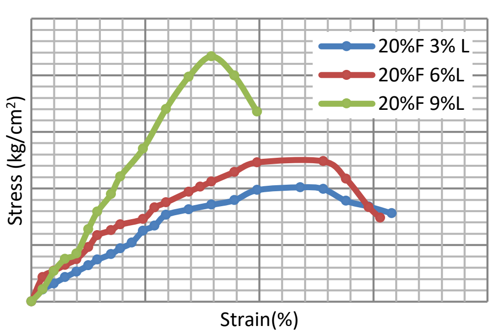


(a) Varying percentages of lime

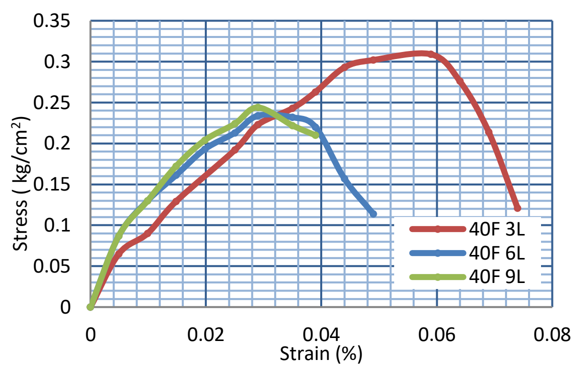


(a)

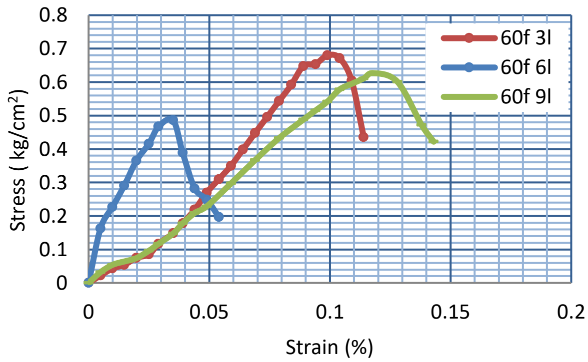
(b) Varying percentages of flyash



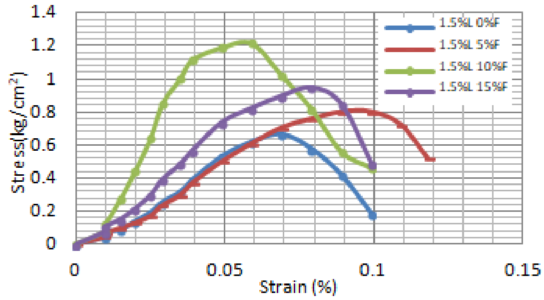
(c) 20% flyash and varying percentages of lime



(d) 40% flyash and varying percentages of lime



(e) 60% flyash and varying percentages of lime



(f) 1.5% lime and varying percentages of flyash

Fig.3 UCS test results on lime-flyash treated soil

Table 2: Water contents of lime- flyash treated UCS samples

Lime content (%)	Flyash content (%)	Water content (%)	UCS(Kg/cm²)
3	0	23.42	1.465
6	0	25.4	1.679
9	0	28.51	0.233
0	20	25.51	0.52
0	40	26.35	0.323
0	60	23.1	0.35
3	20	27.2	0.202
6	20	26.54	0.246
9	20	23.02	0.433
3	40	26.17	0.31
6	40	25.17	0.234
9	40	25.02	0.244
3	60	25.76	0.68
6	60	23.2	0.48
9	60	25.5	0.62
1.5	0	27.8	0.663
1.5	5	27.9	0.799
1.5	10	25.13	1.215
1.5	15	25.27	0.948

5.1.2 UCS on Fibre Reinforced Soil

Further improvement in strength is achieved by reinforcing the optimum sample by fibres. Fibres can be used to improve the properties in which the soil is poor, such as tensile capacity, shear strength, density, hydraulic conductivity etc. Time being we have used polypropylene fibre having a length of 20mm for this study. The selected percentages of fibres were 0.25%, 0.5%& 0.75%. So totally 3 specimens were made, with each having a proportion of 1.5%L, 10%F&0.25%fibre, 1.5%L,10%F&0.5%fibre and 1.5%L,10%F&0.75%fibre. The specimens were made at wet of optimum and allowed to cure for a period of one day, in a water bath. After one day UCS tests were done on these samples and stress-strain curves were plotted. Fig 4 and table 3 shows the results obtained. Results indicating that, incorporation of fibres have improved the overall UCS value of all the three specimens. The least strength obtained is 0.165Kg/cm², for 10%F&0.25%fibre, which is even higher than the unconfined compressive strength of optimum lime flyash combination-1.5%L&10%F (1.215Kg/cm²). The highest UCS value is observed for 1.5%L, 10%F&0.5%fibre (2.148Kg/cm²), which indicates a drastic increase in compressive strength. So, the optimum percentage of fibre is obtained as 0.5% and the final proportion of lime-fibre-flyash is fixed as 1.5%L, 10%F&0.5%fibre.

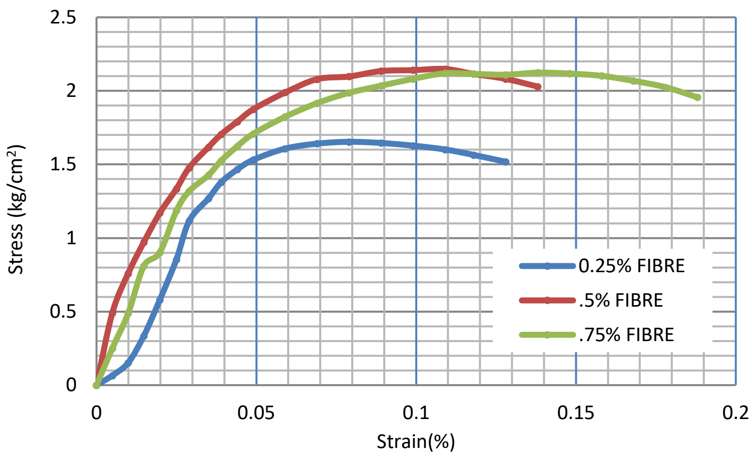


Fig.4 UCS: Stress strain curve for fibre treated soil

Table 3: Water contents for fibre treated specimens for UCS test

Fibre content (%)	0.25	0.5	0.75
Water content (%)	25.96	22.50	24.19
UCS Kg/cm²)	1.65	2.148	2.12

5.1.3 Effect of Curing on UCS Samples

For all the above UCS tests, we have used one day cured soil samples. But it is necessary to have a study, in order to understand the effect of curing period variations on unconfined compressive strength. So, we have selected 7 day and 14-day curing periods for this study and it is done on optimums of lime (1.5%L) and flyash (10%) and on their combination (1.5%L&10%F). Totally 6 number of samples were made, two number of 1.5% lime samples, two 10% flyash samples & two 1.5% lime and 10% flyash combination samples. These specimens were made on wet of optimum and they were preserved by means of wrapping with a cling film and kept in a water bath. After 7 days, one specimen from each combination, that is totally 3 samples (one 1.5% lime sample, one 10% flyash sample & one 1.5% lime and 10% flyash combination sample), were tested for UCS and on 14th day, the remaining 3 samples were also taken out from the water bath and were tested. The results so obtained are provided in fig 5, fig 6 & fig 7. From the test results of all the combinations, it is a common trend that 14th day UCS is much higher than 7th day UCS. In the case of 1.5%L specimens, 7th day strength was 0.894Kg/cm², which increased to 1.26Kg/cm² by 14 days of curing. Similarly, for 10%F samples, the increase was 0.88Kg/cm² to 1.057Kg/cm². The highest value of 7th day and 14th day UCS is obtained for the samples with a combination of 1.5%L&10%F (which was the optimum combination of lime-flyash from the earlier result) and here the increase is noted as 1.495Kg/cm² to 1.816Kg/cm² with the increase in curing period from 7 to 14 days.

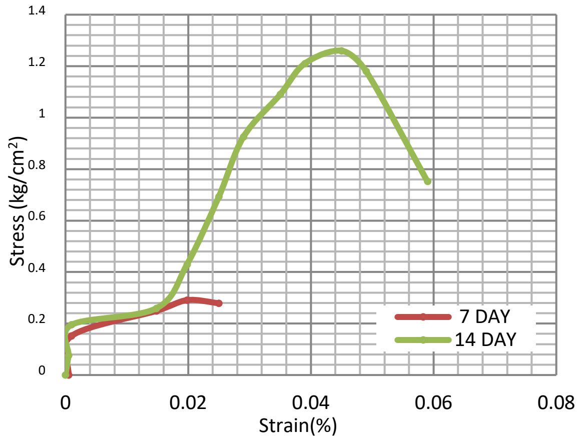


Fig.5 UCS: stress strain curve for soil specimen with 1.5% lime with varying curing period

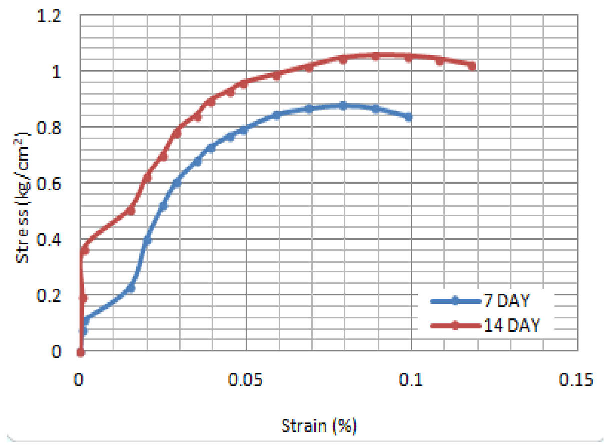


Fig.6 UCS: stress strain curve for soil specimen with 10% flyash with varying curing period

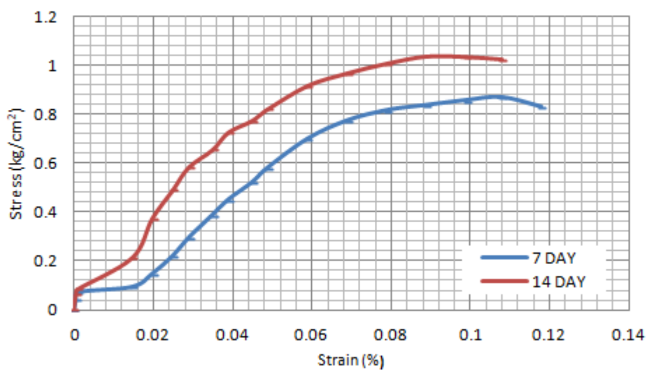


Fig.7 UCS: stress strain curve for soil specimen with 10% flyash and 1.5% lime with varying curing period

6 Conclusions

From the study, the following conclusions are drawn

1. All combinations of lime and flyash mixed soil gives UCS value greater than that of natural soil.
2. Among all 0%, 3%, 6%, 9% lime and 0% 20% 40% flyash combinations maximum UCS value is for 6% lime 0% flyash (1.6kg/cm^2) and 3% lime 0% flyash (1.4kg/cm^2).
3. Generally, it is found that UCS value increases with increase in flyash content to an extent.
4. Generally, in case of 20%, 40% & 60% flyash, a combination with 3% lime is giving better results.
5. Since there was a possibility of lower percentages of lime and lower percentages of flyash giving better results, UCS tests were carried out with 1.5% of lime and 5-15% of flyash mixed soil. Results showed that 1.5% lime alone gives a UCS value of 0.663 Kg/cm². Whereas 1.5% lime and 10% flyash gives a UCS value of 1.215Kg/cm².

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6. So, from the view of better unconfined compressive strength as well as less material usage 1.5% lime and 10% flyash mix is observed as optimum lime-flyash combination.
7. Soil mixed with 1.5% lime and 10% flyash is again strengthen by adding polypropylene fibre. It is observed that 0.5% fibre with optimum lime-flyash combination is giving a high unconfined compressive strength. UCS strength had increased from 1.215 Kg/cm^2 to 2.148 Kg/cm^2.
8. Curing period has influence on unconfined compressive strength of soil sample. Results indicate that 14-day curing is giving high UCS value compared to 7-day curing period. For soil specimen mixed with 10% flyash alone, UCS value increased from 0.88 Kg/cm^2 to 1.057 Kg/cm^2 as curing period increased from 7 day to 14 day. Similarly, it is 0.894 Kg/cm^2 to 1.26 Kg/cm^2 for soil specimens with 1.5% lime alone and it is 1.495 Kg/cm^2 to 1.816 Kg/cm^2 for specimen with optimum lime-flyash combination (1.5% lime and 10% flyash).

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References

Puppala A., Hoyos L., Viyanant C., Musenda C., (2013), Fiber and Fly Ash Stabilization Methods to Treat Expansive Soils, *American Society of Civil Engineering,* pp.136-146

Kumar A., Walia B. S., Baja A., (2007), Influence of Fly Ash, Lime, and Polyester Fibers on Compaction and Strength Properties of Expansive Soil, *American Society of Civil Engineering,* 10.1061/:0899-1561

Pasupalak S., Sinha A. K., (2017), Swell Characteristics of Soil Reinforced with Polyester Fibres, *Indian Geotechnical Conference, GeoNEst*

Zha F., Liu S., Du Y., Cui K., (2008), Behavior of expansive soils stabilized with fly ash, *Nat Hazards*, 47:509-523

Mir B.A., (2015), Some Studies on the effect of fly ash and lime on physical and mechanical properties of expansive clay, *International Journal of Civil Engineering,* Vol.13, pp. 203-212

Sindhu M. M., Shanmugavadivu P. M., Mukilan G. K., (2019), Stabilization of Black Cotton Soil using Fly Ash, *Indian Journal of Research*, Vol-8(issue-2), pp.45-46 9. Zha F., Liu S., Du Y., Cui K., (2008), Behavior of expansive soils stabilized with fly ash, *Nat Hazards*, 47:509-523

Dang L. C., Khabbaz H., (2007), Experimental Investigation on the Compaction and Compressible Properties of Expansive Soil Reinforced with Baggase Fibre and Lime, Springer *Nature Switzerland*, pp. 64-78