Effect of Lime and Cement Kiln Dust on Strength Characteristics of Expansive Soil

D. Ashwini[1] and H. N. Ramesh[2]
[1]*M.E. Student, Dept. of civil engineering, UVCE, Bengaluru, Karnataka, India*
[2]*Professor, Dept. of civil engineering, UVCE, Bengaluru, Karnataka, India*
E-mail: ashusujadhan@gmail.com

ABSTRACT: The research objective is to study the potential use of cement kiln dust to advance the engineering characteristics of black cotton soil (BCS) in India, which covers about 20% of the country's surface area. Cement kiln dust is an industrial waste that is difficult to dispose of and poses environmental risks, and the demand for cement is growing globally. The study aims to use laboratory tests to assess the impact of lime and cement kiln dust on the strength properties of BCS and to mitigate the excessive heave associated with the soil. The research methodology involves conducting Atterberg limit, free swell, compaction, and unconfined compression strength tests on BCS specimens treated with lime in incremental orders of 2% up to 10% of the dry weight of the soil sample. The optimum percentage of lime treated BCS sample treated with CKD in incremental order of 5% to 20% of dry mass of sample. 6% lime content was considered to be the optimum dosage with maximum UCS value for 7, 14 and 60 days and further on addition of CKD to lime treated BCS 6%lime + 15% CKD was found to be the optimum dosage with maximum UCS value for 7, 14 and 60 days.

KEYWORDS: CKD, Lime, Black cotton soil, and UCS.

1. INTRODUCTION

Expansive earth is type of soil that may be found in several Indian states and it's difficult to build with. Its properties include low shear strength, excessive swelling, shrinkage and compressibility. Many geotechnical investigators focused on making use of industrial waste by-products for soil stabilization so as to reduce environmental impacts resulting from their disposal. Some of such industrial by products which are successfully employed in soil stabilization practice includes fly ash, stone dust, biomass ash, cement kiln dust, sugar cane bagasse ash etc.

Investigation on the effect of CKD on BC soil to help overcome expansive heave associated with the soil (Iorliam *et al.,* 2012). use of cement kiln dust to enhance the durability of black cotton soil (BC soil) subgrade modified with quarry fines (Agapitus Ahamefule Amadi, 2014. Chemical stabilization of an expansive high plastic soil using cement kiln dust (CKD) and cement kiln dust with lime (L) to reduce their swelling and improve their geotechnical properties (Hesham A. H. Ismaiel *et al.,* 2013). A detailed chemical (X-ray diffraction), thermogravimetric and morphological (scanning electron microscope) analyses of both the CKD powders and the hydrated CKD pastes are presented (Sulapha Jan Olek *et al.,* 2008), black cotton soil treated with up to 16% Cement Kiln Dust (CKD) by dry weight of soil to assess its suitability for use as road pavement material (G. K. Moses, A. Saminu 2012). The change in pH of soil as a function of CKD content is related to the PI of the untreated soil, and good correlation between pH response and performance of CKD treated soil was observed (Gerald A. Miller, Shahriar Azad, 2000). The other fresh and the landfilled CKD (both with only traces of free lime) suggest that these materials may be used for treating wet subgrades or water-logged areas (Asha Sreekrishnavilasam *et al.,* 2007). The use of cement kiln dust (CKD) and fly ash (FA) to improve the unconfined compressive strength (UCS) of soft Bangkok clay compared with ordinary Portland cement (OPC), the UCS of the stabilized clay increased relative to the formation of the primary reaction product, calcium silicate hydrate (CSH), as analyzed using the XRD (Naphol Yoobanpot *et al.,* 2017). Effects of cement addition to expansive clay on its deformation characteristics and stress responses during swelling (Sopheap Por *et al.,* 2017). Improve the engineering properties of sedimentary soil using Portland cement for possible use in road construction (Thanakorn Chompoorat *et al.,* 2019). Multiscale laboratory investigation into the mechanical properties and microstructural characteristics of dredged sediments stabilized with Ordinary Portland cement (OPC) type I and fly ash (FA) (Naphol Yoobanpot *et al.,* 2020). Studies concerned with the suitability of natural ornamental limestone dust to reduce the swelling characteristics of high expansive soils and the swelling pressure and percent of heave are greatly decreased with increasing the inserted core diameters and mixing percentages of limestone dust (Waleed *et al.,* 2016). Swell-shrink behaviour of cement with fly ash-stabilised lakebed sediment (Thanakorn Chompoorat *et al.,* 2021), Solidification of sediments deposited in reservoirs with cement and fly ash for road construction (Thanakorn Chompoorat *et al.,* 2021) Combined treatment techniques have been adopted by many pavement designers and site engineers to improve the strength and stability of subgrades or foundation soils of expansive sites (Amadi A.A, Osu A.S 2016) Mechanical - microstructure properties and shrinkage characteristic of cement- and fly ash- treated soft Bangkok clay used for deep mixing (Thanakorn Chompoorat *et al.,* 2021), Multiscale laboratory investigation of the mechanical and microstructural properties of dredged sediments stabilized with cement and fly ash (Naphol Yoobanpot *et al.,* 2020), Repurposing of stabilised dredged lakebed sediment in road base construction (Thanakorn Chompoorat *et al.,* 2021), Mechanical and microstructural properties of dredged sediments treated with cement and fly ash for use as pavement materials (Pitthaya Jamsawang *et al.,* 2019). In this regard, research work has been carried out on the effect of lime and cement kiln dust on strength characteristics of expansive soil as no work has been done on strength characteristics of expansive soil with lime and CKD.

Therefore, in this research work CKD is used along with lime to advance geotechnical properties of Expansive Soil. This research study mainly aims at obtaining a reliable solution for improving geotechnical properties of expansive earth by stabilizing it with the addition of Lime and cement kiln dust in a manner so as to form an inert mass, which has excellent geotechnical properties and least side effect on the health of environment.

Also, by compacting stabilized soil to three important ratios of moisture content to dry unit weight, influence of moulding water content on the strength development process of stabilized soil is also studied.

2. MATERIALS AND METHODS

a) Expansive Earth (ES)
b) Cement Kiln Dust (CKD)
c) Lime (L)

The soil used for the study was found from a construction site in Hubli district, Karnataka state, India, and its index properties, chemical composition, and grain size distribution were analyzed and presented in Table 1 and Table 2 and Figure 1 denotes the Grain size analysis.

The fact that attempts are being made to manage cement kiln dust (CKD), which is produced during the manufacturing of Portland cement clinker, is positive. Since CKD frequently contains significant levels of lime, it might be a great choice for chemical stabilization of challenging soil, such as those with high clay contents, by enhancing their toughness and durability. The cement kiln dust utilized in study came from the Mycem cement plant in Ammchandra, Tumkur district, Karnataka, which is produced during the production of Portland cement. Tables 3 and 4 present the cement kiln dust's physical and chemical characteristics and it is noted that the dust contains abundant lime and silica content. The Lime used in existing investigation is taken from the Chemical store.

Table 1 Geotechnical properties of expansive soil

Sl. NO.	Index Properties		Value
1	Colour		Grey
2	Particle Size Distribution	Fine sand size (%)	14
		Silt size (%)	25
		Clay size (%)	61
3	Specific gravity of soil solids		2.78
4	Consistensy limits	Liquid limit (%)	75
		Plastic limit (%)	31
		Shrinkage limit (%)	10
	Plasticity Index (%)		44
5	IS Soil Classification		CH
6	Standard Compaction Test	Moisture level at Optimum Level (%)	28
		Maximum Dry Density (kN/m3)	14
7	Free Swell Index (%)		80

Table 2 Chemical composition of expansive earth used in the study

Chemical compound	Quantity (%)
Silica (SiO_2)	51.85
Alumina (Al_2O_3)	12.34
Iron oxide (Fe_2O_3)	8.05
Oxide of Calcium (CaO)	6.11
Oxide of Magnesium (MgO)	2.84
Oxide of Sodium (Na_2O)	0.26

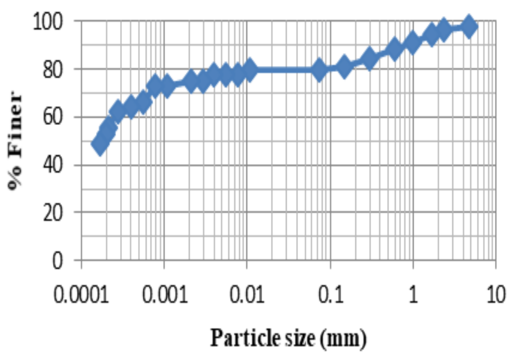


Figure 1 Particle size distributions curve of expansive earth

Table 3 Physical properties of cement kiln dust

Sl.No	Physical properties	Value
1	Colour	Grey
2	Specific Gravity of solids	3.1

Table 4 Chemical Composition of cement kiln dust

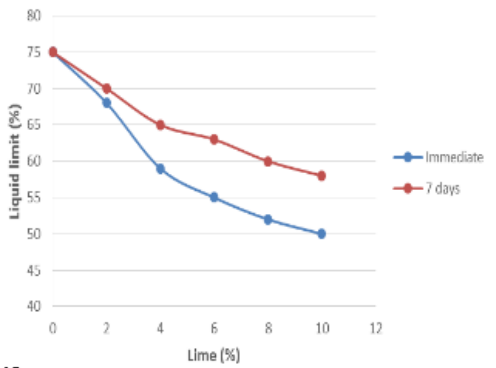
SL.No.	Chemical Compounds	Quantity (%)
1	Silica (SiO2)	14.94
2	Alumina (Al2O3)	4.07
3	Iron oxide (Fe2O3)	2.27
4	Oxide of Calcium (CaO)	53.89
5	Oxide of Magnesium (MgO)	1.84
6	Sulfur trioxide (SO3)	10.96
7	Oxide of Potassium (K2O)	3.62
8	Oxide of Sodium (Na2O)	2.78

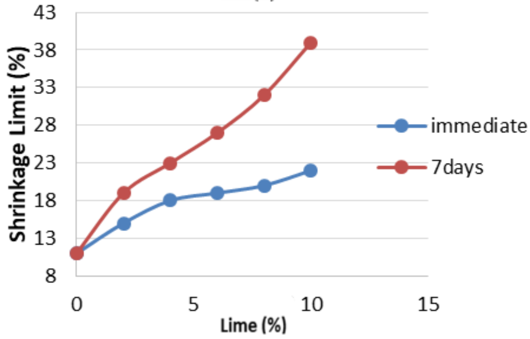
The test were conducted in accordance with guidelines set forth in relevant Indian Standard Codes, but A. Sridharan's mini compaction test equipment and procedure was used to measure the compaction characteristics.

3. RESULTS AND DISCUSSIONS

3.1 Consistency Limits of BC Earth Treated with Lime

The deviation of liquid limit with lime content for instantaneous and 7 days curing period is been represented graphically in Figure 2 as a decreasing curve, with the liquid limit gradually decreasing with increasing lime content. This trend is observed not only for the immediate mixtures but also for the 7-day cured samples, indicating that the effects of lime on the soil persist over time.





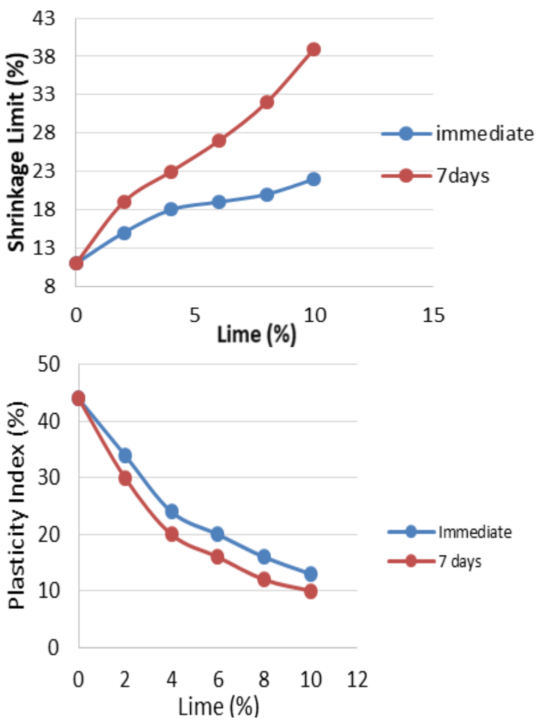


Figure 2 Deviation of liquid limit, shrinkage limit, plasticity index with lime content for immediate and 7 days curing

The presence of lime increases the silica content in the soil, leading to the formation of more CSH gel. This results in a higher gel water content and an increase in the liquid limit of the soil. The addition of lime also improves the gradation of the stabilized soil due to the pozzolanic reaction. This results in a reduction in the clay content and an increase in the shrinkage limit of the soil. The plasticity index of soil decreases gradually with an increase in the percentage of lime. This trend is observed even for 7 days of curing.

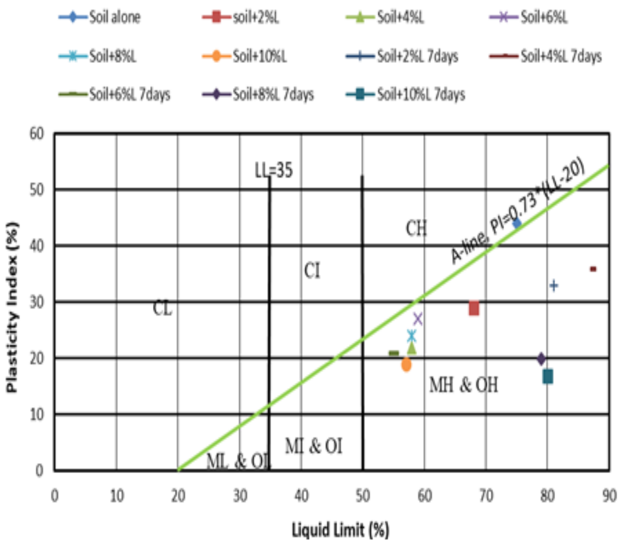


Figure 3 Classification of BC soil treated with lime for immediate and 7days curing

Classification of soil treated with lime for various curing times is shown in Figure 3. The soil is categorised as very compressible clay as per IS soil classification (CH). As soil is stabilised with lime, it goes from being classified as highly compressible clay (CH) to highly compressible silt (MH).

3.2 Effect of Lime on Compaction Characteristics of Expansive Earth

From this Figure 4, it can be inferred that maximum dry unit weight has decreased slightly with increase in percentage of Lime. The decrease in maximum dry unit weight is due to flocculation of particles. From the figure it is observed that optimum moistness content decreased up to 6% Lime content and then slightly increases with rise in percentage of lime.

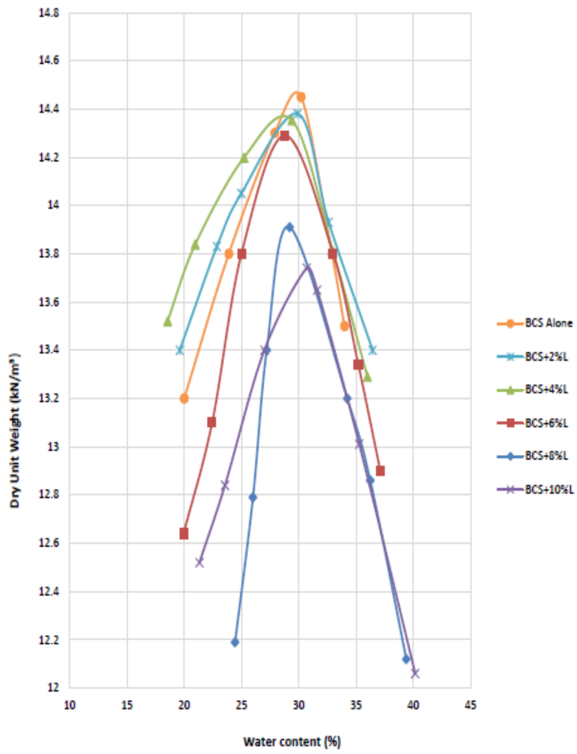


Figure 4 Water content-dry unit weight relation of BC soil for different percentage of lime

3.3 Effect of Cement Kiln Dust on Consistency Limits of Lime Treated Expansive Earth

Figure 5 shows the deviation in liquid limit and shrinkage limit of Soil-Lime mixture with Cement Kiln Dust content. It is interesting to note that the liquid limit increases for 7 days cured samples compared to uncured samples for a given percentage of Cement Kiln Dust content, indicating the conversion of Soil structure into flocculated with curing. This can be attributed to the hydration of lime and the reaction of Cement Kiln Dust with the soil, resulting in improved soil properties.

It is noted that the shrinkage limit rises as cement kiln dust content rises; however, it is interesting to note that for a given percentage of cement kiln dust content, there is no appreciable difference in shrinkage limit between uncured and 7-day cured specimens. Plasticity index of (BC Soil+6%L) mixture treated with addition of Cement Kiln Dust will decrease for both immediately tested samples and 7 days tested samples.

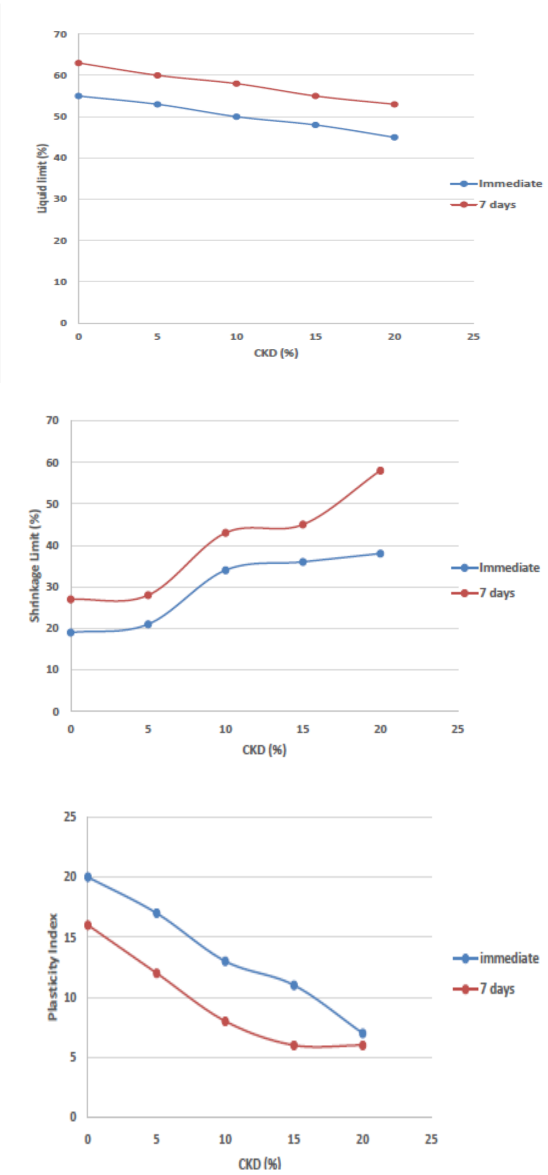


Figure 5 Variation in liquid limit, shrinkage limit, plasticity index of BC soil-lime mixture with immediate and 7 days curing for different percentage of cement kiln dust

3.4 Effect of CKD on Compaction Characteristics of Lime Treated Expansive Soil

Figure 6 shows water content-dry unit weight relationship for Soil-Lime mixture treated with Cement Kiln Dust. Optimum moistness content increased with addition of cement kiln dust to (Soil+6%L) mixture. Due to introduction of cement kiln dust due to pozzolanic reaction and flocculation of particles, it results in increasing optimum moisture content.

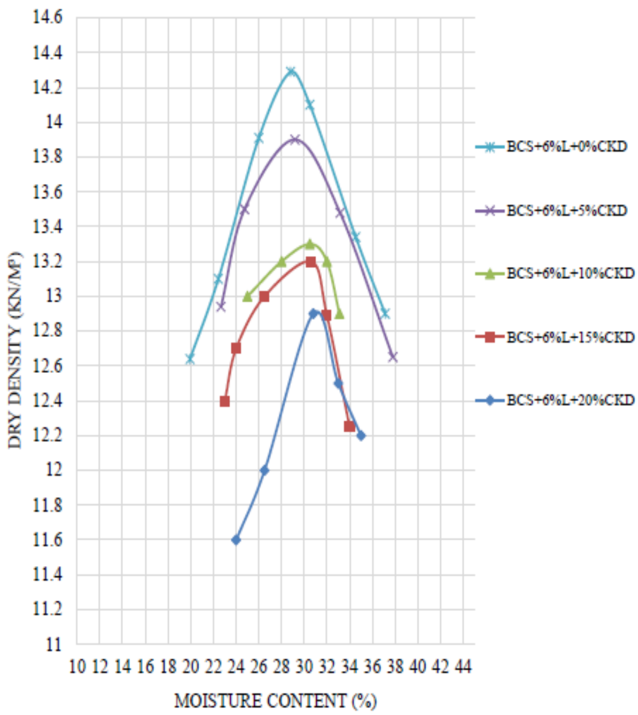


Figure 6 Water content-dry unit weight relationship for BC earth-lime mixture treated with cement kiln dust

3.5 Role of Moulding Water Content on Strength Properties of Lime Treated BCS and Lime Treated BCS in Existence of Cement Kiln Dust

The specimens are prepared for soil and treated soil for water content corresponding to dry of optimum, optimum and wet of optimum water content.

Unconfined compressive strength of soil alone tested immediately is 299kPa. Upon curing period of 7, 14 and 60 days the strength values do not change. By adding 6% of Lime (Optimum percentage) to the soil the strength increases from 299kPa to 489kPA and further curing has increased the strength significantly for all the moulding water content i.e., at DOO, optimum, WOO. The increase in strength of soil treated with an optimum percentage of Lime and Cement Kiln Dust (Soil + 6%L + 15% CKD) can be attributed to pozzolanic reactions that occur between the reactive silica in the soil and the free lime present in the lime and cement kiln dust. The increase in strength with increasing number of curing days for all the moulding water content (DOO, optimum, WOO), during the curing process, these reactive silica and free lime react chemically to form new cementitious compounds such as calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H). These compounds contribute to the development of strength in the treated soil by filling in the voids and forming a cohesive matrix.

In the case of soil treated with lime and kiln dust, it is observed that higher strength is achieved when the soil is relatively dry, i.e., on the dry side of optimum moisture content. This is because, on the dry side, the soil particles are relatively flocculated, i.e., they are held together in clusters. This helps to create a stronger bond between the particles and results in higher strength.

3.6 Stress – Strain Behaviour of BC Soil Alone and BC Soil Treated with Lime and Cement Kiln Dust

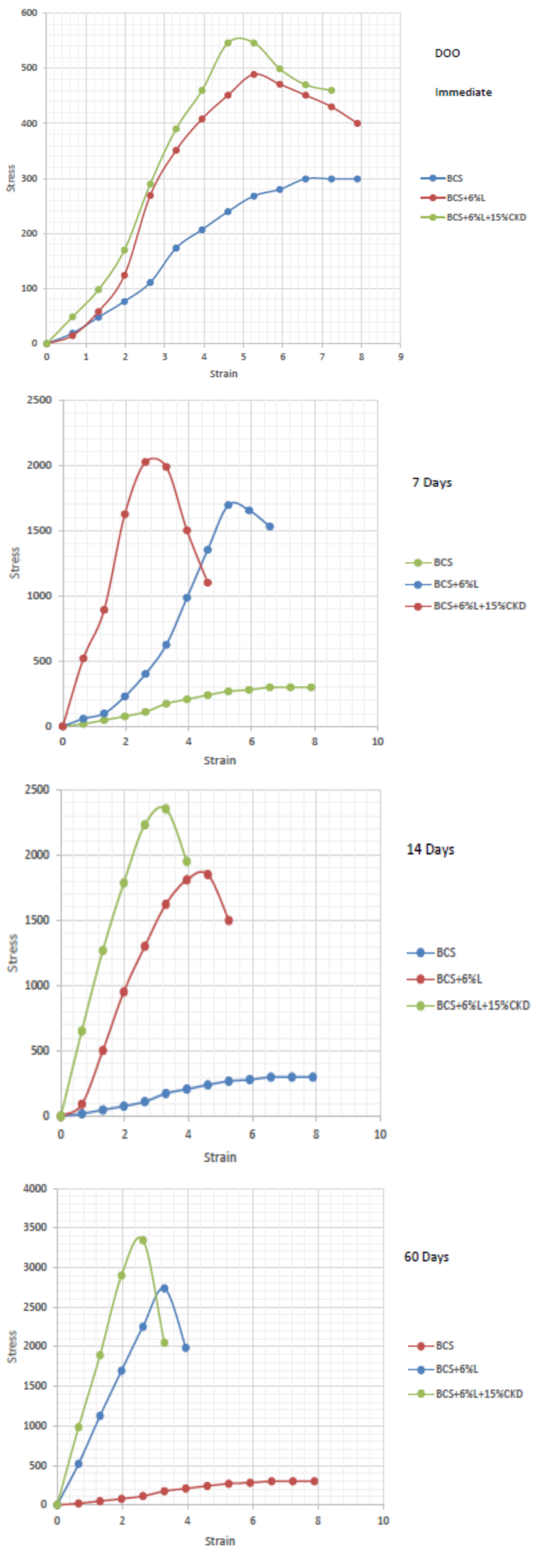


Figure 7 Stress-strain relationships of BC earth alone and BC earth treated with lime and cement kiln dust at Dry of optimum for different curing period

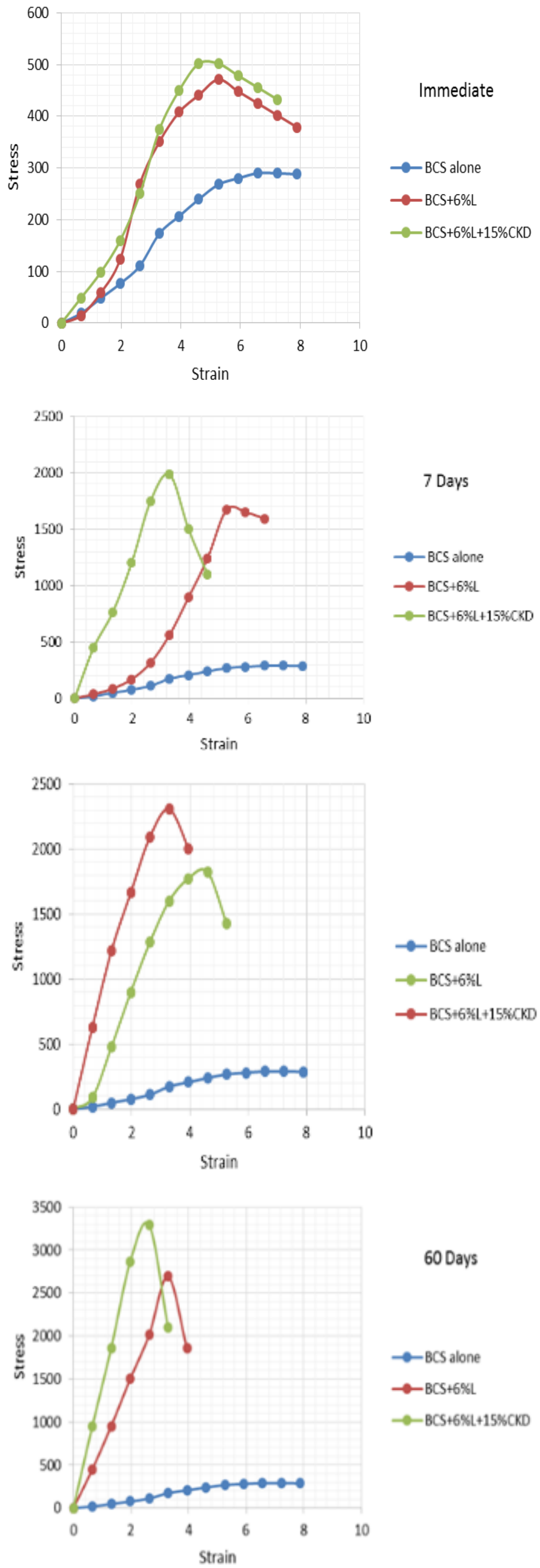


Figure 8 Stress-strain relationships of BC earth alone and BC earth treated with lime and cement kiln dust at optimum for different curing period

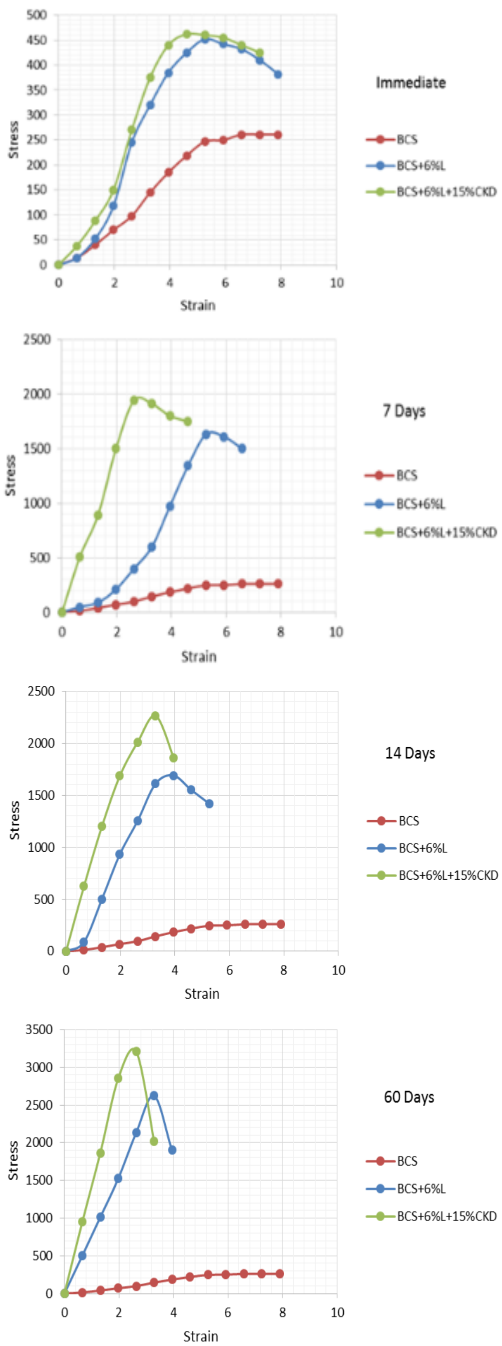


Figure 9 Stress-strain relationships of BC earth alone and BC earth treated with lime and cement kiln dust at wet of optimum for different curing period

Figures 7, 8 and 9 show the stress – strain characteristics of treated soil at dry of optimal, optimal and wet of optimal for different curing period. From Figures 7, 8 and 9 it can be concluded that as load is applied there is increase in strain up to 8 – 10% initially for soil alone and treated soil tested immediately. Thereafter by curing the treated specimen, the strain reduced up to 2-3 % with increase in stress. Pronounced peak can be observed in case of cured samples treated with cement kiln dust. There is no significant variation in stress – strain behavior of treated soil with that of the soil alone for immediate testing. Therefore, a higher load is required to deform the cured samples. However, as the particle are more flocculated on dry side of optimal and more dispersed on wet side of optimum, higher strength was seen in dry side of optimum (DSO) compared to optimal and wet side of optimum (WSO).

4. CONCLUSIONS

The compressive strength of the soft clay improved when it was stabilized with lime and CKD, where the CKD was added with optimum content of lime. The cementitious CKD led to a rapid increase in strength in the short-term curing period and tended to have a gradual increase in strength for the long term curing period. The CKD-only mixture can improve the strength of the soft clay, which has a similar development trend to that of the cement strength characteristic curve but is lower in compressive strength.

In this study, it was suggested to use 15% CKD and lime of 20% to lead to a greater strength of the stabilized clay at a curing of 60 days.

It's also interesting to note that the strength of the stabilized soil mixture is higher in the dry side of optimum condition compared to the optimal and wet side of optimum condition, as particles are relatively flocculated on the DSO and dispersed on the WSO. Overall, it seems like the use of lime and cement kiln dust as stabilizers can greatly enhance the properties of expansive soil, making it more suitable for construction purposes.

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