Experimental Investigation on stabilization of Expansive clays treated with Cement Kiln Dust

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Abstract

Expansive clays were widely occurring in India. It is characterized by its low strength and expansive nature, thereby posing a serious problem for the geotechnical engineers. In order to overcome this problem various stabilization methods were developed. Cement Kiln Dust (CKD) is a fine-grained waste product produced during the process of making cement. It has potential applications towards soil stabilization. Therefore, utilization of CKD in soil not only solves the problem of disposal but also helps in improving strength characteristics and to control volume change behaviour. The expansive clay blended with various percentages of CKD were tested experimentally for index properties, compaction parameters, unconfined compressive strength, and swell potential. The findings of the unconfined compressive strength (UCC) test are used to establish the optimum CKD dosage for the stabilization of expansive clays. The effectiveness of natural soil treated with CKD in subgrade stabilization evaluated from Group Index method is also presented.

Keywords: Cement Kiln Dust (CKD), Expansive clay, Group Index Method, Swell Potential, Unconfined Compressive Strength.

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1. Introduction

. Expansive clays, which range in colour from dark grey to black, are regarded as highly fertile for cotton plantations, hence the term "Black Cotton Soil." It has a high swelling and shrinkage characteristics, whereas its bearing capacity is low. (Jones and Jefferson 2012). These volumetric changes may result serious damage to the structures resting on them.

Expansive clays have been found to be abundant in zones where yearly evapotranspiration exceeds precipitation. They can only be found in semi-arid climate zones in tropical and temperate climate zones. (Chen, 1975). Such soils are reported all over the world but majorly concentrated in the tropical countries of Africa and Indian subcontinent. Expansive clays cover almost 20-25 percent of India's entire land area, or 0.8 million square kilometres. It was found in most parts of the southern peninsula and some parts of North India. (M J Singh et. al., 2020, Verma and Maru 2013).Economic losses of $2.3 billion were reported as a result of damages and hazards caused by swelling soils.

Smectite group of clay minerals are the major minerals generally present in expansive clay, in which montmorillonite is the predominant mineral with significant amount of illite and kaolinite (Dang and Khabbaz 2018). The physical structure of montmorillonite has two tetrahedral sheets of silica separated by an octahedral sheet of Alumina. (Ranjan and Rao 2007). This makes the expansive clay impermeable and is also responsible for high volume changes in it. (Peiping Zhang et. al., 2019)

Cement kiln dust (CKD) is a byproduct of the cement manufacturing process that consists of micron-sized particles. It refers to the anhydrous and oxidised product produced by electrostatic precipitators during the manufacture of cement clinker. The capacity of worldwide cement production was estimated to 4.99 billion tonnes per year in 2017 with CKD generation rates ranging from 54 to 200 kg per tonne of cement clinker output.(MinhyeSeo et.al., 2019).The dusts were characterized by significant concentrations of chlorine, calcium and potassium. The contents of Silica, Alumina, Sulphur, Titanium oxide, Chromium, Magnesia, Iron, Copper, Zinc, Lead has also been confirmed (AlicjaUliasz-Bocheńczyk, 2019).When disposed in landfills for longer duration, CKD absorbs moisture from the atmosphere and undergoes hydration to form solid piles with hard weathered outer layer with the dust particles (Manisha Meena et. al., 2018). Further, lack of land filling space and ever-increasing disposal cost also makes the disposal of CKD problematic. It has some cementitious properties, because it is a byproduct of cement clinkers. Hence, it can be effectively used in cement replacement, soil stabilization, waste treatment, asphalt pavements. This serves two functions. The disposal of CKD can be done along with there is considerable enhancement in the properties of natural soil.

2. Literature Review

Several researches have shown positive results in stabilizing expansive clay with CKD. When CKD is added to soil, it absorbs the moisture from soil and atmosphere and undergoes hydration reaction with water to form hydration products. They harden upon curing and gain strength similar to Portland cement. Thus, the hydrated CKD gel binds together the soil mass, which increases the strength and reduces its expansive nature.

Manisha Meena et. al., (2018) presented the influence of cement kiln dust on index properties, compaction parameters, and UCC strength in expansive clays. The study revealed that there is a drop in liquid limit, plasticity index, maximum dry density and gain in optimum moisture content is noticed on the inclusion of CKD. It was concluded that the unconfined compressive strength of expansive clay-cement kiln dust mixtures after curing is 1.5 to 5 times that of untreated expansive clay.

R.K. Sharma (2017) carried out laboratory tests to understand the combined influence of CKD and polypropylene fiber on various parameters of expansive clays such as compaction parameters UCC strength and CBR. The addition of CKD causes an increase in maximum dry density and a decrease in optimum moisture content, according to the test results. The maximum dry density further increases upon the addition of Polypropylene fibers. It was concluded that an optimum blend of 12% cement kiln dust and 0.3% polypropylene fibers is suggested for treatment of expansive soil when the same is used as sub grade.

Rizwan Khan and Vinod Kumar Sonthwal (2019) utilized brick kiln dust-coir fiber mixtures for soil stabilization. It was discovered that adding brick kiln dust to the expansive clay reduces both the maximum dry density and the optimal moisture content. The CBR value improves significantly, when brick kiln dust is added to natural soil and it increases even more when coir fibre is further added. The optimum results were obtained with a 30 percent brick kiln dust and

1% coir fibre mixture. The performance study of expansive clay treated with a brick kiln dust-coir fibre mixture revealed a 40% decrease in the thickness of the subgrade layer.

Ahmed Mancy Mosa et. al, (2017) carried out experiments on the use of CKD as a stabilizing agent in expansive clay. The CBR of treated soil improves with the increment in percentage of CKD. It was noted that the maximum decrease in swelling ratios were observed at 20% CKD content. The performance evaluation of expansive clay stabilised with 20% CKD confirmed that the asphaltic and base layers' thicknesses had been decreased by 80 mm and 75 mm, respectively, resulting in significant cost savings in pavement construction.

Salahudeen et. al, (2019) presented the results of an investigation study that looked into the influence compactive effort and curing time on the properties of black cotton soil blended with CKD in various percentages. It was found that both UCC strength and CBR increase with the increasing CKD content in all the three ways of compaction energies such as BSL, WAS and BSH. It was determined that an optimum dosage of 8% CKD for the stabilisation of subgrade in flexible pavements supporting light traffic is recommended.

Sudhakar et. al., (2021) utilized quarry dust at varying percentage from 10 to 25% for stabilizing expansive clay. The highest increase in unconfined compressive strength was discovered at a quarry dust content of 15%. At the optimum dosage of 15% quarry dust, the swell potential dropped from 14.73 to 7.17 percent. It was verified that the cost of flexible pavement construction is significantly reduced according to the cost analysis, when quarry dust is utilized as a stabilising agent in expansive clays.

3. Objectives and Scope

The primary goal of this research is to find out effects of CKD on geotechnical characteristics of expansive clay and to find the ideal CKD mixture that gives the optimal results in terms of engineering properties.

The specific scope of present study is outlined as follows:

- Conducting laboratory experiments to assess physical and index properties of the expansive clay.
- Carry out experiments to assess the impact of various percentages of CKD on index properties, compaction parameters and shear strength of expansive clay.
- Deriving optimum blend of expansive clay- CKD mixtures based upon measured test results, fulfilling the requirements of a good foundation material for buildings, pavements and other infrastructures.
- Conducting experimental studies on optimum dosage of cement kiln dust blended with expansive clay in order to evaluate swelling potential.
- Performance evaluation of expansive clay treated with optimum dosage of CKD to make it appropriate for use as a subgrade in flexible pavements

4. Materials

4.1. Expansive clay

The expansive clay sample was obtained from Thiruverumbur region in Trichy district, Tamilnadu. The soil sample was taken from 1.5 metres below ground. The clay was dark grey to black in colour. It consist of 29% sand, 28 % silt and 43% clay

4.2. Cement Kiln Dust

Cement kiln dust (CKD) was collected from Dalmia cement manufacturing plant in Ariyalur. It was light yellowish in colour and finely powdered.

5. Experimental Investigation

The tests below were carried out on expansive clay and expansive clay stabilized with various amount of cement kiln dust in accordance with IS: 2720.

- Specific gravity test
- Dry and wet sieve analysis
- Index tests
- Standard proctor compaction test
- Unconfined compression test
- Swell potential test

The density bottle was used to conduct the specific gravity test according to IS: 2720 (Part III /Sec 1)– 1980. Dry and wet sieve analysis was carried out as per the guide lines of IS: 2720 (Part 4) – 1985 to assess the percentage of courser and finer particles in the expansive clay used for the present investigation.

The Index tests were conducted according to the requirements of IS 2720 (Part 5) – 1985 and IS 2720 (Part 6) – 1972. A standard proctor compaction test was used to evaluate compaction parameters such as maximum dry density and optimal moisture content in compliance with IS: 2720 (Part 7) – 1980 recommendations.The cylindrical samples of diameter and height 38 mm and 76 mm respectively were made with maximum dry density and optimum moisture content. Then the samples were tested in an unconfined compression testing machine at a constant strain rate of 0.5 mm/ minute after 7 days of curing, according to IS:2720 (Part 10) – 1991 guidelines. The swell potential of specimens was estimated using IS: 2720 (Part 15) guide lines. The samples were flooded in the consolidation test apparatus by delivering water from the top. They are permitted to swell freely after being subjected to a 6.25 kN/m^2 surcharge load. The geotechnical parameters of expansive clay with and without CKD were presented in Table 1.

6. Results and Discussions

The influence of CKD on index properties, compaction parameters, unconfined compressive strength, differential free swell and swel potential of expansive clay is reported.

6.1. Effect of CKD on Index Properties

The variation of index properties obtained from experiments with regard to increase in percentage of CKD is presented in Figures 1 and 2(a). It was revealed that the liquid limit of expanding clay lowers as the percentage of CKD increases. The liquid limit is reduced by 15% and 21.67% on the addition of 5% and 15% CKD content respectively. As the spaces between soil particles are filled with CKD content, the distance between particles increases. This results in lowering the soil's cohesive behavior and hence the liquid limit. Up to the inclusion of 10% CKD content, the plastic limit is reduced by 4.09 percent. The maximum drop in plastic limit for 15 percent CKD content is 12.30 percent. It was also found that plasticity index reduces 28.09% for 10% CKD content, after which it remains unchanged. Hence, it was established that increased CKD content lowered the plasticity characteristics of the expansive clay. It was revealed from the Table 1, the index properties of expansive clay have a greater plasticity index indicating that the soil is more expansive. However, the addition of CKD to expansive clay reduces both the liquid limit and the plasticity index. The existence of inactive minerals in expansive clay-CKD mixtures is revealed by data comparison.

It was noted that the maximum reduction in shrinkage limit is 47.10% for the combination of expansive clay treated with 10% CKD. However, there was gain in shrinkage limit of about 27.40% is observed when the natural soil is mixed with 15% CKD content.

6.2. Effect of CKD on Compaction parameters

The measured compaction characteristics of expansive clay and expansive clay treated with various proportions of CKD is shown in Figures 2(b) and 2(c). When expansive clay is blended with 5% CKD content, it has a marginal increase in maximum dry density of 1.72%. This could be due to cement kiln dust particles filling voids in between soil particles, causing increase in maximum dry density. The increase in CKD content resulted decrease in maximum dry density by 1.41 % and 3.38% on the addition of 10% and 15% respectively. This decrease in maximum dry density could be due to segregation of soil mass as a result of excess amount of CKD. This result in increasing the total volume of the soil, thereby decrease in its density. The optimum moisture content of expansive clay decreases up to the inclusion of 10% CKD content. As the CKD content is increased from 10% to 15%, the optimum moisture content increases as well. The water affinity of CKD is more than that of soil, due to the existence of calcium oxide in CKD. This attributes to increase of OMC at higher content of CKD.

6.3. Effect of CKD on UCC Strength

The change in UCC strength of expansive clay with CKD content is illustrated in Figure 3. It was noticed that increasing the amount of CKD in natural soil increases its UCC strength in the early stages. The enhancement in UCC strength is 45.43% and 120.56% on the addition of 5% and 10% CKD content respectively. The establishment of a strong bond between the expansive clay and cementitious compounds in CKD may be attributed for the increase in UCC strength. The reduction in UCC strength of expansive clay-CKD mixtures is observed at greater percentages of CKD concentration.It may be due to development of inactive minerals as well as a weak bond between the expansive clay and cementitious compounds. There is also potential that when the amount of CKD increases, the friction improves and the cohesion of expansive clay decreases leading to reduction in UCC strength.

6.4. Effect of CKD on Swell Potential

The effect of CKD on the swell potential of expansive clay is exhibited in Figure 4. When expansive clay is treated with 10% CKD content, it was observed that the swell potential is reduced by 7.76%. Due to exchange of cations between expansive clay and CKD, the distance between interlayer may gets decreased. As a result, the amount of water that passes through the layers is lowered. This results in reduction of swell potential of expansive clay.

7. Performance Evaluation of the subgrade using Group Index Method

The Group Index is determined in accordance with AASHTO specifications (2010) as follows:

$$GI = 0.2\, a + 0.005\, ac + 0.01\, bd$$

where, a = percentage of soil particles smaller than 75µ sieve, greater than 35 and not more than 75 (0-40)

b = percentage of soil particles smaller than 75µ sieve, greater than 35 and not more than 55 (0-40)

c = Liquid limit more than 40 and not greater than 60 (0-20)

d = Plastic limit more than 10 and not greater than 30 (0 -20)

When expansive clay is utilised as a subgrade, the Group Index value is:

$$GI = 19$$

When expansive clay + 10% CKD is utilised as a subgrade, the Group Index value is:

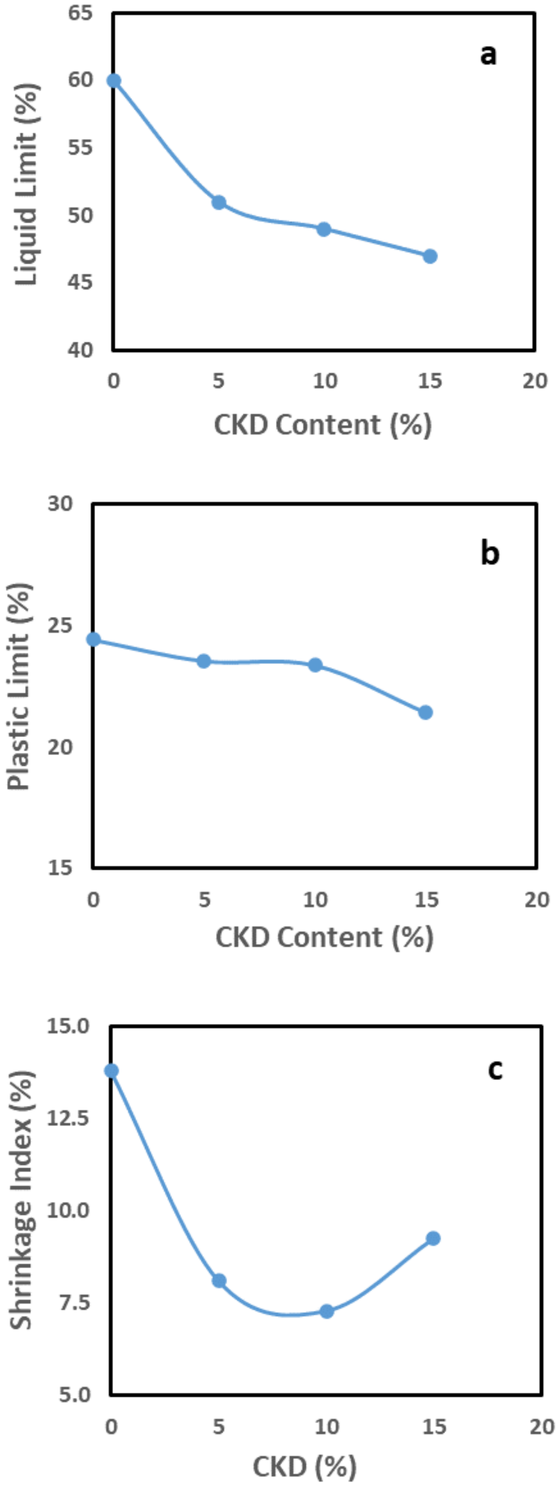
$$GI = 15$$

The pavement thickness with respect to GI values is calculated from the Group Index chart. The resulting pavement thickness for expansive clay and expansive clay blended with 10% CKD under various traffic characteristics is exhibited in Table 2.

8. Conclusions

The following are some of the major conclusions that can be drawn from the present experimental investigation:

- The liquid limit and plasticity index of expansive clay reduces by 21.67% and 28.09% respectively on addition on 15% CKD. The results confirm reduction in compressibility and degree of expansion of expansive clay.
- The maximum dry density of expansive clay rises until it reaches 5% CKD content, beyond which it drops. The optimum moisture content of the same falls as the percentage of CKD increases.
- Expansive clay combined with 10% CKD content has a 120 percent higher unconfined compressive strength than expansive clay on its own. The increase in unconfined compressive strength could be attributed to the formation of a strong bond between the expansive clay and cementitious compounds during the 7-day curing interval.
- The swell potential reduces by 7.76% upon addition of 10% CKD. This may be due to reduction in the distance between interlayer because of interchange of cations so that the quantity of water that immigrates in between the layers drops as well.
- The performance analysis using Group index method indicates that the total pavement thickness decreases by 6.78% when cement kiln dust is utilized up to 10% under heavy traffic characteristics. The same trend is also observed for both light and medium traffic considerations. Further, this additive also enhances strength of sub grade in flexible pavement.
- The optimum mixture determined from the present investigation is 90 % expansive clay: 10% CKD.



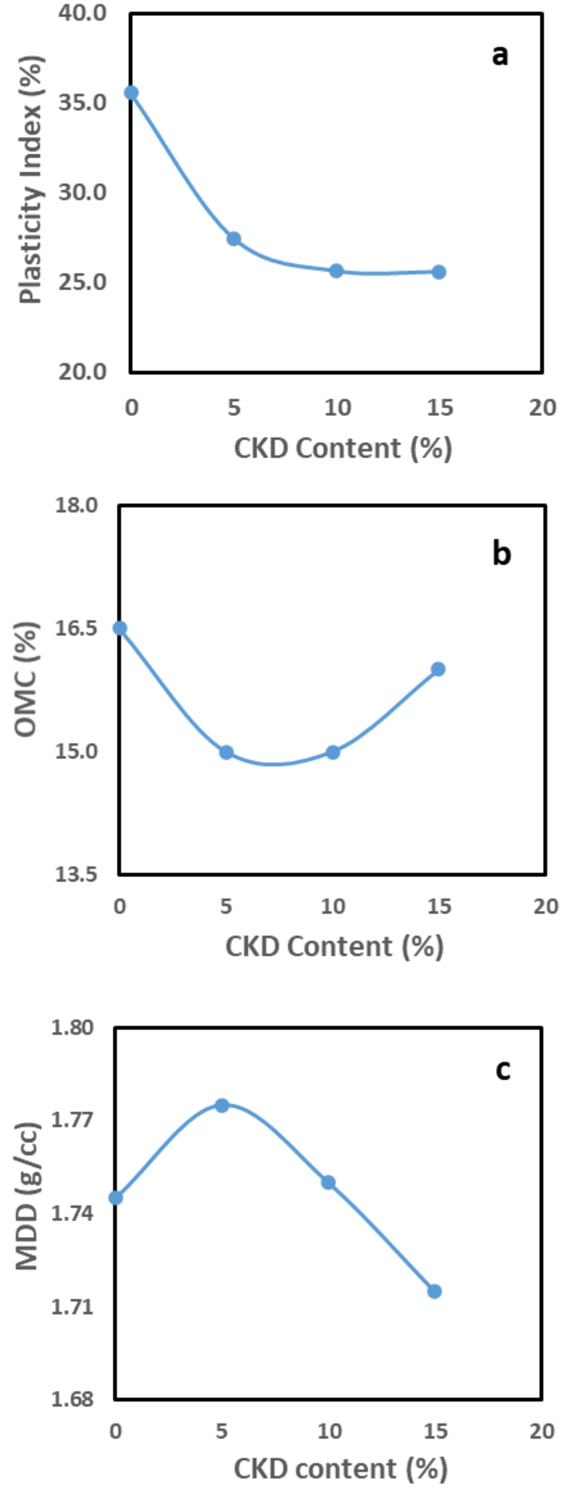


Figure 1: Variation of (a) liquid limit (b) plastic limit (c) shrinkage limit with CKD content

Figure 2: Variation of (a) plasticity index (b) optimum moisture content (c) maximum dry density with CKD content

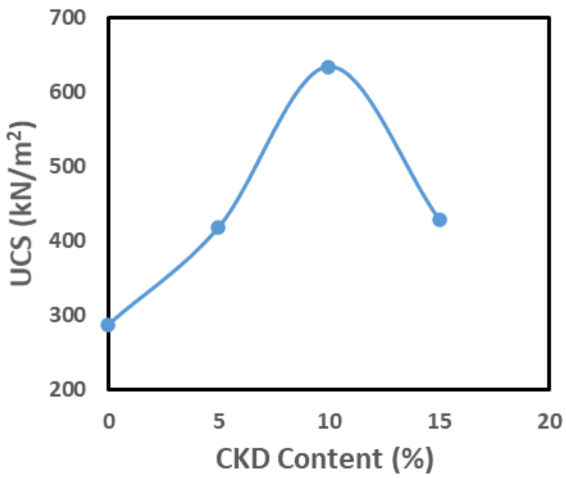


Figure 3: Influence of CKD on unconfined compressive Strength

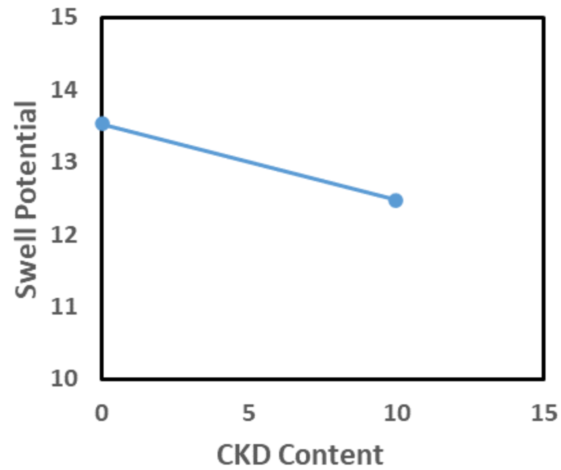


Figure 4: Influence of CKD on swell potential

Table 1: Geotechnical Properties of expansive clay and expansive clay stabilized with CKD

Property	Untreated expansive clay	Soil + 5% CKD	Soil + 10% CKD	Soil + 15% CKD
Specific Gravity	2.66	-	-	-
Liquid Limit (%)	60	51	49	47
Plastic Limit (%)	24.4	23.5	23.4	21.4
Plasticity Index (%)	35.6	27.5	25.6	25.6
Shrinkage Limit (%)	13.8	8.1	7.3	9.3
Optimum Moisture Content (%)	16.5	15	15	16
Maximum Dry Density (g/cm^3)	1.745	1.775	1.75	1.715
Unconfined Compressive Strength (kN/m^2)	287.5	418.1	634.1	428.7
Cohesion (kN/m^2)	143.75	209.05	317.05	214.35
Swell Potential (%)	13.53	-	12.48	-
Soil Classification	CH	CH	CI	CI

Table 2: Variationin total pavement thickness for expansive clay and expansive clay stabilized with 10% CKD as sub grade under different traffic conditions

S. No.	Traffic characteristics	Pavement Thickness (in centimeters)								Variation in total pavement thickness (%)
		Expansive clay				Expansive clay + 10% CKD				
		Sub Base (SB)	Base (B)	Surface course (S)	Total	Sub Base (SB)	Base (B)	Surface course (S)	Total	
1	Heavy traffic	29	26	4	**59**	25	26	4	**55**	6.78
2	Medium traffic	29	19	4	**52**	25	20	4	**49**	5.77
3	Light traffic	29	11	4	**44**	25	11	4	**40**	9.09

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