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Stabilization of Dune Sand by Using Cement Kiln Dust (CKD)

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Abstract

To determine the geotechnical properties of Stabilized dune sand by Using Cement Kiln Dust (CKD) and to assess the suitability of resting shallow foundation on it, an extensive laboratory testing program was carried out. The results indicated that: Cement kiln dust (CKD) caused an irregular decrease in the liquid limit when it was mixed with sand. The mix of CKD allowed compaction of the soil at lower maximum dry unit weight and higher optimum water content. Cement dust caused an increase in φ and (c). The variation in shear strength parameters became almost constant after fourteen days of curing. Stabilization of collapsible soils with CKD can provide tremendous economical advantages.

Keywords: Dune sand, Cement kiln dust, Stabilization, Loading tests

1 Introduction

The real problem of sand dunes is their creep that affects development of projects; such as highways, railways, irrigation and drainage canals, agricultural lands, and other projects. Dunes are causing a decrease in the efficiency and increase in the maintenance costs for these projects. There are almost fifteen cement factories in Iraq that produce about two million tons of cement a year. Their locations are near highly - populated towns, for example: Sulimanya, Hammam Al-Alell and Sadit Al-Hindeya. In an attempt to balance the benefit with the cost of these factories in addition to environmental benefits, the use of cement kiln dust is introduced (CKD a by-product from cement industry), in stabilization process of dune sand. It seems worthy to try carrying out some basic tests for this material and give suggestions for further studies.

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1.1 Soil stabilization by Cement Kiln Dust (CKD)

Many different admixtures are occasionally used to stabilize soil in the field. The most common of these admixtures are: lime, lime-fly ash, cement, and asphalt [1].

Cement kiln dust (CKD) is a significant by-product material of the cement manufacturing process; CKD contains almost similar constituents as those of the Portland cement, lime, silica and many metal oxides. Chemical and physical consistency of CKD widely varies depending on the raw materials used in the manufacturing process [2].

Over several years, dramatic advantages have been found for the CKD. Progress was mainly achieved in the management and use of cement dust as much as possible to reduce its stocks and piles that have negative impact on environment and health. There are many beneficial uses for cement dust include: raw feed stock, base stabilizer for pavements, as solidifier and stabilizer for contaminated wastes, agricultural soil enhancement, low-strength backfill material, and municipal daily landfill cover [3].

1.2 Hazard of Cement Kiln Dust

In spite of the many researches carried out on using of cement kiln dust, its known hazards to human beings and environment were not taken into consideration. This hazard is assessed and updated in the health effects sections HSE of an earlier report of Portland Cement Association [4].

It is recommended to specialized researches for more studies to clarify the proper use and treatment of symptoms related to the use of CKD for inland filling, roads or in properly covered lands. HSE recommend the dust moisture to be more than 1% and compacted immediately. In high wind conditions, the filling operation is restricted. More recommendations are given in [4, 5].

There are many studies about dune sands stabilization with many different types of improvement methods; physical, chemical, biological methods and combination of such methods. Cement dust is one of the stabilizing agents (or admixture) that is used for its physical and chemical actions. It is cheap and available material that encourages its use, but the negative impacts on the environment should be exhibited.

Studying the stabilization by cement kiln dust using loading tests and geotechnical tests has not been investigated.

2 MATERIAL PROPERTIES OF DUNE SAND

2.1 Physical properties

Affek dune sand was chosen in this study. It is located between Diwaniya and Kut governorates at the south of Iraq. Affek dune sand is predominantly fine sand with non-plastic fines. According to the Unified Soil Classification System, the soil is classified as SP-SM material [6].

Physical properties, shear strength and compressibility parameters are shown in Table 1, while the Chemical tests results are shown in Table 2.

Small difference can be noticed between the maximum and minimum unit weights and this may attributed to the poorly grading of dry soil. On the basis of permeability, the soil may be classified as low permeability soil [7].

Table 1: Physical properties, shear strength and compressibility parameters

Property	Value	Type of test	Standard
L.L	23%	Atterberg limits	BS 1377:1975 test No.2
PI	NP		
Gs	2.67	Specific Gravity of Solids	ASTM D-854
γ_{max}	15.9 kN/m^3	Maximum Unit Weights	ASTM D4253
γ_{min}	13.0 kN/m^3	Minimum Unit Weights	ASTM D4254
γ_{dmax}	18.5 kN/m^3	Standard Compaction	ASTM 698-70
k	1.6×10^{-4} cm/s	Coefficient of Permeability	ASTM D2434-64T
e_o	0.508	One dimensional consolidation	ASTM D2435
Cc	0.120		
c	0	Direct Shear Tests	ASTM D3080-72
φ	42.7°		

Table 2: Results of Chemical Tests

Chemical Composition	Percentage (%)
SiO_2	41.25
CaO	16.39
MgO	6.70
SO_3	0.05
Cl^{-1}	0.11

2.2 Cement Kiln Dust (CKD)

Cement dust was obtained from the Cement Factory of Al-Kuffa, Al-Najaf Governorate, Iraq. Some of the physical properties and chemical analysis results are shown in Table 3.

2.3 Stabilized soil samples

The cement kiln dust is used for stabilizing the dune sand by adding three different percentages to find the optimum percentage for stabilization. Effect of soaking and curing time on stabilization was also studied.

Table 3**:** Physical Properties and Chemical Analysis Results

Physical Properties	
Liquid Limit	26%
Plastic Limit	NP
Specific Gravity	2.68
Fineness	5280 cm^3/g
Chemical Compounds	
SiO_2	12.58%
Al_2O_3	1.86%
Fe_2O_3	1.44%
CaO	27.57%
SO_3	15.73%
T.D.S	6.13%
L.O.I	15.82%
$CaCO_3$	51.50%

2.4 Atterberg limits

The addition of CKD in different percentages to soil decreases the liquid limit (L.L.) irregularly. The change in the liquid limit may be attributed to cementitious properties of CKD which have a high content of calcium oxide, Table 3 [8]. Table 4 shows the variation of Atterberg limits with the CKD percentage.

Many previous studies found similar trend in decreasing of L.L. with small percentage of CKD and increasing L.L. with increasing CKD percentage up to 8% [9, 10]. The plastic limit results showed that all mixtures were non-plastic.

Table 4: Atterberg Limits for CKD Stabilized Soil

CKD Percentage	Liquid Limit, %	Plastic Limit, %
0% CKD	23.0	NP
4% CKD	22.0	NP
8% CKD	17.8	NP
12% CKD	18.1	NP

2.5 Compaction tests

Standard Proctor compaction tests were conducted on stabilized soil. Figure 1 shows the moisture-unit weight relationship for stabilized soil. From the laboratory results, the following points could be noticed.

For small percentage of CKD (4%) there is a decrease in the optimum water content with slight decrease in maximum dry unit weight. The stabilized soil with 8% and 12% of CKD (which is fine material) were compacted at lower maximum dry density and higher optimum water content. The shape of curves became more flat with increase of the CKD percentage. Similar finding was reported by [9].

2.6 Strength tests

Series of direct shear tests and unconsolidated undrained triaxial compression tests were carried out to study the shear strength parameters (c and φ). Also compressibility characteristics of stabilized soil with different percentage of CKD at optimum moisture content were carried out.

2.6.1 Direct shear tests

The direct shear tests were carried out on three stabilized soils with (4%, 8% and 12%). Seven days of curing was chosen as the minimum practical time of curing. Figure 2 shows the results of this test. Generally the angle φ is almost constant with increasing CKD. In comparison with unstabilized soil, the angle φ changes with little variation in CKD (8%) with cohesion 66 kPa, while the soil stabilized with 4% and 12% CKD has a small increase in the angle of internal friction φ and the cohesion but less than that with 8% CKD. The reason behind that may be related to the little percentage of fines that did not bound soil particles enough to form conglomerate and increase (φ and c) while 12% CKD was related to formation of lumps in the stabilized soil.

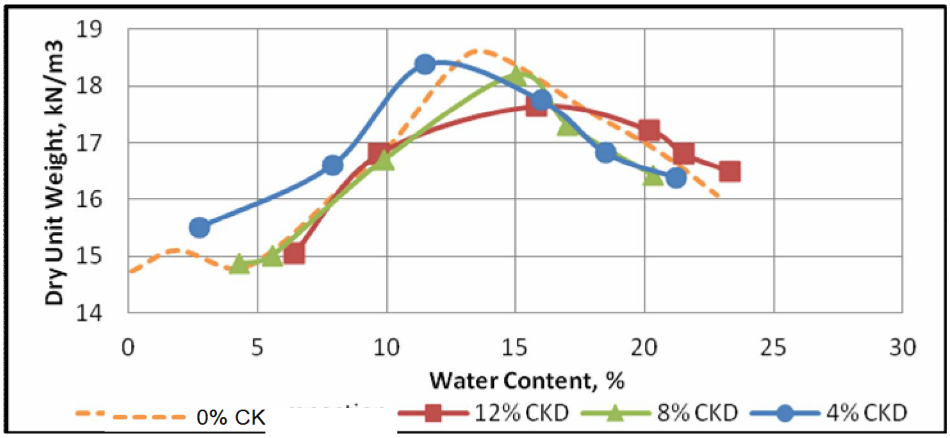

Figure 1: Results of compaction tests for stabilized soil at different percentages of CKD

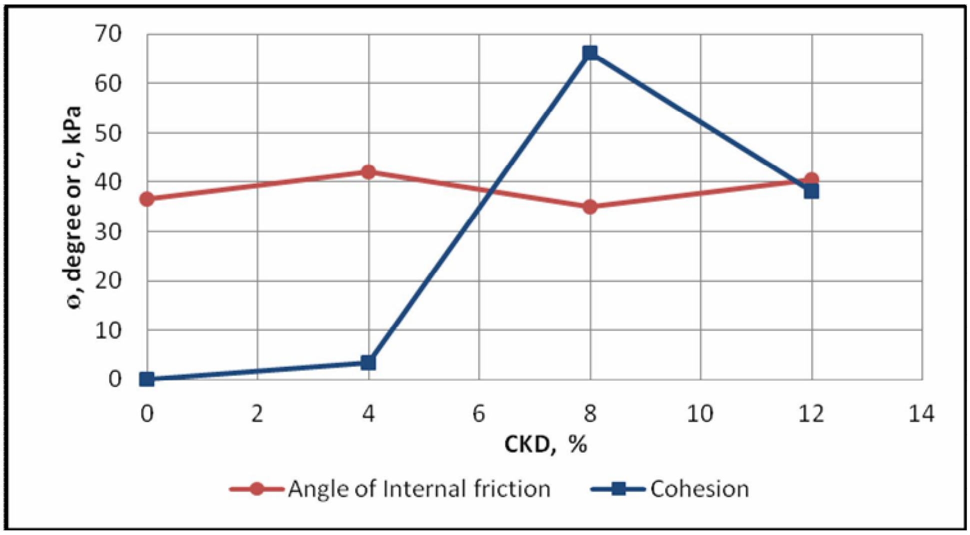

Figure 2: The variation of angle of internal friction and cohesion for stabilized soil with different percentages of CKD.

2.6.2 Triaxial compression tests

Unconsolidated undrained triaxial compression tests were carried out on the stabilized soil with different percentages of CKD, at optimum moisture content, after twenty-eight days of curing covered with plastic bags and then closed tight till the time of tests.

The results showed that the peak strength increased with the increase in confining pressure, and failed with less than 5% of axial strain. The failure was noticed as slight plateau with little stress softening, this was clearer with high confining pressure (Figure 3).

Figure 3: Failure of samples of compacted stabilized soil after triaxial testing

The Mohr-Coulomb failure criterion was used to establish the relation between shear strength parameters. From these values, higher strength can be achieved by using stabilized soil with 8% CKD, and there was no dramatic change on angle of internal friction.

2.7 Collapse tests

Two series of collapse tests were carried out: single and double collapse on soil stabilized with different percentage of CKD and at seven days of curing. Results showed that collapse potential was changed substantially by addition of CKD (Figure 4). The collapse potential decreased to less than half in stabilized soil as compared with unstabilized soil.

The results of double collapse tests are shown in Figure 5. The results indicate an extremely different behavior from an unstabilized soil; the specimens were gaining strength when water was added.

In an attempt to understand this behavior, swelling characteristics of the mixtures were investigated (the results are shown in Table 5). The "swelling potential" of the soil based on classification of soil is classified as "Negligible Swelling Potential". The real mineralogical composition of the soil may cause this behavior; the soil has less than 10% of clayey sized particles. So, the more reasonable behavior of the mixture was that CKD particles used the water and started hydration. It is obvious that improvement with CKD is more efficient only after curing. Note that the initial water content of all mixtures was the same. The unsoaked specimens were covered with plastic sheets to prevent losses of water in hot summer days.

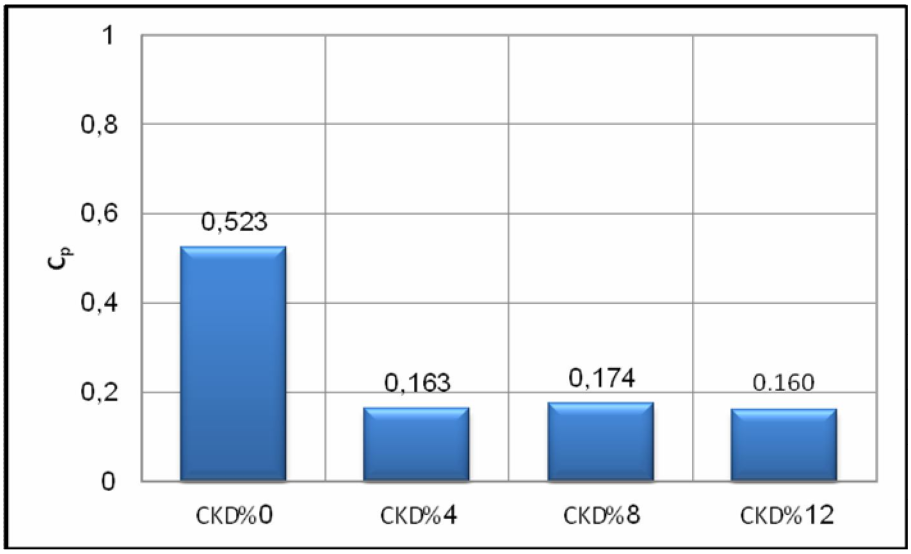

Figure 4: Variation of collapse potential with the increase in added percentages of CKD (Single Collapse)

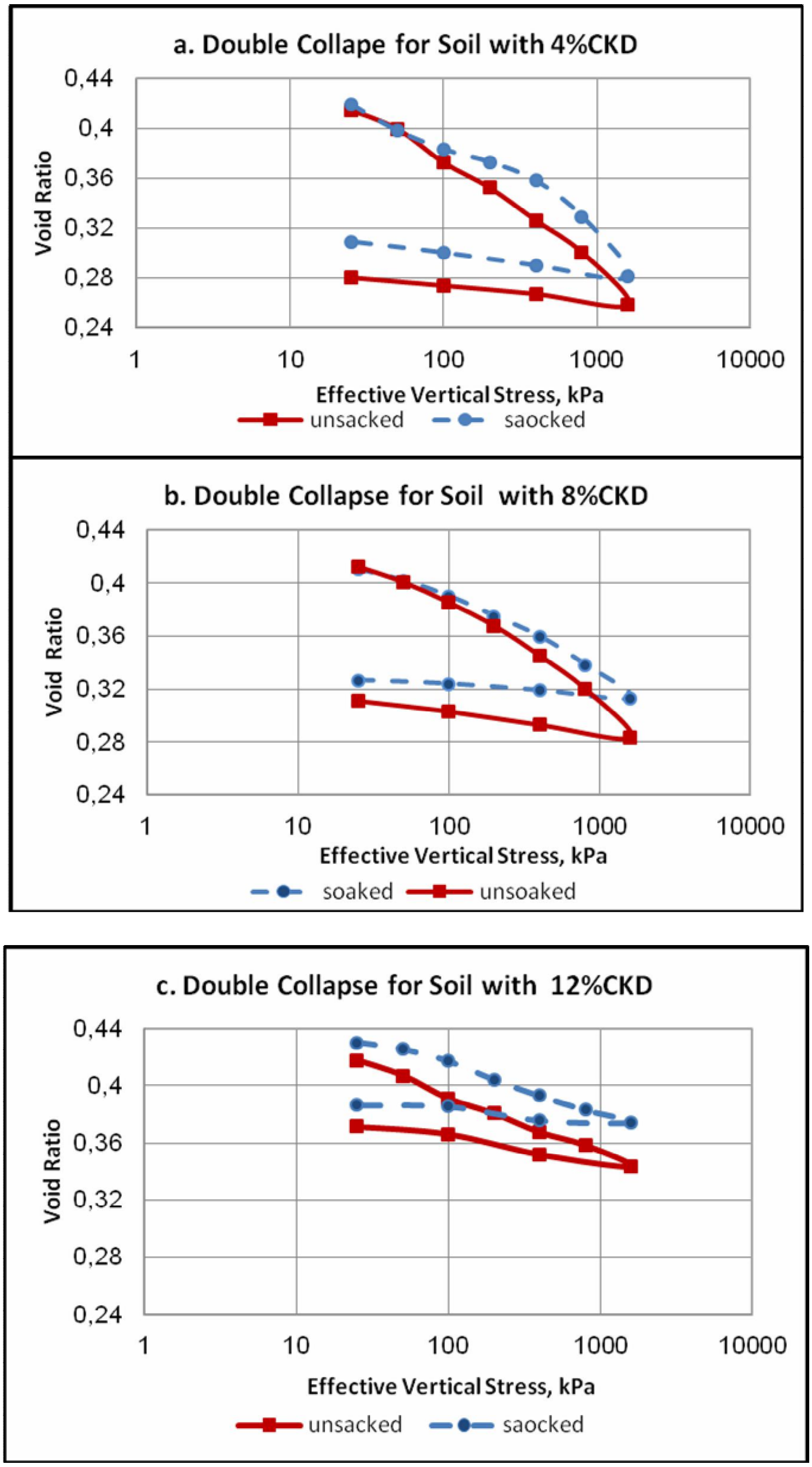

Figure 5: Results of double oedometer tests for stabilized soil with different CKD percentages

Table 5: Results of the Modified Free Swelling Tests

CKD Percentage	Modified Free Swell Index
4% CKD	2.4
8% CKD	2.0
12% CKD	1.7

2.8 Time of curing tests

In attempt to select an optimum time of curing, a series of direct shear tests were carried out and tested after 1, 3, 7, 14, and 28 days on soil stabilized with 8% CKD as this percentage was the optimum based on previous results. Results are shown in Fig 6. The angle of internal friction (φ) and cohesion (c) changed in the first fourteen days, especially for cohesion, and stayed almost constant after that. This behavior may be due to the loss of water. In other words, the hydration process was stopped. High cohesion was recorded in the first seven days with little variation in the angle of internal friction. This may be caused by a significant portion of the fine material that permanently bound together to form larger conglomerate particles [9].

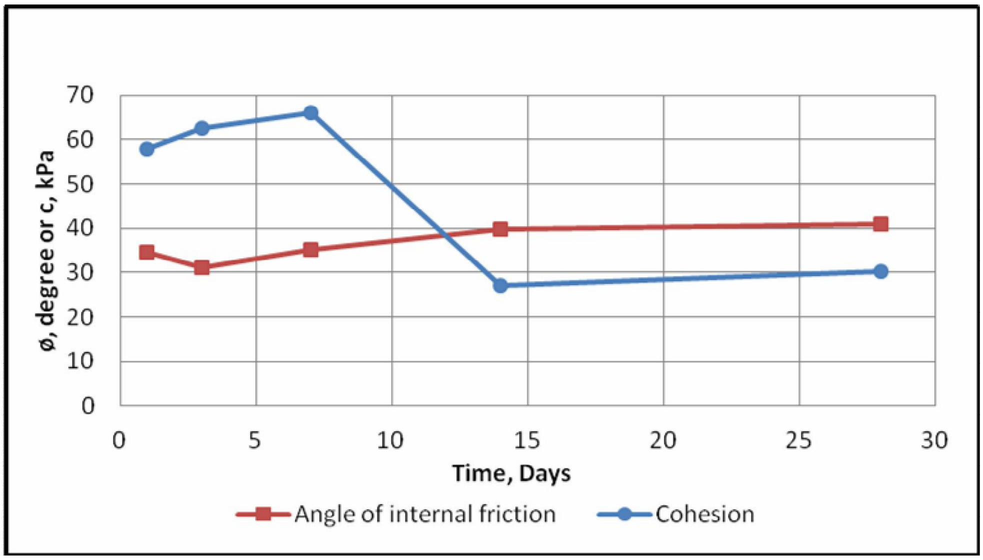

Figure 6: Variation of angle of internal friction and cohesion with time of curing for stabilized soil

2.9 Loading tests on stabilized soil

The loading test on the stabilized soil required the preparation of stabilized soil in the steel box. The preparation consists of two main steps. In the first, the soil was compacted at dry unit weight as recommended in (ASTM D2049-64T). Then, in the second step, a layer of stabilized soil with different percentage of CKD (4%, 8%, and 12%), with thickness of 1.5B was placed over the soil prepared in the first step. This layer was compacted at optimum unit weight and corresponding water content. The prepared box for testing was carefully covered with plastic sheets and then closed tightly till the chosen time of curing was finished. Series of selection of time for curing showed that there were no dramatic changes after fourteen days. After that, the box became ready for testing. The bearing pressure-settlement curves are shown in Figure 7.

Using CKD as an additive does not maximize the strength of the stabilized soils only, but rather improves the global properties of the mixture. The observed relationship between the bearing pressure and settlement demonstrates a significant increase in the ultimate bearing capacity, which shows the strength gain obtained with cementation.

Adding CKD increases the ultimate bearing capacity, and then generally, tend to remain constant. It is clear to suggest that the optimum percentage of CKD is 8%, which can be recommended for Affak dune sand.

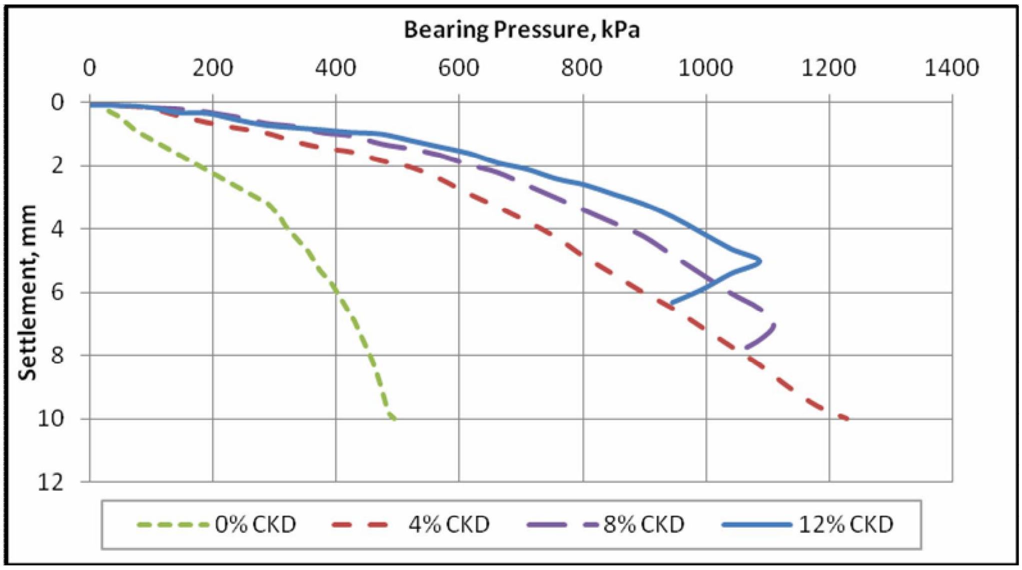

Figure 7: Bearing pressure-settlement curves for different percentages of CKD

4 Conclusions

1. Cement kiln dust (CKD) caused an irregular decrease in the liquid limit when it was mixed with sand. The mixtures were non-plastic. The mix of CKD allowed compaction of the soil at lower maximum dry unit weight and higher optimum water content.
2. Cement dust caused an increase in φ and (c). Higher cohesion was reached with higher percentage of CKD. The variation in shear strength parameters became almost constant after fourteen days of curing.
3. Stabilization of collapsible soils with CKD can provide tremendous economical advantages. Adding CKD increase the ultimate bearing capacity to 250% for 8% CKD as an example.

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