ENHANCING STABILITY OF CLAYEY SUBGRADE MATERIALS WITH CEMENT KILN DUST STABILIZATION

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ABSTRACT

For clayey soil materials to be effective as pavement subgrades, satisfying the stability conditions is essential especially in wet and dry climatic conditions prevail. This could be achieved using some sort of stabilization methods. Stabilization of pavement subgrade soils has traditionally relied on treatment with lime, cement and sometimes special additives, which are regarded as waste materials. Alternatively, the by-pass Cement Kiln Dust (CKD) is generated during the course of Portland cement manufacture. It represents a mixture of raw feed, partly calcined cement clinker and condensed volatile salts. This study investigated the use of CKD to enhance the durability of clayey subgrade soils. Standard laboratory soil tests were conducted to measure changes in the engineering properties of clayey soils when treated with CKD. Tests were conducted on untreated control soil samples and on varieties of treated samples with CKD ranged from 2% to 10%. The results showed that the CKD clay samples exhibit low plasticity, swelling, maximum dry density and consolidation settlement. On the other hand, results showed significantly increasing in CBR, soil cohesion and soil strength. The internal friction angle concerning shear strength parameters is also enhanced. Overall, the testing programme produced data showing that mixtures with CKD admixture have significant enhancement in engineering properties of clayey soils. This is advantageous for work construction in the civil engineering field.

KEYWORDS: Unusual stabilizer; Clayey Subgrade; Cement Dust Stabilizer, CKD

1. INTRODUCTION

Material engineers are continually confronted by the depletion of quality construction materials for road construction. Even if good quality construction materials are available, the haul costs may preclude their use. Engineers are frequently required to incorporate poor quality soil and aggregate into pavement designs. For example, most of the agricultural roads in the Egyptian roads network were originally constructed as a canal or drain embankments, which are molded with high percent of clay. Clays are notoriously well known for giving rise to swelling problems and difficulties in construction due to excessive settlement and limited strength. These poor quality materials typically have the potential to demonstrate undesirable engineering behavior such as, low bearing capacity, high shrink/swell potential, and poor durability (Chen 1981, Cokça 1999, Abo-Hashema et al. 1994, Kumar and Puri 2013). Hence, such types of soils need to be stabilized before construction for improving their engineering properties. Traditional stabilization methods include the application of various combinations of lime, cement, fly ash, and bituminous materials. These traditional stabilization techniques often require lengthy cure times and relatively large quantities of additives for significant strength improvement. Delays in construction can be costly if adequate planning has not accounted for material cure times (Muntohar 1999).

One may achieve stabilization by mechanically mixing the natural soil and stabilizing material together to achieve a homogenous mixture or by adding unusual stabilization additives. These additives range from waste products to manufactured material, which includes Silica Fume, Rice Husk Ash, Portland cement, Fly ash, chemical stabilizers and Cement Kiln Dust (CKD). These additives can be used with variety of soils to improve their original engineering properties. The effectiveness of these additives depends on the soil treated and the amount of additive used. The high strength obtained from cement and lime may not always be required, however, and there is justification for seeking cheaper additives, which may be used to alter soil properties (Muntohar 1999, Filho et al. 2007, Abd El Aziz 2003, Abd El Aziz and Abo-Hashema 2013).

These unusual stabilizers are marketed as requiring lower material quantities, reduced cure times, higher material strengths, and superior durability compared to traditional stabilization additives (Abd El Aziz 2003, Abd El Aziz and Abo-Hashema 2013). However, most transportation agencies are hesitant to specify such these unusual stabilizers without reliable data to support vendor claims of product effectiveness. Unfortunately, the rapid evolution of existing products and introduction of new stabilizers further complicate the process of defining the performance characteristics of the various unusual soil stabilization additives. While, the nature of soil stabilization dictates that stabilizers may be soil-specific and/or environment-sensitive. In other words, some stabilizers may work well in specific soil types in a given environment, but perform poorly when applied to dissimilar materials in a different environment (Muntohar 1999). For that reason, this research is trying to identify the effect of using unusual stabilizer, such as CKD on the engineering properties of clayey subgrade.

The main objective of this study is to investigate the effect of blending clayey soils with Cement Kiln Dust on their engineering properties. Tests were conducted on untreated control soil samples and on samples treated with CKD. A series of laboratory experiments have then been conducted for varieties of samples: 2%, 2%, 6%, 8%, and 10%. Each treated and untreated soil was characterized in terms of the Atterberg limits, swell potential, compaction characterization, California Bearing Ration (CBR), consolidation test, and un-drained Triaxial shear strength.

2. LITERATURE REVIEW

Soil Stabilization, in its broadest sense, implies the improvement of both durability and strength of soil (Yoder and Witczak 1975). A review of the literature indicates that there has been a large quantity of research completed regarding the application of traditional stabilization additives such as lime, cement, and fly ash. However, little research has been documented pertaining to the use of unusual stabilization additives. Material engineers may find a large quantity of advertisements, pamphlets, and videos in the market testifying to the benefits of a particular stabilization additive. Unfortunately, most of the information disclosed in these media are subjective and traditional engineering properties are poorly documented.

Xeidakis (1996) investigated the stabilization of the swelling clay structure by intercalation of Mg(OH)2 and the development of a brucite interlayer between the clay layers. A final conclusion that could be drawn from this work is that the intercalation of Mg-hydroxide into the clay layers and the stabilization of the swelling clay structures are beyond any doubt; nevertheless, the method, as formulated, is not easily applicable to the field; more research is needed in this direction.

Ajayi-Majebi et al. (1991) conducted an experiment designed to determine the effects of stabilizing clay-silt soils with the combination of an epoxy resin (bisphenol A/epichlorohydrin) and a polyamide hardener. The additive mixture was composed of a 1:1 ratio of epoxy resin to polyamide hardener. Ajayi-Majebi et al. concluded that admixing up to 4 percent stabilizer into a clay-silt material produced large increases in the load-bearing capacity of the material in terms of its un-soaked CBR. They observed that increases in the temperature of the curing environment led to increased strength formation. Cure times for the stabilization agent were reported as low as 3 hours.

Kalkan and Akbulut (2004) measured the positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners. They concluded that a significant improvement on the permeability, swelling pressure and compressive strength of composite samples was obtained by using silica fume. The investigation showed that the silica fume is a valuable material to modify the properties of clay liners to be used in the landfill sites.

Bell (1996) used lime as stabilizer for clay minerals and soils. The research proved that lime could be used to enhance the engineering properties of clayey soils. All materials experienced an increase in their optimum moisture content and a decrease in their maximum dry density, as well as enhanced CBR, on addition of lime. Some notable increases in strength and Young's Modulus occurred in these materials when they were treated with lime. Length of time curing and temperature at which curing took place had an important influence on the amount of strength developed.

Miller and Azad (2000) performed a laboratory study to evaluate the effectiveness of Cement Kiln Dust (CKD) as a soil stabilizer. The study revealed that increases in the unconfined compressive strength (UCS) of soil occurred with the addition of CKD. Increases in UCS were inversely proportional to the plasticity index (PI) of the untreated soil. Significant PI reductions occurred with CKD treatment, particularly for high PI soils.

Chen and Lin (2009) conducted experiments to evaluate using of incinerated sewage sludge ash (ISSA) when mixing with cement in a fixed ratio of 4:1 for use as a stabilizer to improve the strength of soft, cohesive, subgrade soil. The study showed that the unconfined compressive strength of specimens with the ISSA/cement addition was improved to approximately 3–7 times better than that of the untreated soil; furthermore, the swelling behavior was also effectively reduced as much as 10–60% for those samples. In some samples, the ISSA/cement additive improved the CBR values by up to 30 times that of untreated soil. This suggested that ISSA/cement has many potential applications in the field of geotechnical engineering.

Al-Rawas et. al. (2005) conducted a research to investigate the effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman. The physical results of the treated samples were determined. The untreated soil values were used as control points for comparison purposes. It was found that with the addition of 6% lime, both the swell percent and swell pressure reduced to zero. Heat treatment reduced swelling potential to zero. The use of lime showed superior results when compared with the other stabilizers.

Hashim et. al. (2005) investigated the effect of using rice husk ask and cement on a stabilization of residual soil. Test results showed that both cement and rice husk ash reduced the plasticity of soils. In term of compactability, addition of rice husk ash and cement decreases the maximum dry density and increases the optimum moisture content.

3. MATERIALS

3.1 Test Soils

The soil used in this study was obtained from a site located in Gaafraa village, Fayoum City, Egypt, next to Fayoum-Etsa Road. A test pit was excavated to obtain disturbed samples. The expansive soil was encountered at a depth of about 0.60m overlaid by a layer of sand and silt. A field density test was carried out in the pit. The disturbed soil was excavated, placed in plastic bags, and transported to the Soil Mechanics Laboratory at Fayoum University for preparation and testing. The physical characteristics of the untreated soil are shown in Table 1.

The untreated soft subgrade soil is categorized as clayey soil (G_s = 2.68 with 90.76% fines) with expansive behavior. Soil categorization tests that follow the standard of

ASTM D1883-87 (1998) and the classifications of AASHTO refer the untreated subgrade soil to the A-7-5 category, which stands for high-plasticity clay. Based on Universal Soil Classification System (USCS), it was classified as CH, which is clay with high plasticity. All geotechnical tests were performed in accordance with ASTM D 4318-95 (1998), ASTM D 1557-91 (1998) and ASTM D 4546-96 (1998). The soil showed a high plasticity index (39.95%) and an activity of 3.059. Generally, the higher the plasticity index and activity of a soil are; the higher the swelling potential is, which is measured as 48%.

Table 1. Physical Characterization of Clay Sample

Physical Properties	Value
Basic Characteristics	
Depth (m)	0.60
Natural moisture content (%)	71.38
Moisture content (disturbed), %	18.32
Specific Gravity, Gs	2.68
Atterberg Limits[1]	
Liquid Limit, LL (%)	74.85
Plastic Limit, PL (%)	34.90
Shrinkage Limit, SL (%)	13.82
Plasticity Index, PI (%)	39.95
Compaction Properties[2]	
Maximum Dry Density, γ_d	1.33gm/cm3
Optimum Moisture Content	34%
Grain size distribution	
- Coarse particles	9.24
- Fine particles	90.76
- Clay	85.00
- Silt	15.00
Activity	3.059
CBR	3%

[1] Liquid Limit, Plastic Limit, Shrinkage Limit, and Plasticity Index, ASTM D 4318 (1998)
[2] Optimum water content for compaction with a modified Proctor effort, ASTM D 1557 (1998)

3.2 Stabilizer Product: Cement Kiln Dust

Cement kiln dust (CKD) is the fine-grained, solid, highly alkaline waste removed from cement kiln exhaust gas by air pollution control devices. Because much of the CKD is actually unreacted raw materials, large amounts of it can and are, recycled back into the production process. Some CKD is reused directly, while some requires treatment prior to reuse. CKD not returned to the production process is typically disposed in land-based disposal units (i.e., landfills, waste piles, or surface

impoundments), although some is also sold for beneficial reuse (Kumar and Puri 2013).
The cement plants generate large quantities of by-pass cement kiln dust during the manufacture of cement clinker constituting a great source of air pollution. The by-pass cement dust contains a mixture of raw feed, partly calcined cement clinker and some condensed volatile salts.

CKD was collected from a cement plant located in Fayoum city, Egypt. It was classified as SM as per specifications of Unified Soil Classification System, ASTM D 2487-06 (1998). Table 2 depicts CKD Chemical and Physical Analysis. Figure 1 shows XRD pattern of Cement Kiln Dust, collected from electrostatic precipitators.

Table 2. CKD Chemical and Physical Analysis

Chemical Analysis	Percentage
Silicon Dioxide, SiO2	17.62
Aluminum Oxide, Al2O3	4.90
Iron Oxide, Fe2O3	2.58
Calcium Oxide, CaO	62.09
Magnesium Oxide, MgO	1.93
Sodium Oxide, Na2O	0.56
Potassium Oxide, K2O	3.76
Sulfur Trioxide, SO3	5.79
Moisture Content	0.07
Loss on Ignition	4.94
Available Lime Index, CaO	33.70
Water-Soluble Chlorides, CL	--
Physical Analysis	
Retained on No. 325 sieve (%)	16.9
Specific Gravity	2.95

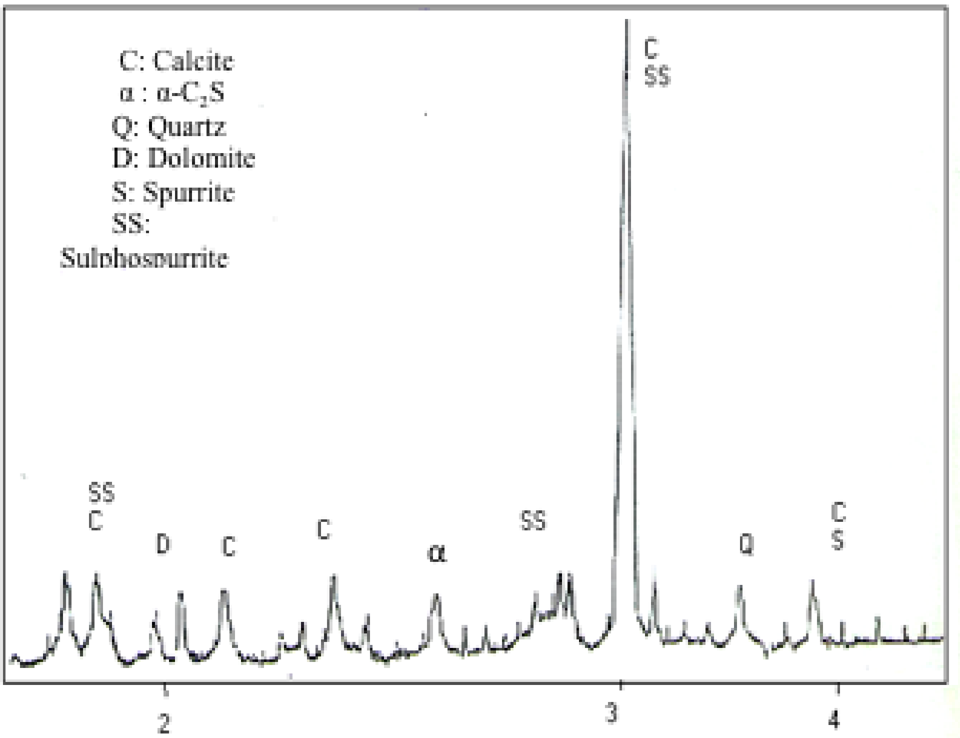

Figure 1. XRD Pattern of Cement Kiln Dust, Collected from Electrostatic Precipitators

4. SPECIMEN PREPARATION

Test samples were mixed from pulverized, air-dry soil and de-ionized water. Treated specimens were prepared following the nine-step protocol outlined here. Untreated control specimens were prepared in the same manner, but without the addition of the stabilizer product (CKD).

1. Using the modified Proctor compaction test, ASTM D 1557-91 (1998), the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for compaction were determined for the untreated soil. These values are listed in Table 1.

2. Based on the product literature, the recommended percentages of the stabilizer product were as follow: 2%, 4%, 6%, 8% and 10% for CKD.

3. The test soil was pre-moistened to a natural moisture content = 71.38 (Table 1). The soil was mixed dry of optimum at this point to allow for the water that would be added with the stabilizer in Step 6.

4. The pre-moistened soil was allowed to mellow for at least 16 hours in a sealed container.

5. The mass of stabilizer needed to achieve the recommended OMC in the treated sample was measured out.
6. The stabilizer was thoroughly mixed with the soil sample, which was then allowed to stand for 1 hour in a covered container. If there were no evaporation losses, the soil water content would now be equal to the OMC.
7. The treated soil was compacted using a modified Proctor effort, ASTM D 1557-91 (1998), extruded from the compaction mold, and sealed in a plastic bag.
8. The compacted soil was cured in a sealed plastic bag at room temperature for 7 days.
9. The cured sample was trimmed to an appropriate size for testing. If the specimen water content was more than 3% above or below the OMC, new specimens were prepared using adjusted initial water content. Almost all test specimens were within ±2% of the target OMC.

A seven-day curing period was selected as a reasonable delay to allow reactions between the stabilizer and the soil prior to conducting the evaluation tests. Laboratory assessments of soil stabilizers often include a 28-day cure following treatment; the additional three weeks may, depending on the stabilizer, yield additional changes in the soil properties. However, it is expected that significant changes due to an effective soil treatment should be measurable at seven days.

It is noteworthy that all specimens, whether untreated or treated, were compacted at the same optimum water content. In this study, however, the same water content was used to prepare all specimens of a given soil, so that the effect of the stabilizer on the measured soil properties could be distinguished from the effects of varying the water content. For the same reason, the samples were maintained at constant water content during the curing period.

5. LAB EXPERIMENTAL WORKS

A series of laboratory experiments have been conducted for varieties of samples. These experiments are to measure the engineering properties of the soil as follow:

5.1 Measurement of Specific Gravities

Specific gravities of untreated and treated clay subgrade soils have been determined based on the recommended percentages of the stabilizer product: 2%, 4%, 6%, 8% and 10%. Measurement of Consistency Limits

The liquid limit, plastic limit, and plasticity index of the natural and stabilized clayey soil samples were determined by Atterberg tests in accordance with ASTM D 4318 (1998).

5.2 Measurement of Swelling Potential

Many researchers have used the term swelling potential. However, a clear definition of the term has not been established. Generally, swelling potential has been used to describe the ability of a soil to swell, in terms of volume change or the pressure required to prevent swelling. Therefore, it has two components: the swell percent, which is defined as the percentage increase in height in relation to the original height, and the swell pressure, which is designated as the pressure, required to prevent swelling.

The swell percent of each test specimen was measured in accordance with ASTM D 4546 (1998). The apparatus used was the standard one-dimensional oedometer. The specimen in its ring was placed between two porous stones with load plate resting on the upper porous stone. The consolidation cell was assembled in the consolidation frame. The specimen was then loaded to a seating pressure of 2.4 kPa. The pressure was maintained until full settlement was achieved. The specimen was then flooded with water and allowed to swell under the seating load. Deformation readings were taken at 0, 0.5, 1.0, 2.0, 4.0, 8.0, 15.0, 30.0, 60.0, 120 and 1440 min, and then every four hours on subsequent days until no further changes in readings were observed and full swell was attained. The increase in vertical height of a sample, expressed as a percentage, due to the increase in moisture content was designated as the ‘‘swell percent’’.

5.3 Measurement of Grain Size Distribution

Grain Sieve analysis has been conducted for the untreated and treated clayey soils to measure the effect of CD stabilizer on the percent of finer and coarse materials.

5.4 Measurement of Compaction Characterization

The compaction parameters such as the maximum dry unit weight (MDD) and the Optimum Moisture Content (OMC) were obtained by Standard Proctor tests using modified effort in accordance with ASTM D 1557 (1998). For this procedure, natural soil and CKD were blended with various amounts of water. During the compaction process, a soil at selected water content was placed in five layers into a mold of standard dimensions, with each layer compacted by 25 blows of hammer dropped from a distance of 457 mm, subjecting the soil to total 56,000 ft-lb/ft3 compaction effort. Each material was evaluated at six different water contents. This established OMC for preparing all of the compacted soil specimens for swell and triaxial testing.

5.5 Measurement of California Bearing Ration and Consolidation Parameter

A portion of 6 kg materials was prepared at the OMC and compacted using a 2.5-kg mechanical hammer. The specimens were compacted in the three layers under 62 blows of hammer for each. After 7 days of moist-curing, the specimen was then soaked for 7 days in water and the other specimen continued to be cured until its old was 14 days. From the test results, an arbitrary coefficient CBR was calculated. This was done by expressing the forces on the plunger for a given penetration, 2.5 and 5 mm, as a percentage of the standard force.

5.6 Measurement of Shear Strength

To measure soil strength, unconsolidated-undrained (UU) Triaxial compression tests were conducted following ASTM D 2850 (1998). The shear strength of highway materials is often characterized using unconfined compression tests, but testing in a triaxial cell yields a more reliable measure of strength. This is especially true for fissured, compacted soils where the confining pressure keeps the specimen intact under load. The compacted and cured soil samples were trimmed into test specimens measuring 38 mm in diameter by 95 mm height at OMC and MDD. During shearing, volumetric strains were measured from changes in the volume of cell fluid. The cross-sectional area of each specimen was corrected using the axial and volume strains and assuming a right-circular cylinder shape.

6. RESULTS AND ANALYSIS

Based on the laboratory experiments, the soil is classified as Clay (Gs = 2.68 with 90.25% fines) with expansive behavior. Soil with PI > 35% is classified to have very high swell potential (Chen 19981), where LL and PI of the sample is respectively 74.85% and 39.95%. The effect of blending CKD on the physical properties of clayey soil can be described in the following subsections:

6.1 Effect of CKD Stabilizer on Specific Gravities

Specific Gravities (Gs) for the untreated and treated soils were determined and the results are plotted in Figure 2. As shown in Figure 2, by increasing CKD the specific gravity of the soil decreases by 6.0 % compared to the untreated sample. This indicates that the treated soil is lighter than that of its natural conditions.

6.2 Effect of CKD Stabilizer on Consistency Limits

The Atterberg limits (liquid limit, plastic limit and plasticity index) of the untreated and treated samples were determined following ASTM D 4318 (1998). The results are plotted in Figure 3 (a), (b), and (c). Results showed, in general, a decrease in liquid limit of all samples. The reduction reached 56.0% when using 10% CKD.

Results showed a fluctuation in plastic limit in some samples when adding CKD. In case of adding CKD 10%, reduction in plastic limit is observed.

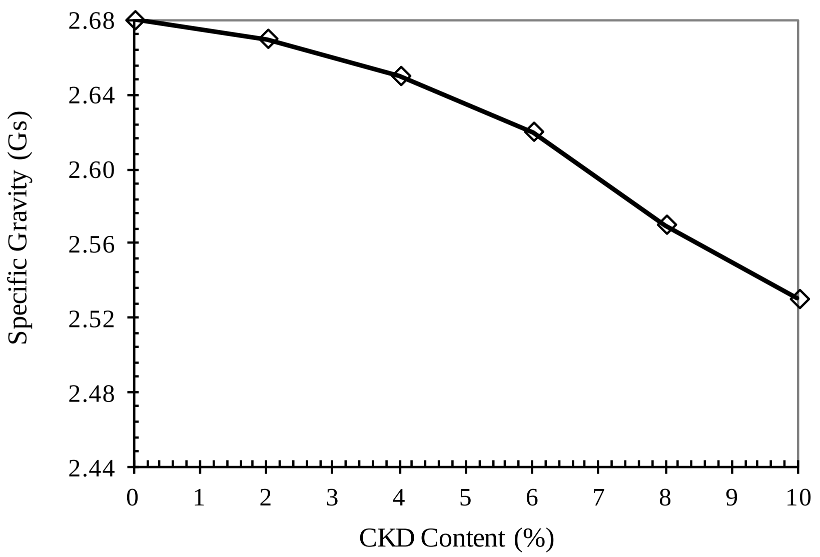

Figure 2. Effect of Blended CKD on the Specific Gravity of Soil

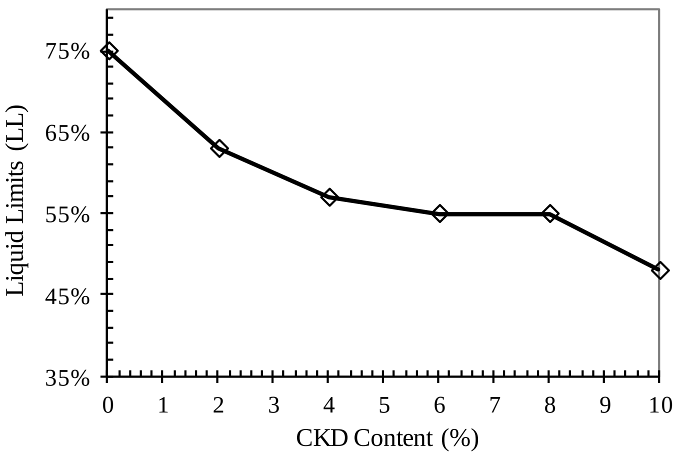

Figure 3-a: CKD Vs Liquid Limit

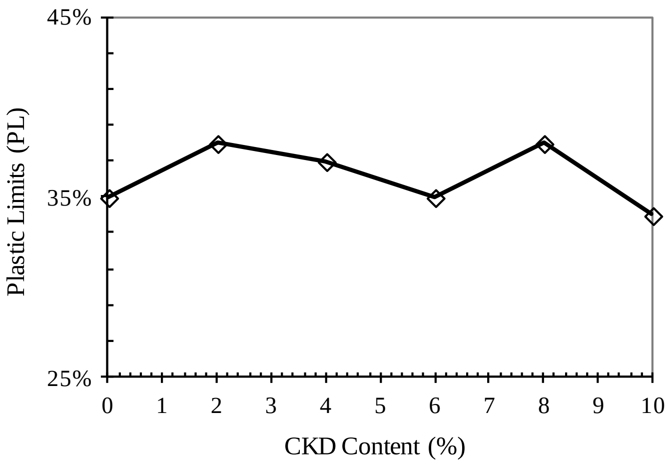

Figure 3-b: CKD Vs Plastic Limit

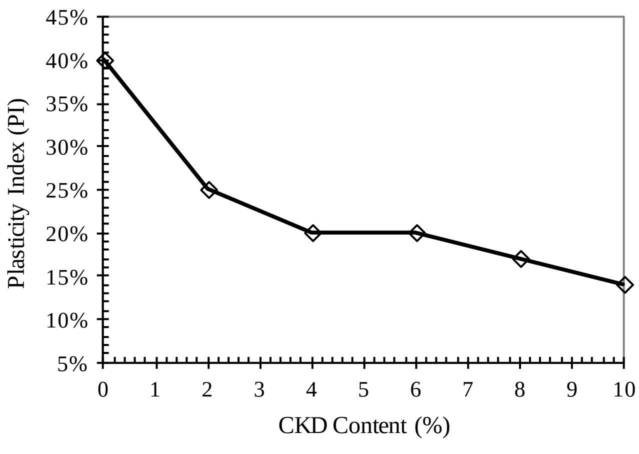

Figure 3-c: CKD Vs Plasticity Index

Figure 3. Influence of CKD on the Consistency Limits

(a) Liquid Limit (b) Plastic Limit (c) Plasticity Index

It can be also observed that CKD reduce the Plasticity Index (PI) up to 65% compared to untreated soils. CKD show reduction in plasticity between 40-65% when using CKD from 2% to 10% compared to the original condition. In conclusion, PI reduction occurred with CKD treatment, which indicates an improvement.

6.3 Effect of CKD Stabilizer on Swelling Potential

Swell percent test was carried out on untreated and treated samples to examine the effect of the various additives on the reduction of the swelling potential of the clayey soil. The swell percent value obtained for the untreated clayey soil was 50%. The swell results are presented in Figure 4, which indicates that swell potential decreases as well.

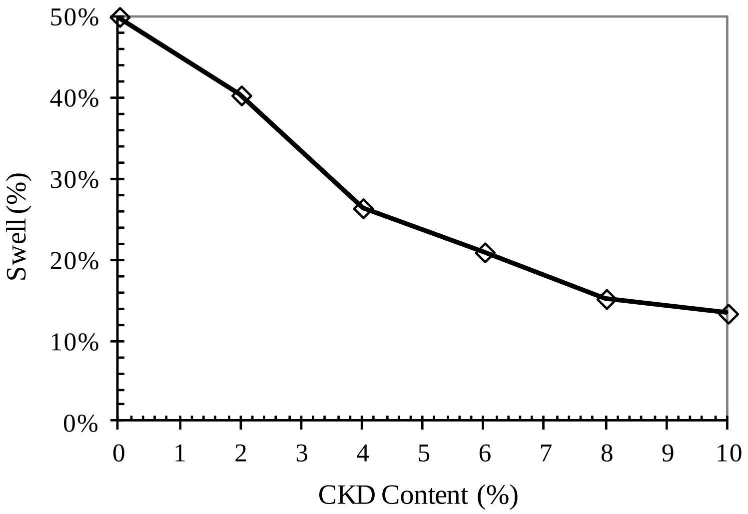

Figure 4. Influence of CKD on the Swelling Potential

It is clear from the test results that CKD significantly decreased the swelling of clayey subgrade soil. The swell percent of the clayey soil is reduced from 50% to 13%, i.e. 75% reduction when using 10% CKD stabilizer caused significant reduction in swell percent.

6.4 Effect of CKD Stabilizer on Grain Size Distribution

The effect of CKD on the Grain Sieve of clayey soil is presented in Figure 5. Figure 5 (a) shows that there is a significant decrease in the percent of finer particles. On the other hand, there is a significant increase in the coarse particles as shown in Figure 5(b). This result indicates that significant improvement in the clayey soil in terms of grain size distribution has been achieved.

6.5 Effect of CKD Stabilizer on Compaction Characterization

Moisture-unit weight curves for all the untreated and treated test soils were determined using a modified proctor compaction effort, ASTM D 1557-91 (1998). Figure 6 shows the variation of the optimum moisture content and maximum dry unit weight values of stabilized samples with CKD. There is an increase in the optimum moisture content and a decrease in the maximum dry unit weight due to the addition of CKD. The reason for increase in the optimum moisture content is due to the change in surface area of composite samples. The CKD changes the particle size distribution and surface area of the stabilized clayey soil samples. In the same way, the reason for the decrease in the maximum dry unit weight is the addition of higher amounts of CKD, which fills the voids of the composite samples.

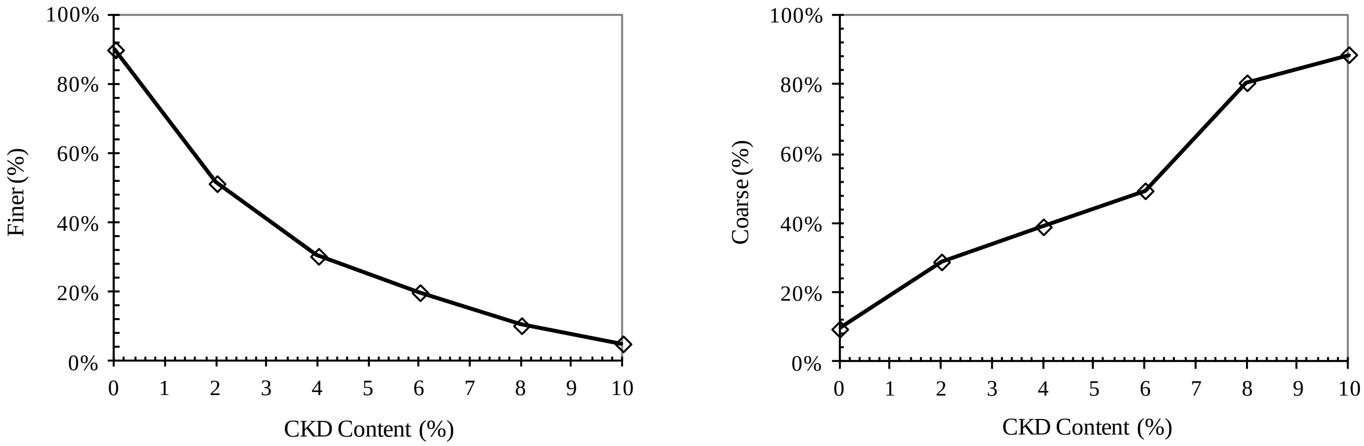

Figure 5-a: CKD Vs Finer Soil

Figure 5-b: CKD Vs Coarse Soil

Figure 5. Effect of CKD on the Grain Sieve of Clayey Soil
(a) Finer Particle of Soil and (b) Coarse Particle of Soil

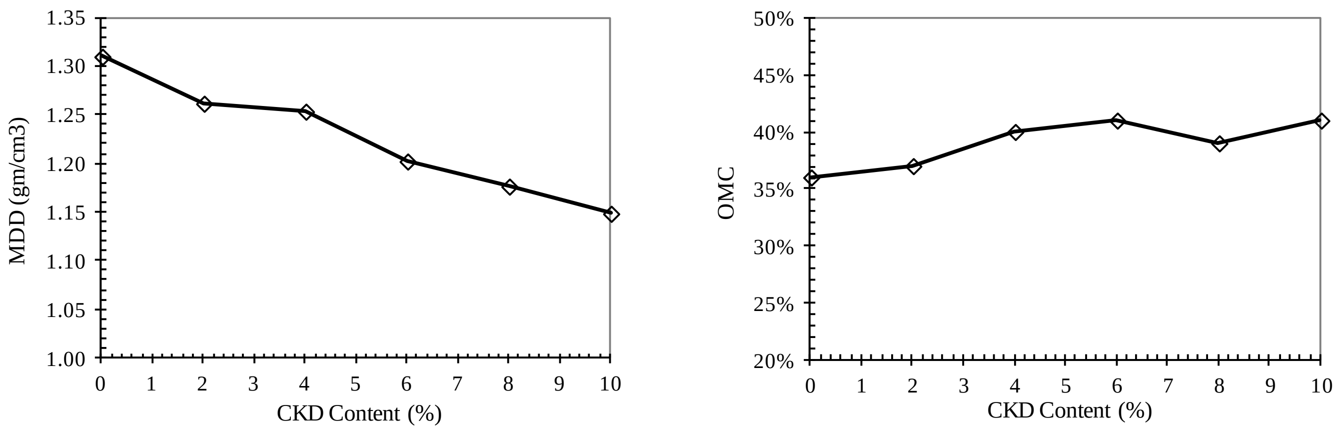

Figure 6-a: CKD Vs Maximum Dry Density

Figure 6-b: CKD Vs OMC

Figure 6. Influence of CKD on MDD and OMC of Clayey Soil
(a) Maximum Dry Density (MDD) and (b) Optimum Moisture Content (OMC)

Statistically speaking, the MDD is decreased by 12% when 10% CKD is added. The maximum reduction in MDD is observed when using 10% CKD. Equal reduction is also noticed when using 2-4% CKD. For OMC, the highest increase is observed with 6% CKD and 10 % CKD, which is 15% increasing compared to the untreated sample.

Compaction characterization of stabilized clayey soil with CKD is plotted in Figure 7. Note that the water contents of many test specimens were a little dry of the target optimum, due to evaporation losses during mixing. However, considering the normal variability obtained in preparing compacted soil samples, there appears to be no significant effect of the stabilizer treatments on the compacted soil unit weight or void ratio. Figure 7 shows that soil, which has been blended with CKD, is best to be compacted in the wet optimum state. Therefore, blended CKD has a place in construction work where a soil's moisture content is very high.

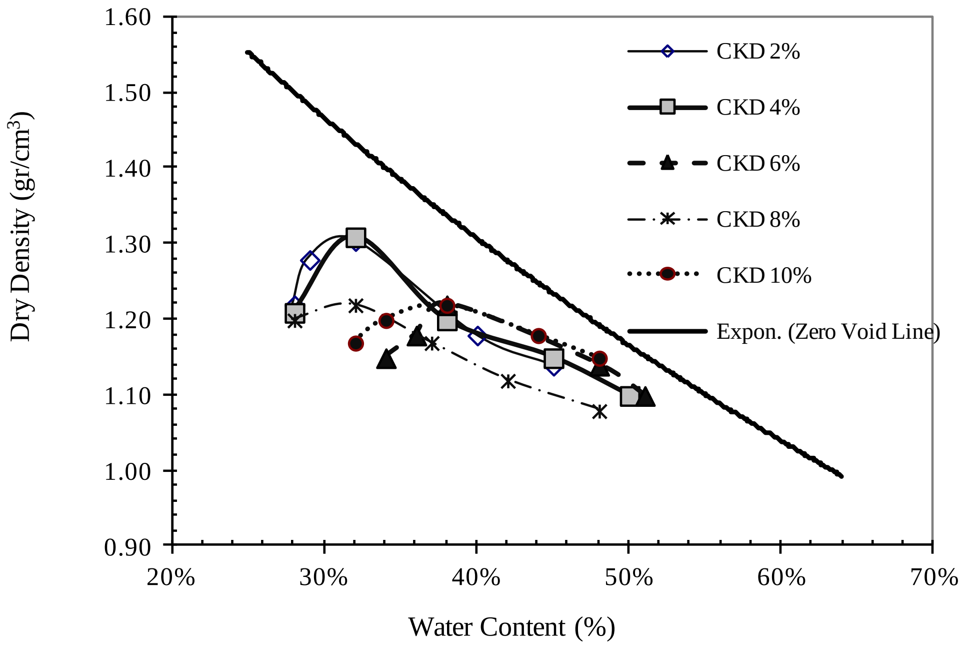

Figure 7. Compaction Characterization of Clayey Soil with Blended by CKD

6.6 Effect of CKD Stabilizer on CBR and Consolidation

Results of California Bearing Ration (CBR Laboratory) and Consolidation Parameter of soil when blending with CKD are presented in Figure 8. Figure 8(a) reveals a trend to enhance and attain the optimum CBR value at 6% CKD and 10% CKD. This means that the CBR of specimens, with the CKD addition 6-10%, was improved to approximately four times better than that of the untreated soil. This enhancement in the CBR is considered excellent improvement to the bearing capacity of the soil. Figure 8(b) shows the compressibility index (Cc) tends to be non-linear. This condition exhibits that when the rate of consolidation is rapid, the settlement of the soil will reduce.

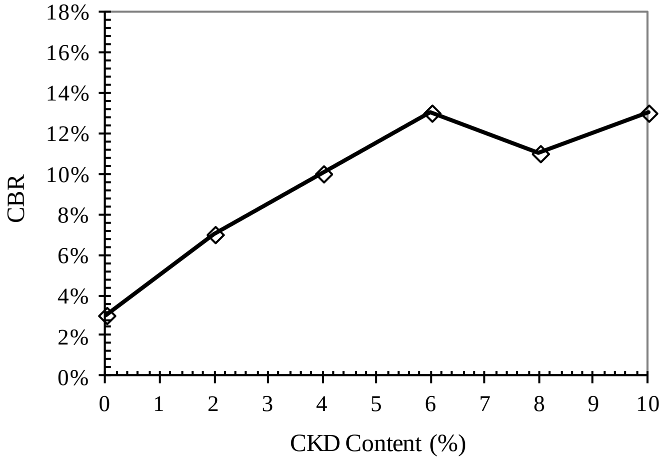

Figure 8-a: CKD Vs CBR

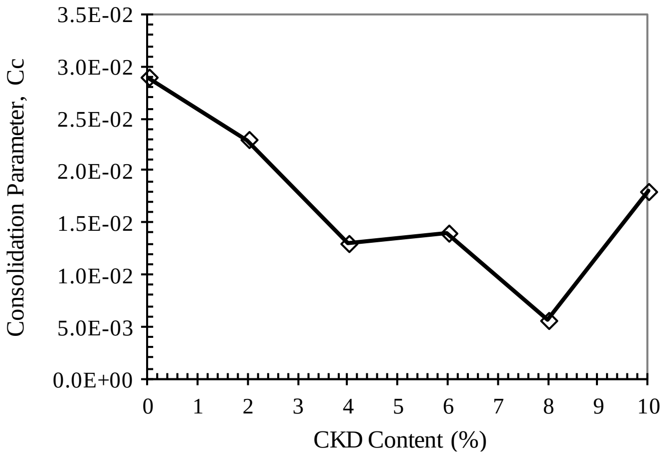

Figure 8-b: CKD Vs Compressibility Index

Figure 8. California Bearing Ration (CBR Laboratory) and Consolidation of stabilized Soil with CKD
(a) CBR Laboratory and (b) Compressibility Index (Cc)

6.7 Effect of CKD Stabilizer on Shear Strength

Typical results, from UU Triaxial tests, are plotted in Figure 9. Stress-Strain behaviour of clayey soil under Triaxial Test is presented in Figure 10. In general, the shear strength parameter, cohesion and internal angle can be enhanced by addition of CKD.

It can be observed from Figure 9 that using up to 6% of CKD has minimal or no effect on shear strength when mixed with clay soils. The effect of CKD starts to appear when CKD is added by above 6%. In conclusion, the soil strength is enhanced and the maximum ultimate strength is attained at 6-10% CKD. Figure 10 shows brittle behavior of the soil when mixed with CKD.

Therefore, it can be concluded that CKD can improve the engineering properties of clayey subgrade soils. Practically, the effective CKD could be blended in the range of 4-8%.

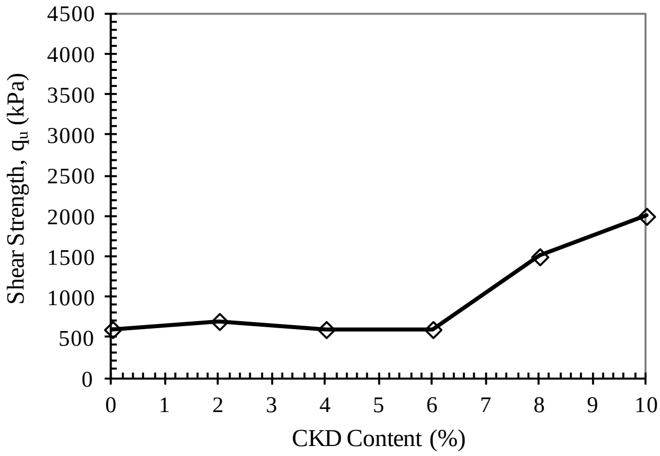

Figure 9-a: CKD Vs Shear Strength

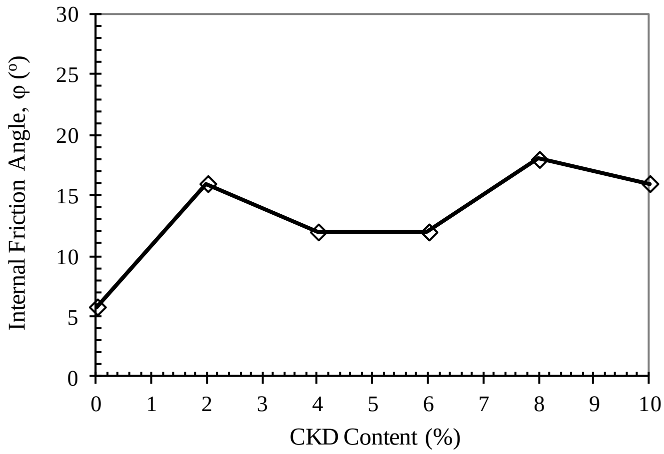

Figure 9-b: CKD Vs Internal Friction

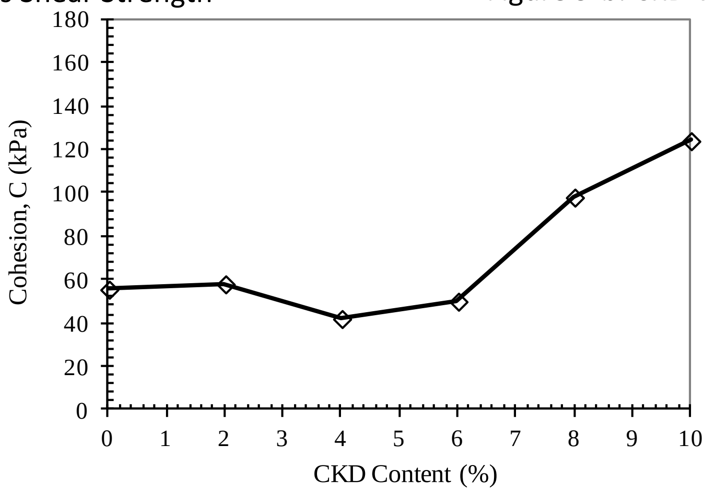

Figure 9-c: CKD Vs Cohesion

Figure 9. Effect of CKD on the Shear Strength of Clayey Soil
(a) Shear Strength of Soil ($q_{ultimate}$), (b) Internal Friction Angle (ø), and (c) Cohesion

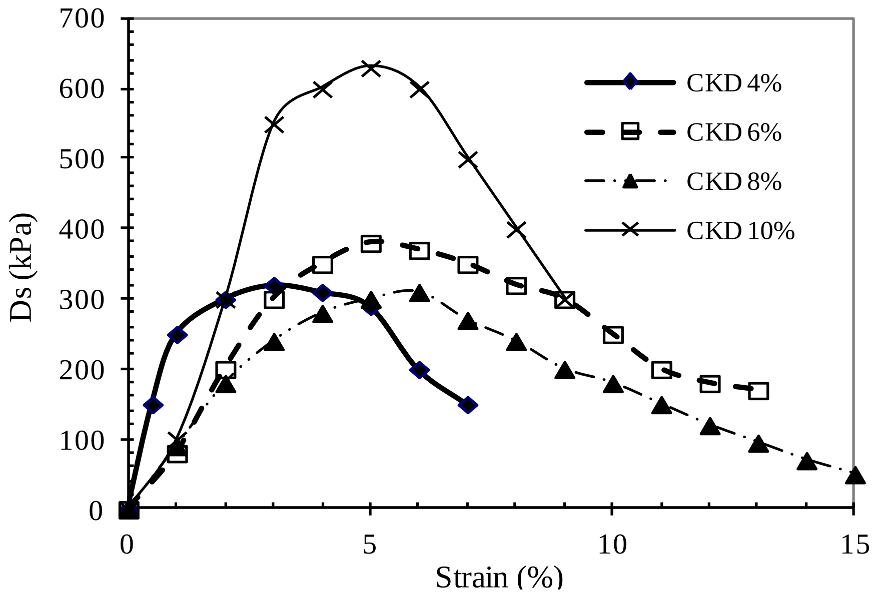

Figure 10. Stress-Strain Behavior of Clayey Soil under Triaxial Test

7. CONCLUSIONS

Cement Kiln Dust (CKD) can be used as unusual soil stabilizer to improve the engineering properties of clayey subgrade. CKD is solid waste materials produced from the manufacture of cement factories. In this study, the effect of adding CKD on the engineering properties of clayey subgrade soils has been investigated. A series of laboratory experiments have been conducted for varieties of samples: 2%, 4%, 6%, 8% and 10 % for CKD. The following conclusions have been drawn:

- The CKD decreases the specific gravities of the clayey soil samples. This indicates that the treated soil is lighter than that of its natural conditions.
- The CKD decreases the liquid limits and plasticity index; and increases the plastic limits in all the stabilized clayey soil samples. For this reason, the soil types of composite samples with high CKD contents change from high plastic to low plastic.
- The CKD has shown a significantly decreasing in swelling potential.
- The CKD has a significant decrease in the percent of finer particles. On the other hand, there is a significant increase in the coarse particles.
- The CKD changes compaction parameters. The addition of CKD increases the optimum moisture content and decreases the maximum dry unit weight.
- The CBR of specimens was improved to approximately 4-times better than that of the untreated soil.
- The shear strength, internal friction angle and cohesion of clayey soil samples increase due to the addition of CKD.
- The modification of clayey subgrade soils using CKD can be a viable and innovative method to enhance the engineering properties.

These findings are considered vital in improving the engineering properties of the clayey soils.

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