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Experimental Study on the Utilization of Cement Kiln Dust for Ground Modification

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Abstract. In recent years, use of various waste products in ground construction and modification has gained considerable attention worldwide in view of increasing costs of waste disposal, and environmental constraints. One of these waste products is the cement kiln dust, which is a by-product of Portland cement manufacturing process. It is generated from burning the raw materials in a rotary kiln to produce clinker. Generally, for each one ton of clinker, a typical kiln generates around .06 - .07 ton of cement kiln dust.

In this study, first, an overview of physical, chemical, and mechanical properties of kiln dust that related to utilization in ground modification are presented. These properties are presented for different samples collected from cement manufactures in central, eastern, and southern regions of the Kingdom of Saudi Arabia. Second, the effect of adding different percentage of cement kiln dust on the engineering properties of three different problematic soils in the central region of Saudi Arabia was investigated. The results show significant improvement in their engineering properties. The plasticity index and liquid limit of clays decrease significantly as the percentage of added cement kiln dust increases. The optimum moisture content and the maximum dry density of dune sand increase as the added cement kiln dust increases. The unconfined compressive strength was found to increase substantially during the first seven days. The permeability of treated dune sand was found to reduce significantly better than that of treated soil with cement. And finally the collapse potential of treated collapsing soil with cement kiln dust was reduced significantly.

Introduction

Cement Kiln Dust (CKD) is a by-product of Portland cement manufacturing process. It is generated from burning the raw materials in a rotary kiln to produce clinker. The production of one ton of cement involves the commination of about 2.6 to 2.8 tons of raw materials. Between 5 and 10% of these finely pulverized materials will be agitated and thus suspended as dust in gases [1]. Generally, for each one ton of clinker, a typical kiln generates around .06 - .07 ton of CKD [2].

The total annual production of Portland cement in Saudi Arabia has increased from 0.667 million tons in 1960 to more than 14.3 million tons in 1995, and is expected to exceed 20 million tons in 1998. The figures on CKD production are not precise. CKD production in Saudi Arabia is now estimated to be 1.2 - 1.4 million tons per year. This present quantity is projected to continue to increase in the future due to the ever increasing cement production and recent restrictions on air pollution in the Kingdom. These waste materials are dumped on big areas. In recent years, use of various waste products in ground construction has gained considerable attention worldwide in view of increasing costs of waste disposal, and environmental constraints.

In this paper, an overview of physical, chemical, and engineering properties related to utilization in ground modification of kiln dust collected from central, southern, and eastern regions of the Kingdom will be presented. The main objective of this research is to investigate the suitability of using CKD collected from central region to upgrade and enhance the engineering properties of three different types of soil which have proved to be difficult for construction and/or which have caused problems for previously completed projects in the central region of the Kingdom.

Test Materials

(1) Cement kiln dust

Cement kiln dust exhibits variability in chemical composition and physical characteristics depending on the source and type of raw materials, plant operation, extracting and disposal practices. Samples of CKD were acquired from local cement manufacturing plants in central, southern and eastern regions of Saudi Arabia. Table 1 presents the typical physical and chemical properties of dust samples. CKD is generally grayish in color and consists of predominantly silt-sized, nonplastic particles with a uniform gradation and is classified as ML using the Unified Soil Classification system based on the grain size (Fig. 1) and nonplastic characteristics of the material. Data on the chemical analyses of the dust shown in Table 1 were provided by the cement manufacturing companies.

The test results showed that CKD samples collected at various locations in Saudi Arabia contain significant amount of calcium oxide (CaO) that gives it good pozzolanic characteristics. The variability of collected CKD is not very significant. Saudi CKD is similar in composition to American CKD [3-4]. Thus tested CKD is not a hazardous waste material according to U.S. Bureau of Mines [4].

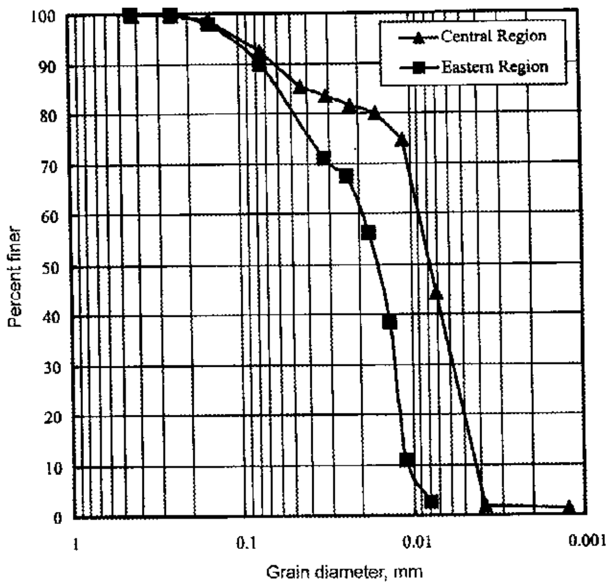


Fig. 1. Grain size distribution curve for the cement kiln dust.

Table 1. Physical and chemical properties of CKD

Property	Region		
	Central	Southern	Eastern
Specific gravity	3.01	-	3.16
Sand %	7.5	-	10.2
Silt %	91.0	-	89.8
% Passing Sieve # 40	100	-	100
Chemical Compound (%)			
Silica (SiO_2)	15.73	17.74	15.69
Aluminum Oxide (Al_2O_3)	5.01	5.26	4.22
Iron Oxide (Fe_2O_3)	2.41	3.01	4.66
Calcium Oxide (CaO)	63.59	54.79	63.18
Magnesium Oxide (MgO)		1.33	1.14
Sulfur Oxide (SO_3)	1.97	4.06	3.24
Sodium Oxide (Na_2O)	0.26	0.20	0.26
Potassium Oxide (K_2O)	1.33	1.38	2.14
Loss on Ignition	8.69	11.66	4.40

(2) Soils

In this study, CKD obtained from cement manufacturing plant in Riyadh, was added in various proportions to upgrade and enhance the engineering properties of dune sand, collapsing soil and highly swelling clay (In order to have an active clay in powder form, easy to prepare and with consistent characteristics, montmorillonitic clay commercially available for drilling and grouting "Bentonite" was used in this study). The soils chosen represent a selection of recurring problematic soil types found in central region of Saudi Arabia that have been troublesome to projects and construction activities. Table 2 summarizes the properties of these soils.

Table 2. Properties of soils used in the present study

Property	Dune sand	Collapsing soil	Bentonite
Liquid Limit %	-	23.1	228
Plastic Limit %	-	21.2	51
Specific Gravity	2.67	2.75	-
Sand %	97.7	36.2	-
Silt %	2.3	46.2	-
Clay %	-	17.0	100
D_{10} (mm)	.28	.001	-
D_{30} (mm)	.22	.008	-
D_{60} (mm)	.09	.06	-
Dry field density (kN/m^3)	-	12.1 - 13.3	-
Natural water content (%)	-	1.3 - 4.2	-

Test Program and Procedures

Laboratory tests were coto assess the feasibility of utilizing CKD to improve the engineering properties of three different types of soil. The conducted tests include plasticity, moisture-density relationships, unconfined compressive strength, and wetting induced collapse. Plasticity and permeability tests were performed on duplicate specimens to obtain average results. If the test results had significant variability, then additional tests were performed before averaging.

(1) Plasticity

Plasticity characteristics of the CKD-treated highly swelling clay (bentonite) were determined by performing the Atterberg's limits tests. The tests were performed in accordance with American Society for Testing Materials (ASTM) specifications. The percentage of the CKD ranged between 0 and 40%.

(2) Compaction test

Compaction characteristics of CKD, dune sand and mixtures of dune sand and cement and CKD were investigated by performing Standard Proctor Test (ASTM D698) immediately following mixing.

(3) Unconfined compression test

Specimens for the unconfined compression test (38 mm in diameter and 76 mm in high) of dune sand stabilized with cement and CKD were prepared by mixing the desired proportions of water, cement or CKD, and dune sand. Immediately following mixing, specimens were prepared by compressing predetermined weight of each mixture to a predetermined volume in a split mold in three layers at their optimum moisture contents and maximum dry densities. A curing program of different curing conditions was carried out. Each of the curing conditions listed below was monitored for a period of 7 days and applied to cement-sand and CKD-sand mixtures.

a. Normal curing: specimens were sealed in airtight polythene sheets. The The temperature was maintained at 23°C.
b. Low humidity: specimens were unsealed and cured at room temperature of 22°C with 23 percent relative humidity.
c. High humidity: specimens were unsealed in an environmental chamber at 23°C and 98% relative humidity.

Testing in unconfined compression was conducted at a controlled strain rate of 0.5 mm/min and at least three specimens were tested for each case.

(4) Permeability

The falling head permeability test was used to determine the coefficient of permeability, K, of each dune sand mixture. The permeameter was 74 mm in diameter and 20 mm in height. The specimens were compacted at their respective optimum moisture contents and maximum dry densities. Measurements were taken for a period of two to three days.

(5) Collapse tests

In order to evaluate the effectiveness of CKD for improving collapsible soil, single oedometer test was performed. Dry CKD was added to dry soil and thoroughly mixed. After adding 5% water and remixing, the batches were allowed to cure in sealed plastic bags for 24 hours. The tests were performed on specimens with initial dry density of 11.8 or 13.3 kN/m^3. Density was directly controlled in standard 63.5 mm diameter oedometer ring by tamping. The test was performed as per ASTM D5333 procedure. Specimens were incrementally loaded up to a specific pressure (100, 150, or 200 kPa) and then inundated with water.

Analysis of Test Results

(1) Plasticity

The results of Atterberg's limits tests on bentonite with various percentages of CKD cured for two hours are shown in Fig. 2. The plastic limits at different CKD percentages are found to have relatively minor changes with increase in CKD content, while the liquid limit shows a sharp decrease with the addition of 10% CKD, the decrease becomes small as the addition of CKD increases. This reduction in the liquid limit is attributed to cementitious properties of CKD due to the high content of calcium oxide. As shown in Fig. 2, the reduction in plasticity index was initially significant and less so with additional CKD added. Zaman *et al.* [4] found that addition of CKD resulted in a reduction of liquid limit and sharp increase in plastic limit of expansive soil. This dissimilar behavior may be attributed to the fact that in case of soils having expanding type of lattice minerals, the contribution due to diffuse double layer overrides and primarily governs the liquid limit. Thus soils containing expanding lattice type of minerals (illite and montmorillonite) are bound to behave in a different way compared to the other less active soils. Liquid limit determinations traditionally produce greater variation in observed effects since liquid limit is far more sensitive than plastic limit to the cation present [6].

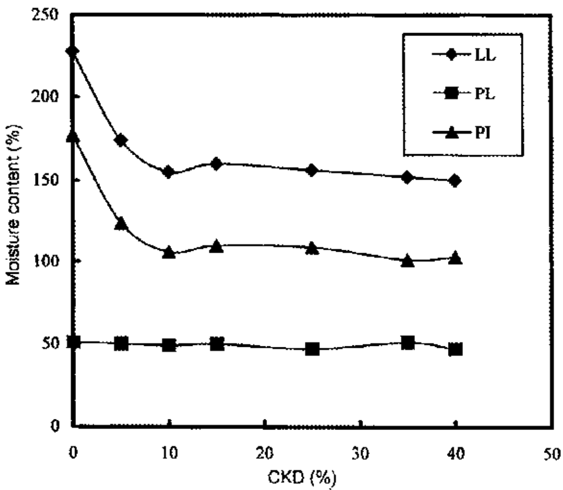


Fig. 2. Variation of plastic properties of Bentonite with increasing CKD content.

Treatment with CKD represents a definite advantage in stabilizing clays. With the decrease in plasticity index and liquid limit, the engineering properties of the high plasticity clays are improved. Also a reduction in plasticity index means an increase in the workability of the soil having less affinity for water.

(2) Compaction characteristics

Experience has shown that dune sand is difficult to compact and it lacks lateral confinement. Thus, the ability to stabilize this abundant soil in Saudi Arabia would be economically attractive.

The standard Proctor compaction curve of the CKD tested in this study is shown in Fig. 3, which shows a typically shaped curve with a single peak, with maximum dry density of 14.2 kN/m^3 at optimum moisture content of 25%.

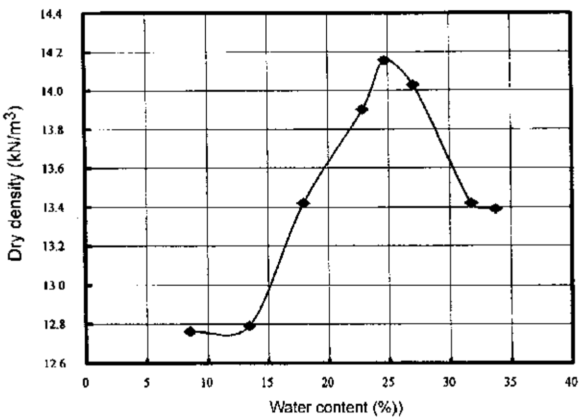


Fig. 3. Compaction curve for CKD.

The relationship between the moisture content and dry density for treated and untreated dune sand using standard Proctor compaction test is shown in Fig. 4. It is noted that the maximum dry density of untreated dune sand is attained when the sand is air-dried. When water is added, dry density drops until it reaches a minimum at about 2% to 4% moisture content due to surface tension between sand particles which resists the re-orientation of sand particles relative to one another. Beyond that, the dry density increases but its relationship with moisture content becomes fluctuating and unstable as seen in Fig. 4. The addition of cement or CKD to dune sand changed the compaction curve from one that shows a peak at a moisture content very close to zero and shows decreasing in density with increasing in moisture content to a typical one hump curve (see Fig. 4).

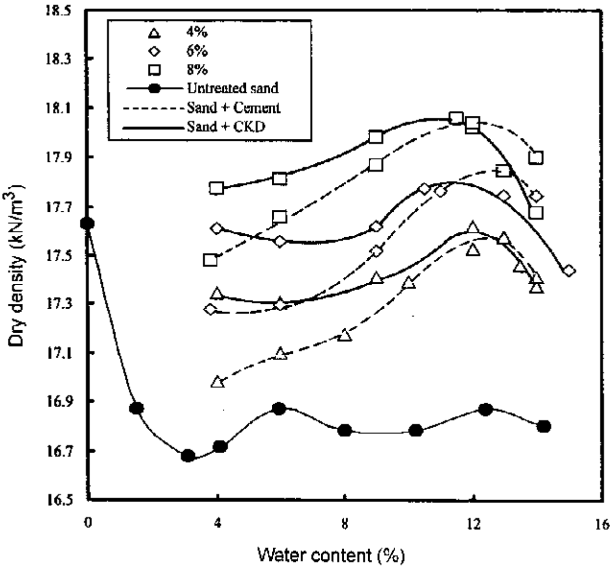


Fig. 4. Standard Proctor test results on dune sand with various cement and CKD contents.

The curves for maximum dry density and optimum moisture content versus the percent of additive are shown in Fig. 5. Cement and CKD gave similar results. The addition of 4% cement or 4% CKD to dune sand produced a significant increase in the optimum moisture content and a slight decrease in the maximum dry density. Beyond that, it is observed that the level of additives has little or no effect on the optimum moisture content with an increase in the maximum dry density throughout the range of additive percentages tested.

(3) Unconfined strength

The compressive strength is an important factor in evaluating the quality of stabilized soils. Typically, relations have been developed relating unconfined compressive strength to other material characteristics (e.g. flexural strength, modulus.... etc.) for stabilized soils.

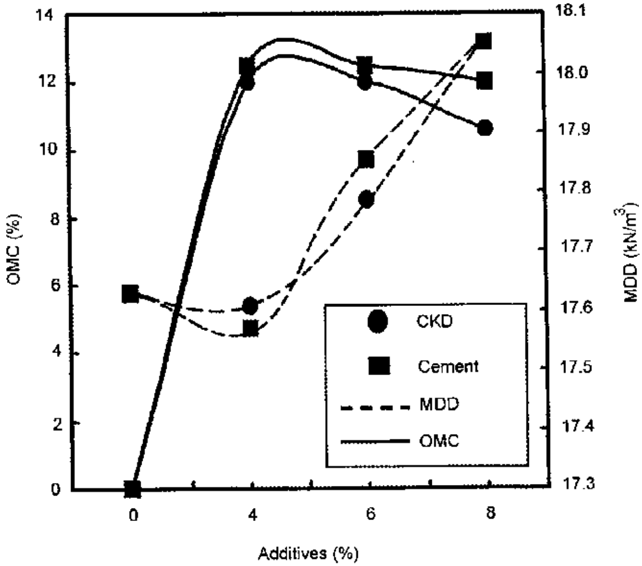


Fig. 5. Variation of optimum moisture content and maximum dry density with cement and CKD additives.

Strength gain for compacted CKD was determined using the unconfined compressive test. Fig. 6 shows the strength development with time for compacted CKD at optimum moisture content (OMC) and maximum dry density (MDD) after normal curing. The initial slope of the strength-time curve is indicative of the early selcharacteristics of the CKD. Most of the strength gain for compacted CKD occurs within the first 7 days after compaction.

The effects of adding cement or CKD or mixture of cement + CKD on the unconfined compressive strength of treated dune sand after 7 days are shown in Fig. 7. As evidenced from this figure, the compressive strengths of treated dune sand were increased substantially as a result of stabilization. Strength gain is obtained through cementation. The strengths attained with CKD are much lower than those attained with cement. Studies on stabilizing highly expansive clay with cement and CKD by Zaman et al. [4] indicated similar findings. This behavior is attributed to the high loss on ignition value of CKD, 8.7 percent, compared to that of cement, which is less than 1 percent. From the curves presented in Fig. 7a at normal curing, increasing cement content causes considerable increases in the strength of treated dune sand. A slight increase is observed with increasing CKD content. The results show that adding CKD (see Fig. 7c) can intensify the improvement in strength of the cement-stabilized dunes. For example, From Fig. 7c, for 4% cement + 4% CKD, the unconfined compressive strength of treated sand is about 1.60 times that of 4% cement only. For the CKD-sand the UCS results are slightly higher than the cement results for samples cured at low humidity, which is typical in a hot, arid area in Saudi Arabia (see Fig. 7b). Unlike cement, dry curing had no adverse effect on strength of CKD treated sand as shown in Figs. 7a and 7c.

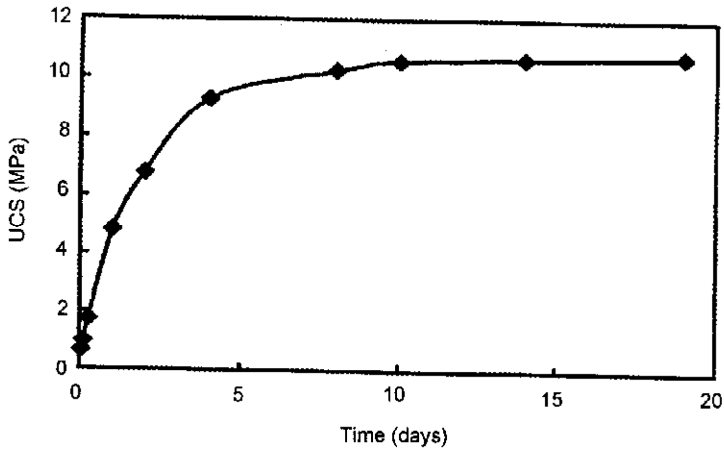
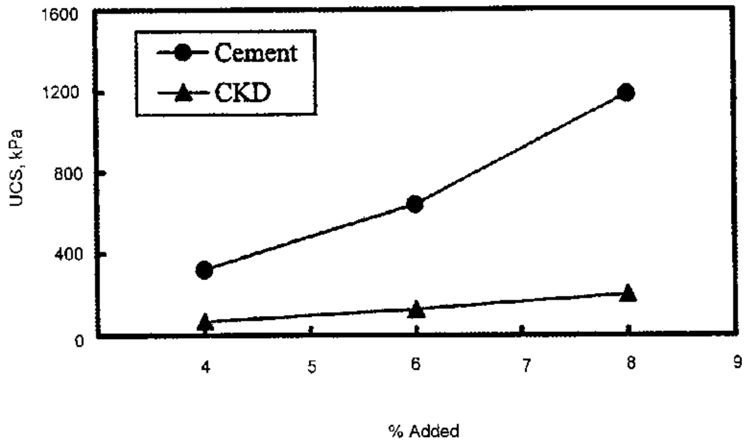


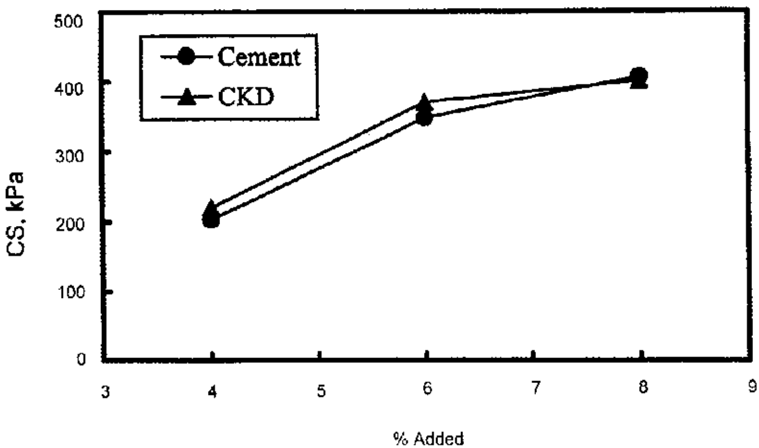
Fig. 6. Variation of UCS with time for 100% CKD at OMC and MDD.

(4) Permeability

To utilize CKD as potential barrier material for seepage control, its permeability is the property of principal concern. Results of the permeability tests are presented in Table 3. The addition of CKD to the dune sand presented a more pronounced effect on permeability compared to cement. The significant reduction in permeability of sand-CKD is primarily due to its low specific gravity (3.01 compared to 3.16 for cement) and suitability in changing the void structure of the sand. The measured coefficient of permeability (3×10^{-8} cm/sec) for compacted CKD correspond to those associated with clay. The CKD with such low permeability show a great potential for use as seepage control, since current design criterion for an earthen liner at a hazardous waste site is to achieve a permeability of less than 1×10^{-7} cm/sec [7].

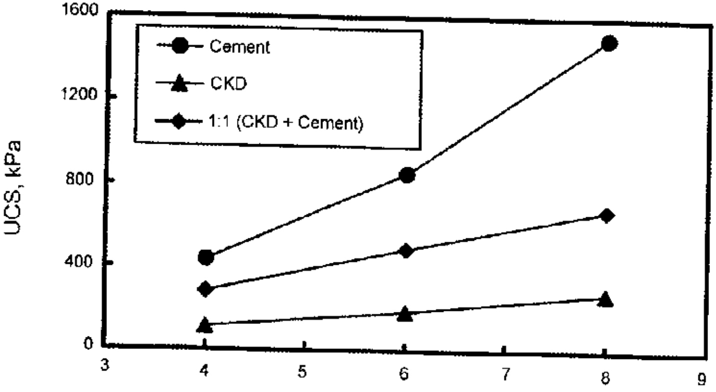


(a) Normal curing



(b) Low humidity (22%) curing

Fig. 7. Variation of UCS with % added for treated dune sand at different curing conditions.



(c) High humidity (98%) curing

Fig. 7. (Continued).

Table 3. Summary of permeability test results.

Material	Density (kN/m^3)	Permeability, K (cm/sec)
Sand	18.1	2.5×10^{-3}
CKD	14.1	3×10^{-8}
Sand + 8% CKD	18.1	3.2×10^{-6}
Sand + 8% cement	18.1	1.2×10^{-4}

(5) Collapse behavior

Utilization of cement to reduce collapse potential was proposed by Bara [8]. Ismael et al. [9] found that collapse potential was substantially reduced by the addition of cement. Stabilization of collapsing soil with CKD can provide a tremendous economic advantage as an alternative to cement.

Results from a typical oedometer collapse test are shown in Figure 8. The results indicate that the amount of collapse observed for untreated soil exceeds 17% at a load intensity of 100 kPa, compared to 10% observed for soil treated with 5% CKD at a density of 11.8 kN/m^3. Miller et al. [10] report that addition of CKD nearly eliminates the collapse potential for their tests on compacted shale.

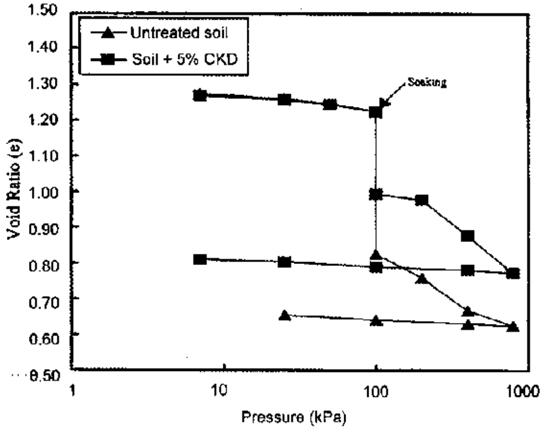


Fig. 8. Oedometer collapse test on untreated and CKD treated soil.

Figure 9 shows the variation of amount of collapse with CKD content for two initial dry densities at three stress levels. The results indicate that collapse potential is significantly reduced with increasing of CKD content specially with high initial density up to 10% CKD, then generally tended to remain constant.

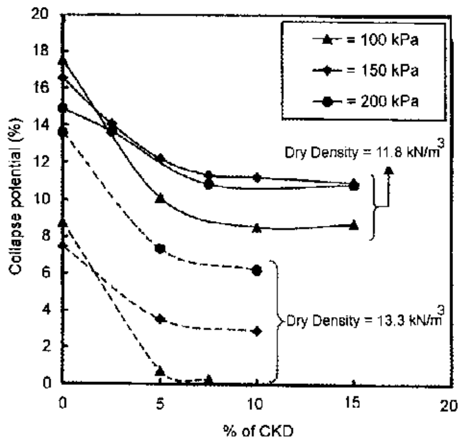


Fig.9. Variation of amount of collapse with CKD content.

Conclusion

A laboratory study was undertaken to evaluate the ability of cement kiln dust (CKD) generated by cement manufacturing plants to improve the engineering properties of three different problematic soils in the central region of Saudi Arabia. CKD has been demonstrated to be an economical effective stabilization agent. The significant findings are:

1. Treatment of clay with CKD will decrease the plasticity index and liquid limit, which resulted in an improvement of the clay engineering properties. The amount of CKD for stabilization of clay is around 10%.

2. An addion of CKD to dunes sand will improve the compaction characteristics in a similar way to the treated soil with cement.

3. The unconfined compressive strength of treated soil with CKD compacted at the OMC and MDD was noticed to increase substantially within the first seven days. Also, the strength of cement-stabilized dune sands can be improved by adding CKD.

4. Considering the seepage control, the CKD was approved to have more pronounced effect on the reduction of the dune sand permeability compared to cement.

5. The CKD can provide a tremendous economic advantage as alternative stabilized material of collapsing soil to cement. This is due to the significant reduction in the collapse potential for treated soil with CKD.

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دراسة تجريبية على استخدام غبار الأسمنت لتحسين التربة

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(أستلم في ١٩٩٨/٣/٣٠م ، وقبل للنشر في ١٩٩٨/١٠/٣م)

ملخص البحث. يستحوذ استخدام أنواع مختلفة من المخلّفات في أعمال المنشآت الأرضية وتحسين موادها على اهتمام المتخصصين في مجال هندسة التربة نظرا لزيادة تكاليف التخلص من هذه المخلّفات بالإضافة إلى تزايد القيود البيئية. ومن هذه المخلّفات ما يسمى بغبار التنّور الأسمنتي. و هو عبارة عن ناتج ثانوي مصاحب لعمليات تصنيع الأسمنت البورتلاندي. ويتكون أثناء حرق المواد الخام في التنّور الدوّار المخصص لإنتاج الخبث. وعموما فإن كل طن من الخبث يولّد حوالي ٠,٠٦ إلى ٠,٠٧ طن من غبار التنّور الأسمنتي.

تمّ في هذه الدراسة أولًا إلقاء نظرة شاملة على الخواص الفيزيائية ، الكيميائية والميكانيكية لغبار التنّور الأسمنتي المتعلقة باستخدامه في تحسين مواد التربة. هذه الخصائص محددة لعيّنات جمعت من مصانع الأسمنت المقامة في وسط ، شرق، و جنوب المملكة العربية السعودية. و تمّ ثانيًا دراسة تأثير إضافة نسب مختلفة من غبار التنّور الأسمنتي على الخصائص الهندسية لثلاثة أنواع مختلفة من التربة ذات المشاكل الهندسية المتواجدة في الجزء الأوسط من المملكة العربية السعودية. وُجِدَ من النتائج المعملية تحسن الخصائص الهندسية لهذه الترب بعد إضافة نسب محدّدة من الغبار الأسمنتي. حيث وجد أن معامل اللدونة وحَدّ السيولة للتربة الطينية يقلّان بحدة كلما زادت نسبة الغبار التنّوري المضاف، ثم تستقر عند نسبة تساوي تقريبا ١٠٪ للغبار المضاف. أيضًا تحسنت خواص الدمك للتربة الرملية وذلك بزيادة القيمة العظمى للمحتوى المائي و القيمة العظمى للكثافة الجافة كلما زادت نسبة الغبار التنّوري. أما قيمة قوة الضغط الغير محتواة فتزيد بحدة خلال السبعة الأيام الأولى من إضافة الغبار التنّوري للتربة. كما وجد أن النفاذية للرمل المعالج تقل بصورة كبيرة وتعطي نتائج أفضل من نتائج النفاذية للتربة المعالجة بالأسمنت. و أخيرا فإن معالجة التربة القابلة للانهيار بالغبار التنّوري يقلل بقدر كبير طاقة الانهيار لهذا النوع من التربة.