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IMPROVIG OF SAND DUNES USING THE CARBONATED CEMENT KILN DUST (CCKD) AND ULTRA-PURE SODIUM HYDROXIDE SOLUTION (NaOH)

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1 Abstract

Sand Dunes are one of the most common types of desert soil formations which are very abundant especially in Western Desert of Egypt. This soil represents difficult obstruction against urban development in those places. It causes problems for structures because of its low strength, excessive settlement, obstruction and difficulty of compaction in field due to its permanent movement, high permeability and uniformity of its small particles. This research aims to study the possibility of using dune sand after improving their properties in various projects rather than importing sand from distant quarries so as to reduce the cost, especially in road projects where the sources of the materials used is one of the most important factors affecting the cost. In this study, one of the waste materials for cements industry, carbonated cement kiln dust (CCKD) brought from Helwan Cement Company in Egypt, was used with the purpose of preserving the environment and reducing the costs. Also, ultra-pure sodium hydroxide solution (NaOH) purchased from LOBA Chemical Company in India was added. Three different ratios of (CCKD), 10%, 20%, and 30% by the weight of soil, in addition of 10% of (NaOH) by the weight of (CCKD) were added to a dune sand soil brought from Wadi El Rayan, Fayoum governorate. Compacted specimens were prepared using the optimum moisture content. These specimens have been cured for 1, 7, and 28 days in air. Tests were carried out to determine the unconfined compressive strength (UCS), direct shear parameters (c and Ø), collapsibility index (Ie), and California bearing ratio (CBR) after soaking. The results of laboratory tests indicated significant increases in the unconfined compressive strength. More enhancements occurred at late ages. If 20% CCKD or more is mixed in addition of 10% NaOH and allowed to cure for a certain period of time (say 7 days), the mixture has an unconfined compressive strength that is much higher than that of very stiff or hard clays. The bearing capacity provided by such mixtures will be sufficient to support a moderate-rise building. Cohesion of the mixture was increased with the increasing of the CCKD ratio, while, the angle of internal friction (Øº) was not affected by the CCKD ratio. The increase of CCKD content achieved considerable increase for CBR. Dune sand stabilized with 10% or more of CCKD with 10% NaOH had CBR more than 40% which can be used as sub-base layers for roads. In general, all CCKD ratios appeared negligible collapsibility.

الملخص العربى

تحسين خصائص الكثبان الرملية باستخدام تراب الأسمنت المكربن ومحلول هيدروكسيد الصوديوم

تعد الكثبان الرملية من أكثر أنواع تكوينات التربة الصحراوية انتشارًا خاصة في الصحراء الغربية بمصر. وتمثل هذه التربة عائقًا صعبًا أمام التنمية الحضرية في تلك الأماكن حيث تسبب مشاكل للمنشآت بسبب مقاومتها المنخفضة ، والهبوط الزائد ، وصعوبة دمكها. يهدف هذا البحث إلى دراسة إمكانية استخدام رمال الكثبان بعد تحسين خصائصها في المشاريع المختلفة بدلاً من توريد الرمال من المحاجر البعيدة وذلك لتقليل التكلفة خاصة في مشاريع الطرق حيث تعتبر مصادر المواد المستخدمة من أهم العوامل المؤثرة على التكلفة. في هذه الدراسة ، تم استخدام أحد نفايات صناعة الأسمنت ، وهو غبار قمائن الأسمنت المكربن (CCKD) ، بهدف الحفاظ على البيئة وتقليل التكاليف. أيضًا ، تمت إضافة محلول هيدروكسيد الصوديوم (NaOH). وقد تم إضافة ثلاث نسب مختلفة من (CCKD) وهى 10٪ ، 20٪ ، 30٪ من وزن التربة بالإضافة إلى 10٪ من (هيدروكسيد الصوديوم) من وزن (CCKD) إلى تربة كثبان رملية التى تم جلبها من وادي الريان بمحافظة الفيوم. وتم تحضير العينات باستخدام محتوى الرطوبة المثلى ، وتم معالجة هذه العينات في الهواء لمدة 1 ، 7 ، 28 يومًا. وتم إجراء اختبارات لتحديد مقاومة الانضغاط غير المحصورة (UCS) ، ومعاملات القص المباشر (c، Ø) ، ومؤشر الانهيار (Ie) ، ونسبة تحمل كاليفورنيا (CBR) بعد الغمر فى الماء. وقد أوضحت نتائج الاختبارات المعملية حدوث زيادات كبيرة في مقاومة الانضغاط غير المحصورة ، وقد حدثت المزيد من التحسينات في الأعمار المتأخرة. إذا تم

خلط 20٪ CCKD أو أكثر بالإضافة إلى 10٪ هيدروكسيد الصوديوم وسمح له بالمعالجة لفترة زمنية معينة (على سبيل المثال 7 أيام)
، فإن الخليط له قوة ضغط غير محصورة أعلى من الطين الجامد مما يسمح لها بتحمل الإجهادات الناتجة عن المباني متوسطة
الارتفاع. وبينت النتائج أيضاً زيادة قوة التماسك للخليط مع زيادة نسبة CCKD ، بينما لم تتأثر زاوية الاحتكاك الداخلي (Øº) بنسبة
CCKD. كما حققت زيادة محتوى CCKD زيادة كبيرة في CBR حيث حققت خلطات الكثبان الرملية بنسبة 10 ٪ أو أكثر من
CCKD مع 10 ٪ هيدروكسيد الصوديوم قيم CBR أكثر من 40% والتي يمكن استخدامها كطبقات أساس مساعد للطرق. وبشكل عام
، أظهرت جميع نسب CCKD عدم قابلية العينات للانهيار.حمل الخازوق.

2 Introduction

Sand dunes cover large areas, especially in the Western Desert of Egypt, which represents a major obstacle to urban development in these areas. Fig.(1) illustrates the distribution of sand dunes in Egypt, Abo Elfath, M., (2015). Improving sand dunes is of great importance so that they can be used in various projects such as highways, airports, replacement soil, etc. Sand dune stabilization methods to curb sand movement are as follows, Keeler dunes meeting, (2011):

- Sand fences
- Straw (checkerboard and bales)
- Mats and netting
- Chemical spray
- Brush
- Vegetation – preferred method worldwide

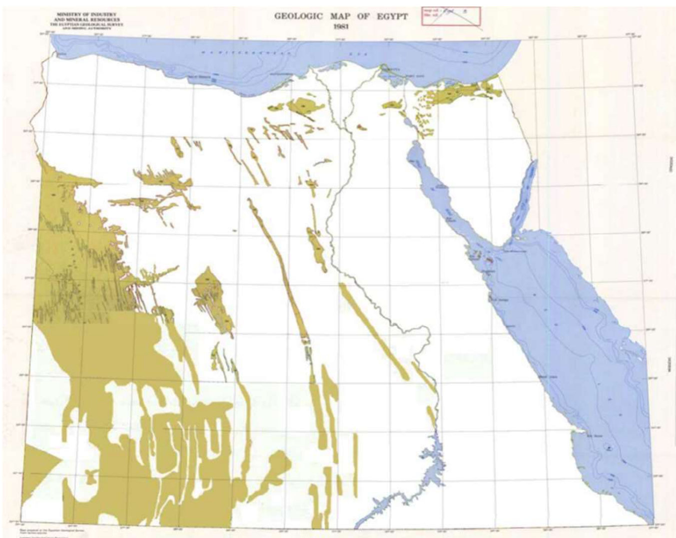


Fig. (1) The Distribution of Sand Dunes in Egypt, Abo Elfath, M., (2015)

Chemical products such as cement, lime, cement kiln dust, bitumen, and other chemicals are widely used to improve the properties of sand dunes, Abo Elfath, M., (2015).The following is a review of some previous researches related to the improving of dune sand properties using cement kiln dust. Baghdadi, Z. A. & Abdel-Rahman, M. (1990) used various percentages of cement kiln dust (CKD) to improve properties of dune sand in Saudi Arabia. Their results showed that sand stabilized with CKD can be utilized for base materials in highway construction. From the point of view of 7-day compressive strength, California bearing ratio and economy, they recommended a mix proportion of 30% CKD + 70% sand for base materials. UCS tests were carried out on sand-CKD specimens by Freer-Hewish, R. J. et al, (1999). They found that large amounts of CKD were needed to meet pavement layer standards, so, they used chemical additives (calcium chloride and sodium metasilicate) to reduce the CKD. Al-Aghbari, M. Y. et al, (2009) found that for CBPD (CKD), a continuous increase in the unconfined compressive strength, the shear strength parameters (c and Ø), and the maximum dry density with the increase of the CBPD content, even at 12%. Moses, G. et al, (2012) studied the influence of compaction efforts on foundry sand treated with up to 12% cement kiln dust. Decreasing of the maximum dry density was observed with the increase in CKD percentage. The peak of CBR values obtained at 12% CKD, while the maximum UCS was achieved at CKD percentage ranged between 8-12%. Al-Homidy, A. A., (2013) studied the mechanical properties of the with 0, 10, 20 and 30% CKD. He found that, as the CKD content increases, the maximum dry density of the sand-CKD mixtures increases. Also, UCS increased linearly with an increase in the CKD content, but up to 30% CKD, it did not meet the minimum UCS (1,380 kPa) specified by ACI [1990] for sub-base course in pavements. Therefore, 2% cement needed to be added to enhance the UCS of sand-CKD mix to meet the ACI requirements. The soaked CBR of sand plus 2% cement and 10 to 30% CKD increased with the increase of the CKD content, and all results were more than 50%, which, in turn, makes stabilized sand suitable for use as a base course in pavements from CBR point of view. Furthermore, the study indicated that stabilizing soils using CKD and other waste materials is eco-friendly and cost-effective. Ahmed Hashad & Mohie El-Mashad, (2014) to compare the retaining wall resistance to backfill soil using medium sand soils as backfill material processed in four different methods. These methods were filling sand using common compaction specifications, using sand filled baskets (gabions), soil reinforcement with geogrid and soil mixing with 30% cement kiln dust. The results showed that the soil mixing with cement dust is considered the best method among the other used methods, although it may not be the fastest when considering the construction process. Abo Elfath, M., (2015) studied the improvement of dune sand with 3, 6, 9 and 12% CKD. He found that the optimum content of CKD to stabilize the soil was 9% where the maximum UCS, shear strength parameters (c and Ø), and the modulus of elasticity were achieved, and beyond this value, decrease of all these parameters were observed. While the stabilized sand

increase in the values of both the CBR and the maximum dry density continued with the increase of CKD up to 12%. Majeed Mattar Rammal & Ahmed Ameen Jubair, (2015) used silica gel and cement kiln dust to improve the sand dune Characteristics in Iraq. They results showed that adding (5%) of CKD + (5%) silica gel to the dune sand gave the best results of the shear strength after 28 days. Many field tests were carried out by Abiola et al, (2016) used cement kiln dust for subgrade soil stabilization in Nigeria. They found that the optimum content of CKD to stabilize the soil was 15% where the maximum CBR and UCS were achieved and beyond this value decrease in CBR and UCS were observed. While, the results of the compaction characteristics of the stabilized soil showed that the maximum dry density decreases with the increase of CKD ratio. They concluded that the stabilized soil at 7 days curing can be used as a sub-base material for pavement construction. Karolina et al, (2020) found that the use of cement kiln dust containing around 21% of free CaO in the same amount of 6–8% allowed observing a gradual increase in compressive strength.
It is noticeable in previous researches that there were differences in the optimal ratios of CKD which used to improve the dune sand. There were also significant differences in the results of improvement in soil properties. Additionally, there were opposite effects on the maximum dry intensity. The reason for this can be attributed to the fact, that the cement kiln dust originating from a given source has its unique properties due to the proportions of raw materials used during production process and used technology, Karolina et al, (2020).

3 The Objective

This research is concerned with the improvement of dune sands for using as alternative construction materials in various projects such as roads, replacement soil. Carbonated cement kiln dust (CCKD) with ultra-pure sodium hydroxide solution (NaOH) were used for the purpose of preserving the environment and reducing the costs.

4 The Materials

4.1 Sand

The dune sand used in this research was brought by Abo Elfath, M., (2015) from Wadi El Rayan, Fayoum governorate (Fig.2). The particle size distribution curve for the used sand dunes is shown in Fig.(3). According to the unified soil classification systems (USCS), it can be classified as poorly graded sand (SP).

Fig. (2) Sand Dunes of Wadi El Rayan, Abo Elfath, M., (2015)

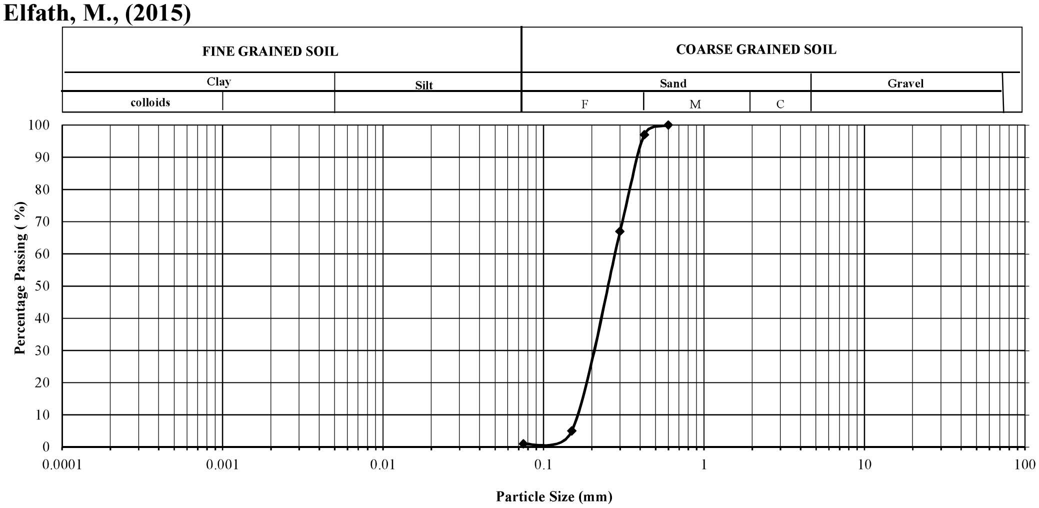


Fig. (3) Grain Size Distribution Curve for the Used Sand Dunes

4.2 Carbonated Cement Kiln Dust (CCKD)

Carbonated cement kiln dust (CCKD) is a bi-product of Portland cement manufacturing collected during the production process. The (CCKD) was obtained from Helwan Cement Company in Egypt.

4.3 Ultra-Pure Sodium Hydroxide (NaOH)

Ultra-Pure Sodium Hydroxide (NaOH) was purchased from LOBA Chemical Company in India.

5.1 Unconfined Compressive Strength (UCS) Tests

The primary purpose of the unconfined compression test is to quickly obtain the approximate value of the strength of cohesive soils in terms of total stresses. Specimens for

5 Laboratory Test Program and Results

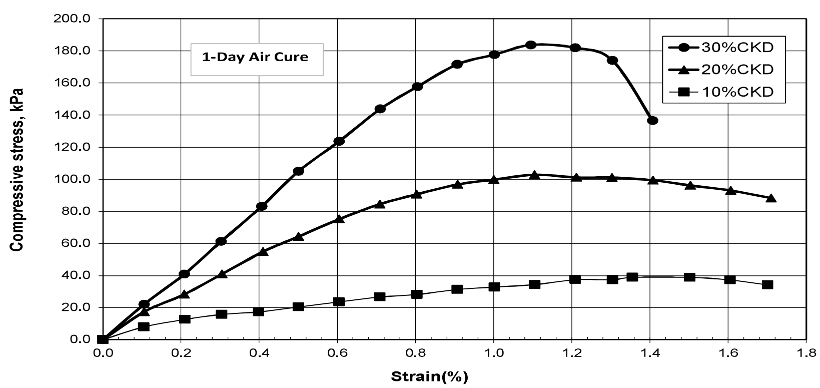
Three different ratios of (CCKD), 10%, 20%, and 30% by the weight of soil, and 10% of (NaOH) by the weight of (CCKD) were mixed with the dune sand soil. Compacted specimens were prepared using the optimum moisture content. These specimens have been cured for 1, 7, and 28 days in air. Tests were carried out to determine the unconfined compressive strength (UCS), direct shear parameters (c and Ø), collapsibility index, and California bearing ratio (CBR) under soaking. The details and results of these tests are explained as follows:

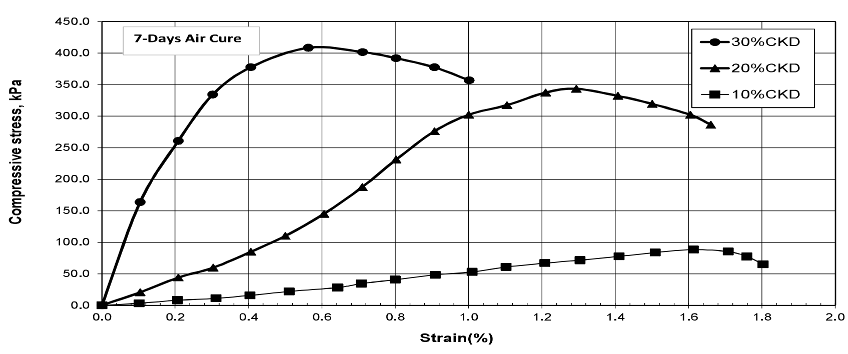
(UCS) tests were prepared and tested according to ASTM D2166 in cylindrical shapes of 40 mm diameter and 80 mm height. The specimens were prepared at optimum moisture content and tested after different air curing periods (1, 7 and 28 days). Fig.(4)

shows stress-strain curves obtained from (UCS) tests. The test results of the compressive strength for the different ratios of (CCKD) at age 1, 7, and 28 days are shown in Fig.(5). Young's moduli (E) were calculated as the slope of the initial tangent in the stress – strain curves obtained from the (UCS) tests. Young's modulus (E) were plotted against the ratio of (CCKD) at different air cure ages as shown in Fig.(6). Effect of using NaOH solution was examined for specimens with 30% CCKD after 7-Days cure age. Comparison between stress-strain curves for 30%CCKD+10NaOH and 30%CCKD without NaOH solution is shown in Fig.(7). The results of the UCS and Young's modulus (E) are summarized in Table (1). It can be seen that both of compressive strength and Young's modulus were increased with the increasing of the (CCKD) ratio. The (CCKD) gave more enhancements at late ages while the rate is decrease with the decreasing of the age. Enhancement about 43% in the UCS of the specimen of 30% CCKD without NaOH solution was occurred by addition of 10%NaOH.

Table (1): UCS and Young's Modulus (E) Results

Mix. Content	UCS (kPa)			E (MPa)		
	1-Day	7-Days	28-Days	1-Day	7-Days	28-Days
10%CCKD+10%NaOH	38.8	88.2	109	4.0	5.3	9.8
20%CCKD+10%NaOH	102.7	343.2	464	13.4	24	31.3
30%CCKD+10%NaOH	183.6	408.4	1090	20.4	125	185
30%CCKD without NaOH	--	285	--	--	--	--





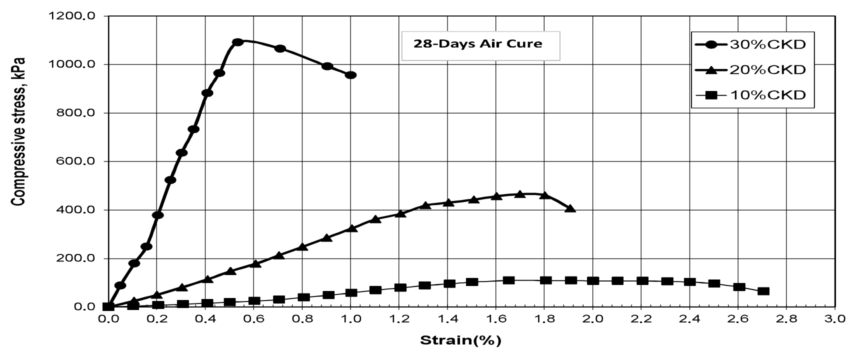


Fig.(4) Stress – Strain Relationships from (UCS) Tests

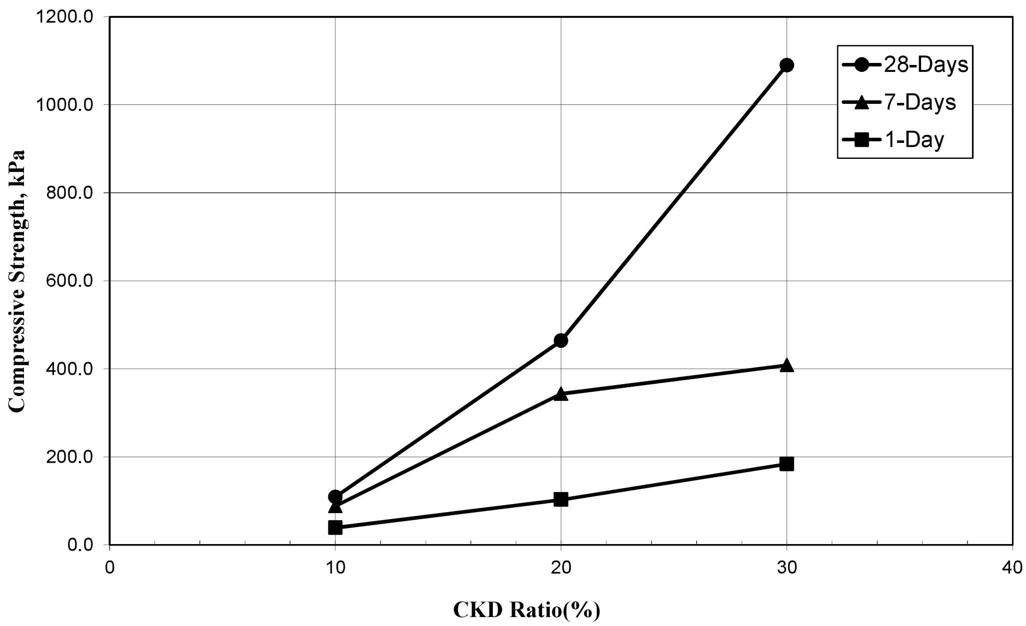


Fig.(5) Compressive Strength at Different Ratios of CCKD and Air Cure Age

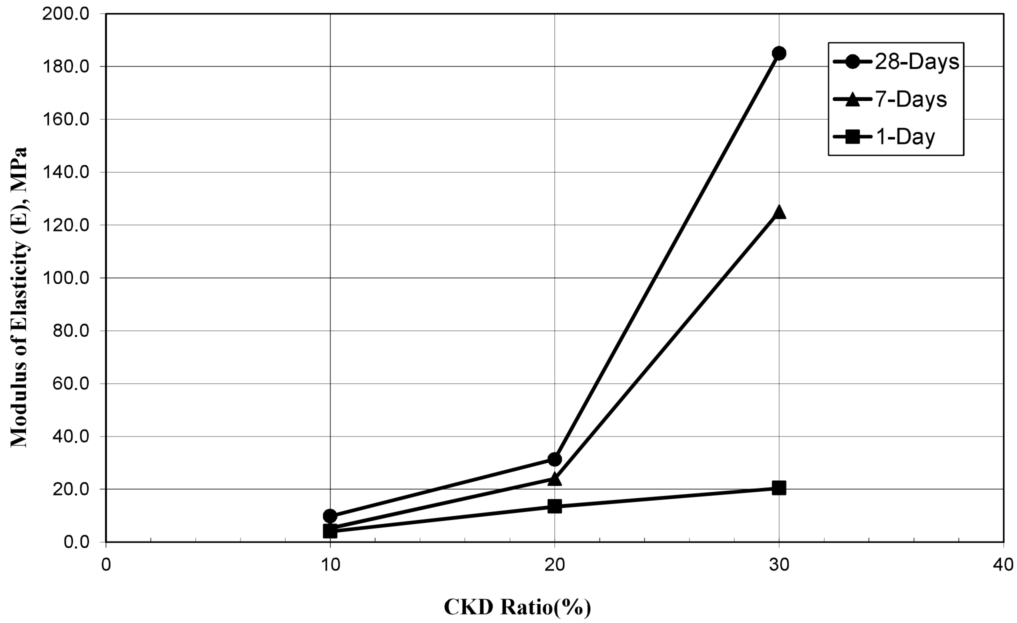


Fig.(6) Modulus of Elasticity at Different Ratios of CCKD and Air Cure Age

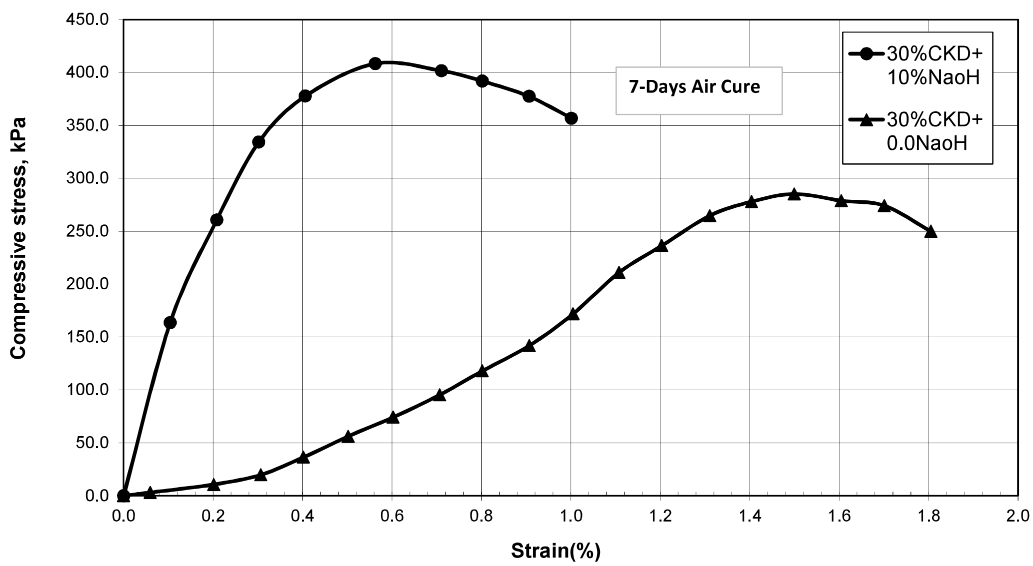


Fig.(7) Effect of NaOH Solution on the Stress – Strain Relationships

5.2 Direct Shear Box Tests

Direct shear tests were carried out according to ASTM D3080 on square specimens of dimensions (60*60*25mm). The specimens were prepared at optimum moisture content and tested under normal stresses (100,150 and 200 kPa) after 7-days air curing periods. Shear stresses versus normal stresses relationships (Shear envelope) for different CCKD ratios after 7-days air cure age were plotted as shown in Fig.(8). Relationships between the (CCKD) ratio versus both of the cohesion and the angle of internal friction (Ø°) are shown in Fig.(89) and Fig.(10) respectively. These results are summarized in Table (2). It can be noticed that the cohesion of the mixture was increased with the increasing of the CCKD ratio, while, the angle of internal friction (Ø°) were not affected by the CCKD ratio.

Table (2): Results of Direct Shear parameters (c and Ø)

Mix. Content	c (kPa)	Ø (Degree)
	7-Days	7-Days
10%CCKD+10%NaOH	101.8	33
20%CCKD+10%NaOH	145.8	33
30%CCKD+10%NaOH	218	33

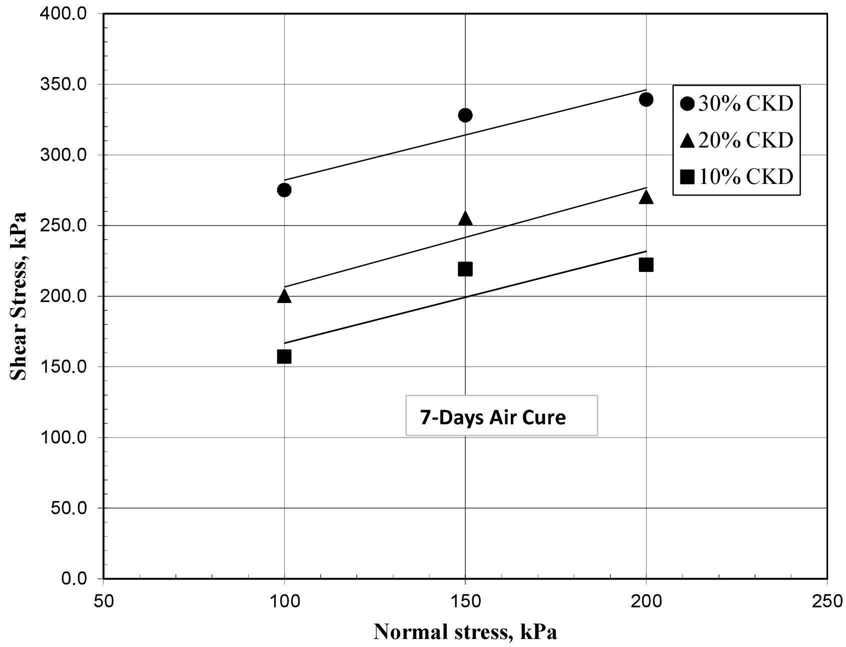


Fig.(8) Shear Envelopes for Various CCKD Ratios After 7-Days Air Cure age

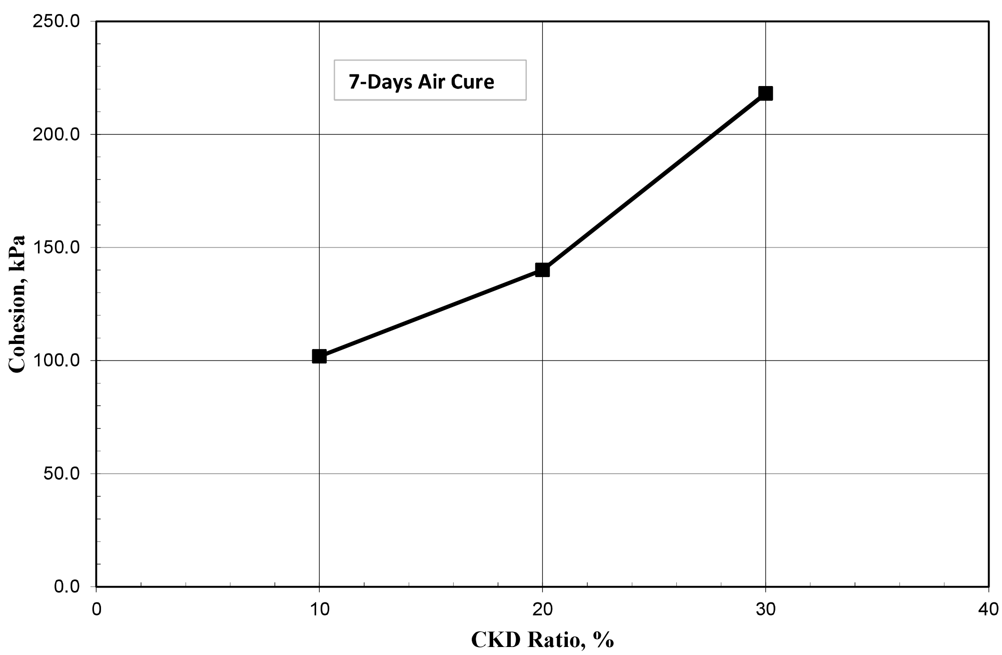


Fig.(9) Cohesion and CCKD Ratios Relationship After 7-Days Air Cure Age

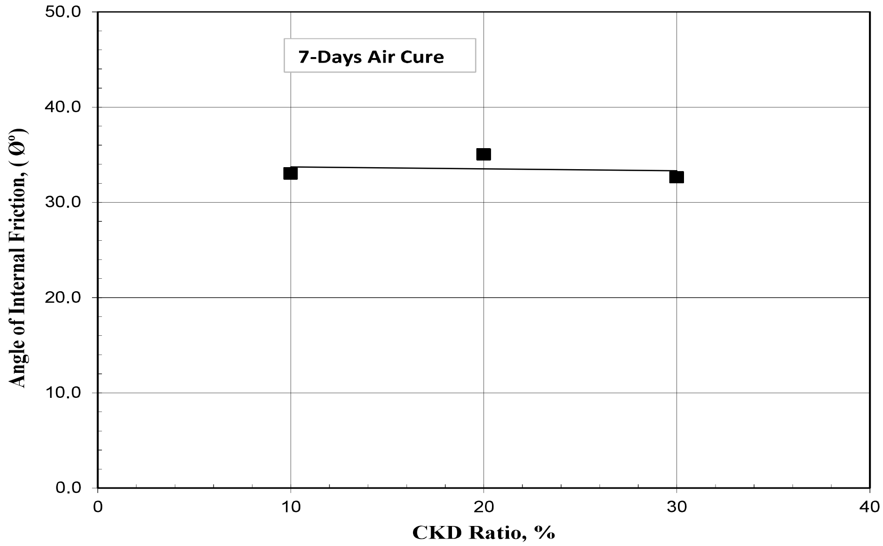


Fig.(10) Angle of Internal Friction (Ø°) versus CCKD Ratios Relationship After 7-Days Air Cure Age

5.3 California Bearing Ratio (CBR) Tests

These tests were conducted to study the improvement in CBR values because it is the most frequently test for characterizing the subgrade soil in pavement design. The CBR tests were carried out according to ASTM D1883. Specimens were prepared on the standard molds of CBR test at optimum moisture content. Tests were conducted after 7-days air curing period for the different CCKD ratios and for the untreated soil samples. Soaked CBR was performed to investigate the effect of inundation of specimens for a periods of 4 days after air curing time. Fig.(11) shows the relationships between the penetration amount versus the stress in piston for different mixtures. CBR values were plotted against CCKD ratio in Fig.(12) and summarized in Table (3). The increase of CCKD content achieved considerable increase for CBR.

Table (3): Results of CBR Tests

Mix. Content	**CBR (%)**
	7-Days
Dune sand	14
10%CCKD+10%NaOH	46
20%CCKD+10%NaOH	63
30%CCKD+10%NaOH	71

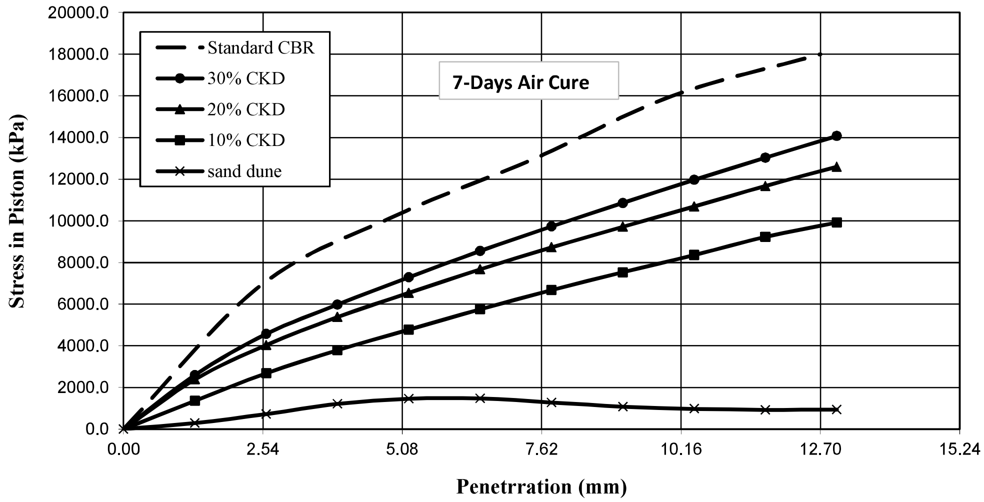


Fig.(11) Stress in Piston versus Penetration Curves for Various CCKD Ratios After 7 days air curing time

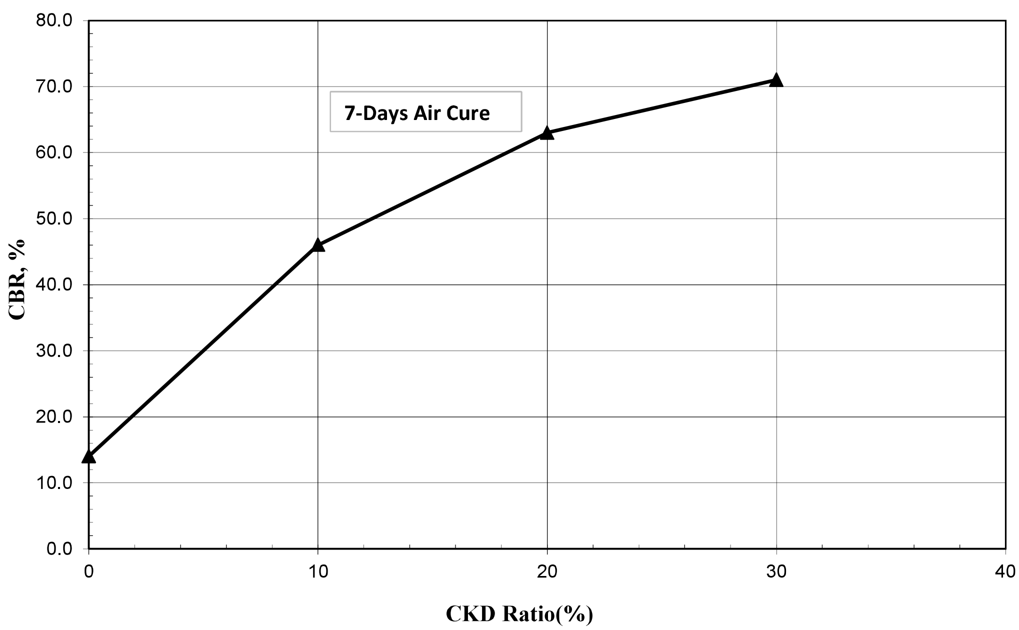


Fig.(12) CBR Values for Various CCKD Ratios After 7 days air curing time

5.4 Collapsibility Tests

Predicting collapse potential or collapse index is important to the design of many engineering structures. Collapse is defined as the decrease in height of a confined soil following wetting at a constant applied vertical stress. A collapsible soil may withstand relatively large applied vertical stress with small settlement while at a low water content, but this soil will exhibit settlement (that could be large) after wetting with no additional increase in stress. These tests were carried out according to ASTM D5333 on specimens of 63 mm diameter and 20 mm height prepared at optimum moisture content for different CCKD ratios and tested after 7-days air curing period. The specimen were inundate with fluid 1 h after loading to the vertical stress 200 kPa to determine collapse index (Ie). The collapse index, Ie, is used to measure a basic index property of soil. Fig.(13) shows the stress–strain relationships from collapsibility tests for various CCKD ratios after 7-days cure age. The relative magnitude of collapse determined at 200 kPa, which represents collapse index (Ie) were plotted versus CCKD ratios in Fig.(14) and summarized in Table(4). In general, all specimens appeared slight collapsibility where the collapse index ranged from 0.315% for 10% CCKD to 0.02% for 30% CCKD.

Table (4): Collapse Index Results

Mix. Content	Collapse Index (%)
	7-Days
10%CCKD+10%NaOH	0.32
20%CCKD+10%NaOH	0.27
30%CCKD+10%NaOH	0.02

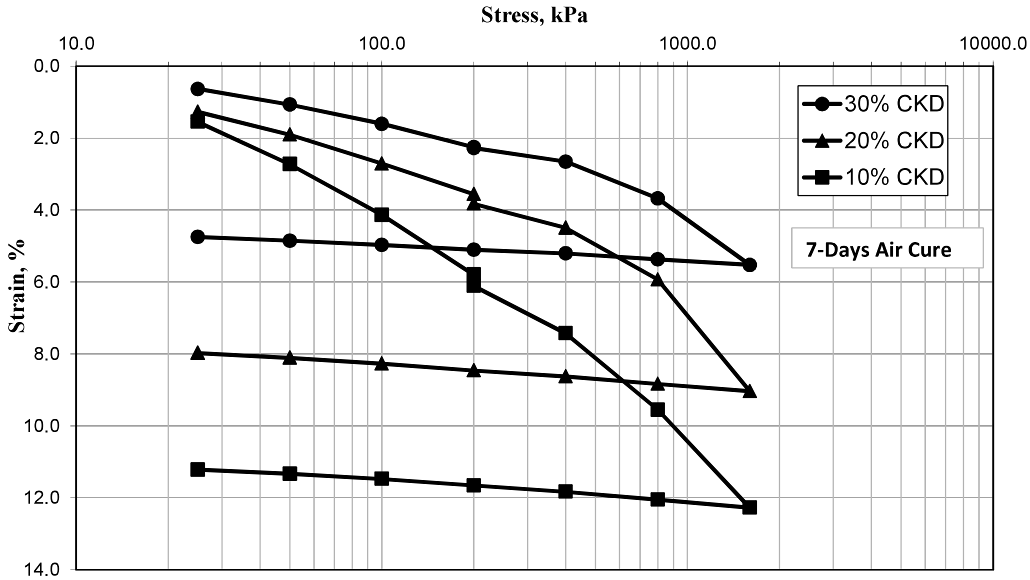


Fig.(13) Stress – Strain Relationships from Collapsibility Tests for Various CCKD Ratios After 7-Days Cure Age

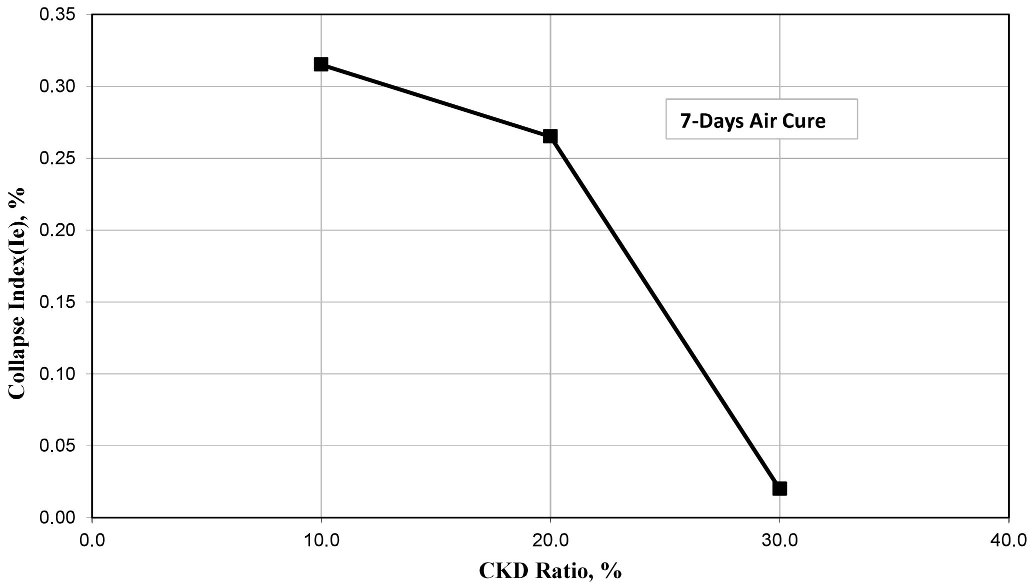


Fig.(14) Collapse Index for Various CCKD Ratios After 7-Days Cure Age

6 Conclusions

The engineering properties of dune sand can be significantly improved by the addition of carbonated cement kiln dust and ultra-pure NaOH solution as follows:

1. The results of laboratory tests indicated significant increases in the unconfined compressive strength, and the cohesion. If 20% CCKD or more is mixed in addition of 10% NaOH and allowed to cure for a certain period of time (say 7 days), the mixture has an unconfined compressive strength that is much higher than that of very stiff or hard clays. The bearing capacity provided by such mixtures will be sufficient to support a moderate-rise building.
2. Cohesion of the mixture was increased with the increasing of the CCKD ratio, while, the angle of internal friction (Øº) was not affected by the CCKD ratio.
3. The increase of CCKD content achieved considerable increase for CBR. Dune sand stabilized with 10% or more of CCKD with 10% NaOH can be used as sub-base layers for roads.
4. In general, all CCKD ratios appeared negligible collapsibility.

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