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PHYSICAL AND CHEMICAL PROPERTIES FOR STABILIZED SAND USING CEMENT KILN DUST

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Cement kiln dust (CKD) produced in a local cement production plant in Assiut Cement Company-Egypt, along with CKD resulting from combustion of cement were utilized as waste materials. These blends were tested for their water requirements for normal consistency, initial setting times, compression and tensile strengths. The materials used in this research are ``untreated'' CKD. It was collected from electrostatic precipitators and ordinary Portland cement (O.P.C). Several specimens were prepared in the laboratory for the compressive strength testing. The specimens were prepared by proportioning sand and CKD according to selected ratios then adding the optimum percentage of water

KEYWORDS: *cement kiln dust, ordinary Portland cement, cement blends; blend properties*

1. INTRODUCTION

Cement kiln dust is considered one of the wastes which are produced in a local cement production plant Portland cement manufacturing in Assiut Cement Company-Egypt, these materials were utilized as waste blended sand with various ratios.

The blended were tested for their water requirements for normal consistency, initial setting times, and compression and tensile strengths. In this study, first, an overview of physical, chemical, and mechanical properties of kiln dust that are related to utilization in sand modification are presented. The effect of different percentages of cement kiln dust adding on the engineering properties of the sand was investigated. The results show significant improvement in their engineering properties. 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.

Hawkins *et al*. [9] mentioned earlier the recent technological advancement that have substantially reduced the quantity of the CKDs generated during the manufacturing processes. Further reduction in the CKD generation is not generally possible due to technical issues related to efficiency of the cement production process. Appropriate disposal of the CKD is a challenging problem in the cement industry due to environmental concerns. Exploring ways to make use of CKD as a value-added product has been of great concern to the cement industry as a whole. The compositions of CKDs are similar to that of cement, consisting of alumina, silica, calcium oxide alkalis and sulfates. However, the amount of alkalis and sulfates, calcium carbonate/calcium oxides are substantially higher in CKDs compared to cement. The higher alkalinity and finer particle size, in addition to its cementations properties, make this material usable for several applications. Connor et al[7], McKay and Emery [14] published some of the potential uses of CKDs, that take advantage of its favorable chemical and physical properties are waste solidification. The replacement for Portland cement in concrete block manufacturing and ready mix concrete and in supplementary cementations materials studied by (Bhatty [6], Udoeyo and Hyee [24], Al-Harthy *et al*. [2], Hawkins *et al*. [9]), hydraulic barrier in a landfill liner/cover suggested by (Ballivy *et al*. [5]), land application as agricultural soil amendment suggested by (Preston [22], flowable fill suggested by (Pierce *et al*. [21], Katz and Kovler [11]), mineral filler in asphalt paving and mine reclamation, and sorbent to remove sulfur dioxide from cement kiln flue gas. Occasionally, Bhatty [6] studied the CKDs containing large amounts of free-lime (CaO) making it a potential candidate for substituting traditional soil stabilizer (lime), fertilizers, sludge stabilizers. Santagata and Bobet [23] Studies reported in the past have shown that treating soils with CKDs improves its various properties and hence some CKDs has great potential to be used as an effective soil stabilizer. The need for soil stabilization and the use of CKDs as potential stabilizers are reviewed in detail in the following sections.

Bhatty *et al*. [6] found that the Maximum dry unit weight (MDUW) and optimum moisture content (OMC) are altered with CKD treatment due to the ability of CKD to absorb water and alter soil structure through pozzolanic and cation exchange reactions. The effect on MDUW and OMC is not consistent throughout the previous studies. In most cases, MDUW decreased and OMC increased with increased CKD treatment (Zaman *et al*. [26], Miller and Azad [15]), but the reverse trend was observed by Baghdadi[4]. Maximum dry unit weight of granular soils tends to increase at lower CKD contents and decrease at higher contents tested by (Baghdadi and Rahman [4], Baghdadi *et al*. [3], Freer-Hewish *et al*. [8]).

The construction of pavements on soils which do not possess sufficient strength to support wheel loads imposed upon them during construction or during the pavement service life sometimes present a difficult problem. Clay soils in particular can present severe problems in pavement design due to the uncertainties associated with their performance. Even after compaction, they can be unstable beneath a pavement; and can be susceptible to shrinkage and swelling due to changes in moisture content. Expansive soils, or shrink-swell soils, cause billions of dollars of damage in the United States each year, second only to insect damage reported by Little [13].

The applicability of cement to stabilize calcareous soils has been described by Ingles and Metcalf [11]. They reported that the presence of excess soluble salts (especially sulfates) in a soil–cement mixture could retard or prevent a proper hydration process. In recent studies by (Mohamed and others[19], Yong and others [25], Mohamed and Antia [18], Hossein and others [10], Mohamed ([16], [17], [18] and Mohamed and others [20]), it has been reported that the presence of sulfates in soil–cement mixtures is attributable to the formation of expansive stringier and traumatize minerals.

The controlling factors in soil-based chemical stabilization with cement, lime and cement-kiln dust (CKD) were studied by (Mohamed and others[20], Mohamed and Antia[18]). They studied and concluded that:-

The strength of the cement-treated soil increases with increasing of cement content and curing time. The effectiveness of cement-treated soil decreases with increasing clay content, moisture content and soil organic matter content. The rate of improvement decreases with increasing plasticity index of soils.

An increase in temperature accelerates the chemical reaction and the solubility of silicates and aluminates, thus increasing the rate of strength gain of the treated soil.

The investigation of CKD for soil stabilization was reported by McCoy and Kinter[20]. The result of this study was analyzed by Bhatty [6]. He concluded that the use of CKDs with appropriate chemical composition and at adequate addition levels (10%) was promising for stabilizing soils. CKDs with high free-lime and low loss on ignition (LOI) provided 7-day compressive strength comparable to those of cement soil mixtures and significantly higher than those of hydrated lime soil mixtures. It was also noted that CKDs with high alkali contents adversely affected the compressive strength.

2. MATERIALS USED AND TESTING PROGRAM

Materials Used

The materials used in this research are:-

1. sand

The used sand for the tests was graded sand. Figure (1) illustrates the grain size distribution curve of sand. The maximum and minimum dry density was determined by using relative density equipment to 1.87t/m3 and 1.5t/m3, respectively. The uniformity coefficient (Cu), the coefficient of curvature (Cc) and main grain size (D50) are 4.12, 1.21, and 0.57, respectively. The sand was prepared to give different relative densities and different shearing resistance angles each time as shown in Table. (1).

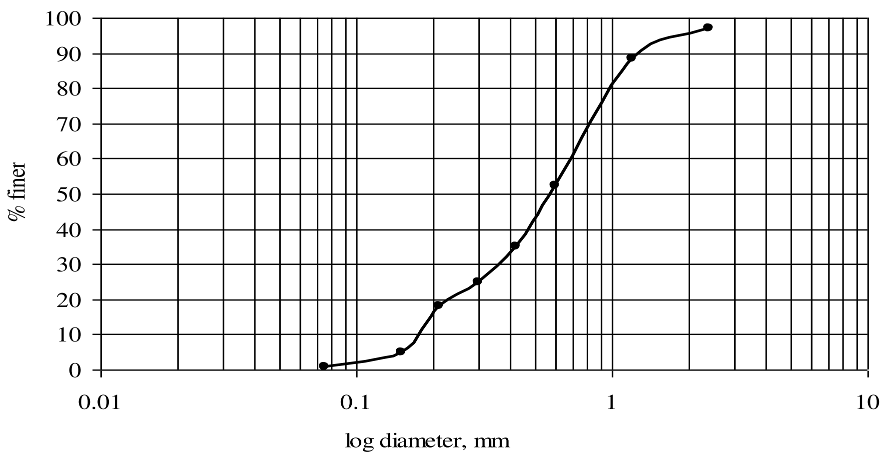


Fig. (1): particle Size distribution

Table (1) Properties of used sand

Unit weight (kN/m^3)	Relative Density, D_r	Angle of internal friction, ϕ^o
17.0	60%	35.5
17.4	70%	37
17.79	81.8%	41

2. CKD

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. The samples of used in this work obtained from Assuit Cement Company-Egypt, The chemical compositions of the CKD were determined by X-ray as shown in Table (2). The CKD consists of calcium oxide (CaO), silicon dioxide (SiO2), alumina (Al2O3) and ferric oxide (Fe2O3).

The materials used in this research are ``untreated" CKD. It was collected from electrostatic precipitators and ordinary Portland cement (O.P.C) from by Assuit Cement Company, Assuit, Egypt. The chemical analysis of the materials used in this investigation is given in Table (2)

Table (2) Chemical Composition of CKD from x-rays test

Chemical composition	SiO2	Al2 O3	Fe2 O3	CaO	MgO	SO3	Na2O
Amount	10.92	3.00	2.03	41.57	0.57	18.08	2.51
Chemical composition	K2O	Cl	LOI	Free CaO	L.S.F	SM	AM
Amount	7.94	7.19	5.26	23.51	81.60	2.17	1.48

3. MIXTURES

To study the effect of CKD in sand mixture on the strength of its 120 cubes, the following variables were considered in this study:

1. Percentage of CKD as ratio to sand used (10%, 20% and 30%).
2. Percentage of cement (O.P.C) as ratio to CKD used (2%).
3. Testing period of mixtures (3, 7, 14, 28, and 56 days).

Three mixes (***Mix (1), Mix (2) and Mix (3)***) with three different types of CKD (10%, 20% and 30% by weight of sand) were used in this study. The ordinary cement mortar content from mix proportions (1cement: 3 sand: 0.7 w/c ratio). The various mixes were prepared as indicated below:-

- ***Mix.(1)*** 1sand **:** 10% CKD (10% of sand weight) **:** 9% OMC (9% of total weight).
- ***Mix.(2)*** 1sand **:** 20% CKD (20% of sand weight) **:** 10.42% OMC (10.42% of total weight).

- ***Mix.(3)*** 1sand **:** 30% CKD (30% of sand weight) **:** 11.45% OMC (11.45% of total weight).
- ***Mix.(4)*** 1(cement) **:** 3(sand) **:** 0.7(water).
- ***Mix.(5)*** 1sand **:** 2% cement(2% of sand weight)) **:** 8%OMC (8% of total weight).
- ***Mix.(6)*** 1sand **:** 10% CKD (10% of sand weight) **:** 2% cement(2% of CKD weight)) **:** 16%OMC (16% of total weight).
- ***Mix.(7)*** 1sand **:** 20% CKD (20% of sand weight) **:** 2% cement(2% of CKD weight)) **:** 17.5%OMC (17.5% of total weight).
- ***Mix.(8)*** 1sand **:** 30% CKD (30% of sand weight) **:** 2% cement(2% of CKD weight)) **:** 18.5%OMC (18.5% of total weight).

Testing Program

The soil may be prepared in several ways by drying the additional amount of water aggregates and stabilizing agent (cement kiln dust). Densification improves the engineering properties of the soil mass. The principle disadvantages are that swell (increase in water content from the reference value) and frost heave potential are often increasing Bowles [1]. The method is designed for determining a relationship between the moisture content and the dry density of the sand when compacted in Proctor moulds test. The tests were obtained on sand mixture with 0%, 10%, 20% and 30% CKD by sand weight.

1) Optimum Moisture Content and Maximum Dry Unit Weight

Maximum dry unit weight of admixtures and optimum moisture content (OMC) of specimens were obtained using modified Proctor test (M.P.T). The same tamper was used throughout specimen preparation, in order to maintain identical compactive efforts. The data of maximum dry unit weight of stabilization-sand and OMC are shown in Figs (2) and (3). Since the optimum moisture content for each specimen was different, thus, in order to add the same amount of water or additive to specimens, the amount of water and chemical additive (CKD) is added to stabilized sand.

In normal mixing method, the stabilizing agent is added to the sand and hand mixed thoroughly. Water or chemical additive is then added and hand mixing continus until a uniform mix is obtained.

2) Compressive Strength

Several specimens were prepared in the laboratory for the compressive strength testing. The specimens were prepared by proportioning sand and CKD according to selected ratios then adding the optimum percentage of water. The compression tests were carried out with standard cubes (7x7x7cm). The compressive strength is measured by ASTM D 422-63 test methods which involves curing of the ash for specified periods of time. Depending upon the specific application, different degrees of compressive strength are required. These results provided an indication of potential construction uses for CKD with very different compositions.

The compressive strength (q_u) of sand with CKD as well as those samples cured for 3, 7, 14, 28 and 56 days are presented and discussed here. The moisture content, dry unit weight during testing and strength values were reported.

Curing Condition

Figure (5) shows the relationship between compressive strength for mixture (1) and the curing time. It can be noticed that the compressive strength increases with increasing the curing time, the rate of increase in compressive strength for mixture is great from 0 to 28 days after which, increasing of compressive strength with time approximately becomes very small.

Figure (6) shows the relationship between compressive strength for mixture (2) and the curing time. It can be noticed that the compressive strength increases with increasing the curing time; the rate of increase in compressive strength for mixture is great from 0 to 28 days after which, increasing of compressive strength with time approximately becomes very small.

Figure (7) shows the relationship between compressive strength for mixture (3) and the curing time. It can be noticed that the compressive strength increases with increasing the curing time, the rate of increase in compressive strength for mixture is great from 0 to 28 days after which, increasing of compressive strength with time approximately becomes very small.

Figure (8) shows the comparison between the effect of CKD and cement added sand. The compressive strength of cement mortar added to sand is much greater than the compressive strength of CKD added to sand.

Figure (9) shows the relationship between compressive strength for mixture (5) and the curing time. It can be noticed that the compressive strength increases with increasing the curing time, the rate of increase in compressive strength for mixture is great from 0 to 28 days after which, increasing of compressive strength with time approximately becomes very small.

Figure (10) shows the relationship between compressive strength for mixture (6) and the curing time. It can be noticed that the compressive strength increases with increasing the curing time, the rate of increase in compressive strength for mixture is great from 0 to 28 days after which, increasing of compressive strength with time approximately becomes very small.

Fig.(11) shows the relationship between compressive strength for mixture (7) and the curing time. It can be noticed that the compressive strength increases with increasing the curing time, the rate of increase in compressive strength for mixture is great from 0 to 28 days after which, increasing of compressive strength with time approximately becomes very small.

Figure (12) shows the relationship between compressive strength for mixture (8) and the curing time. It can be noticed that the compressive strength increases with increasing the curing time, the rate of increase in compressive strength for mixture is great from 0 to 28 days after which, increasing of compressive strength with time approximately becomes very small.

Figure (13) shows the comparison between the effect of CKD-cement mixture on sand. The compressive strength of CKD added to sand is much greater than the compressive strength of percentage 2% from cement added to sand.

Mixture Design and Strength Characteristics

The main aim of cement kiln dust stabilization mixture design is to produce the desired strength for the sand. Fig.(14) shows that strength gain of sand-CKD mixtures increases approximately linearly with CKD content. Accordingly, many mixture design procedures involve molding and curing specimens at various CKD contents until the lowest CKD content, which provides the required strength is achieved. The compressive strength, of sand-CKD mixtures increases with increasing of CKD content, the relation can be represented as:

$$q_u(t) = 886.3\chi^{0.0166CKD}$$

Where: $q_u(t)$ = Compressive strength at 56 days, kPa

χ = exponential term

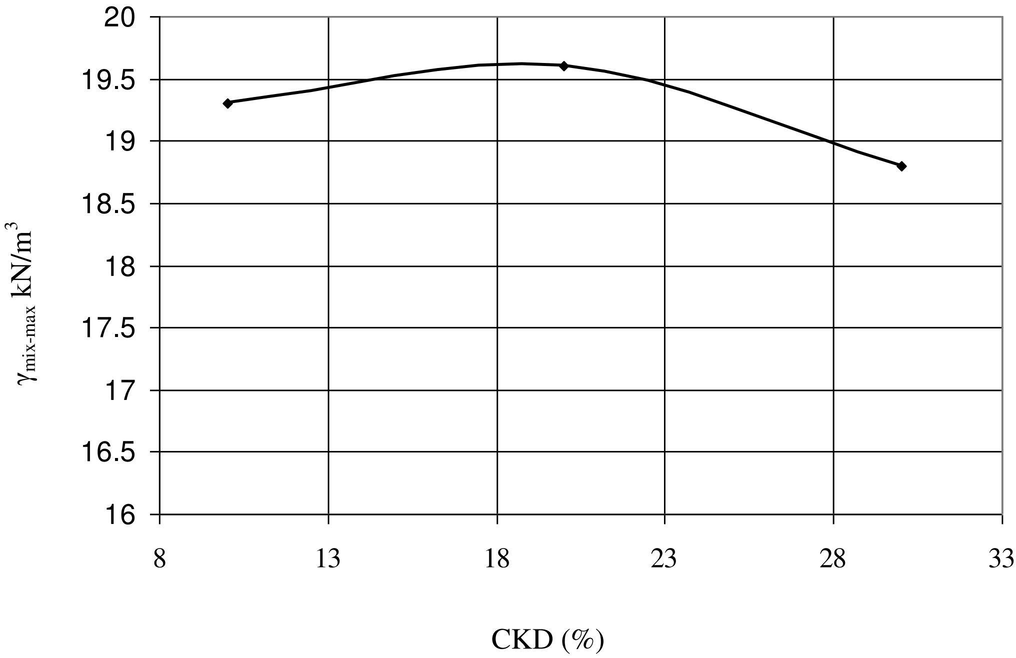
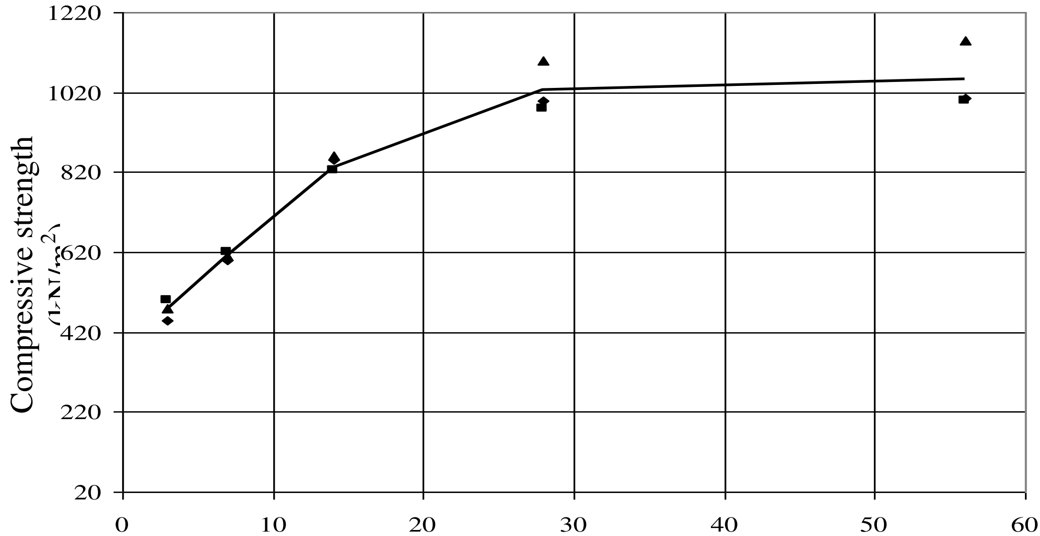
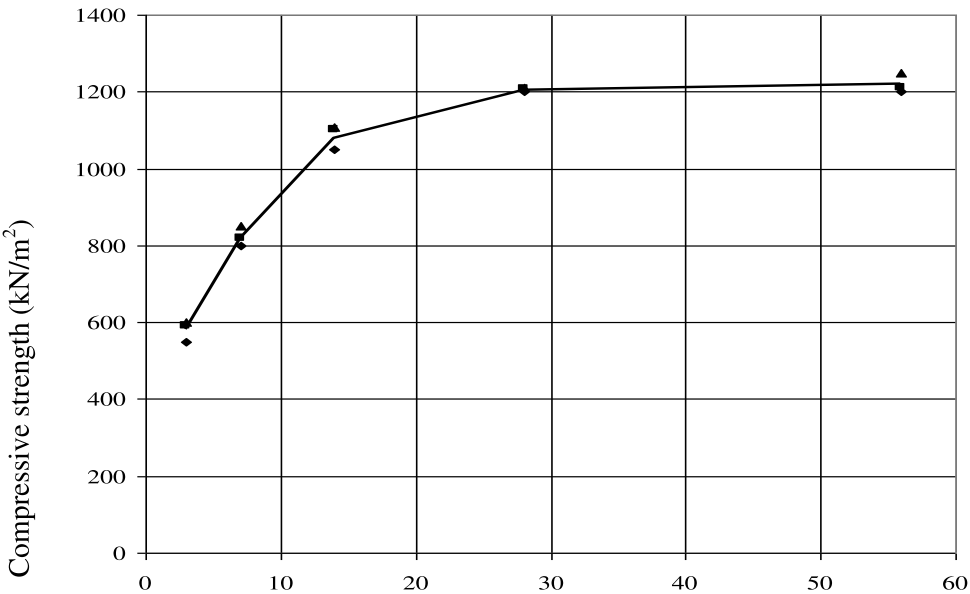


Fig. (4) Relation between dry density of mixtures and CKD(%)



Curing time (days)

Fig. (5) Relation between curing time and compressive strength for ***Mixture (1)***



Curing time (days)

Fig. (6) Relation between curing time and compressive strength for ***Mixture (2)***

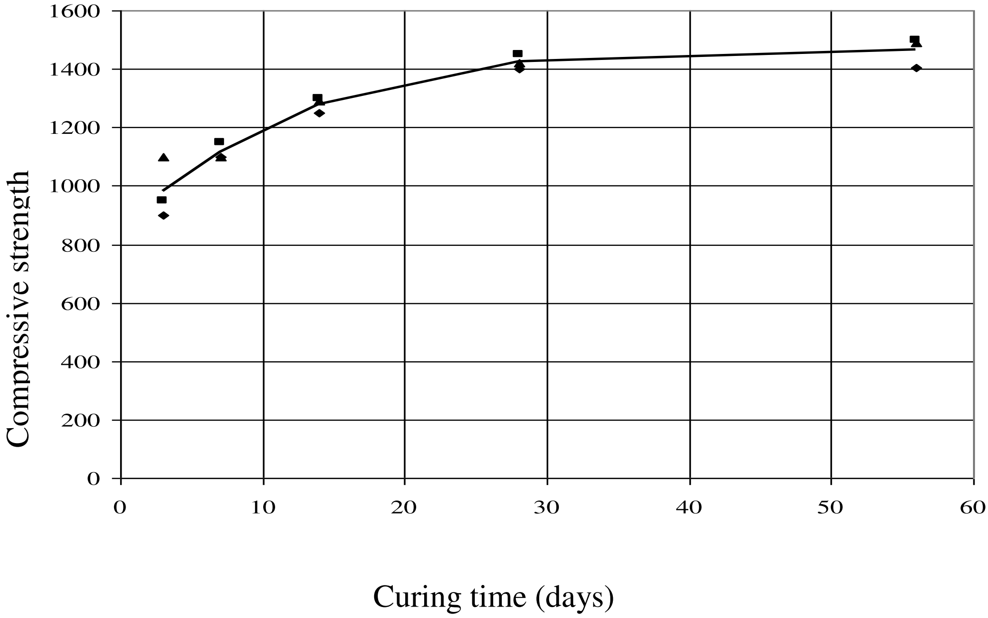


Fig. (7) Relation between curing time and compressive strength for ***Mixture (3)***

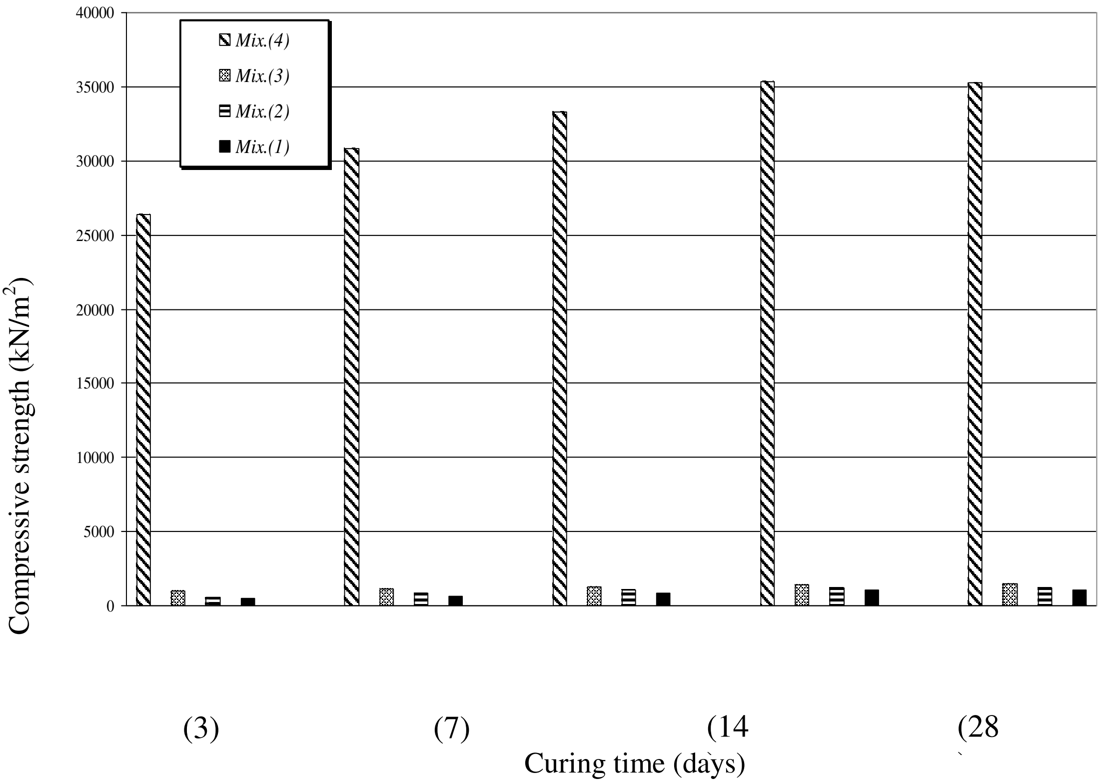


Fig. (8) Comparison between the effect of CKD and cement added on sand

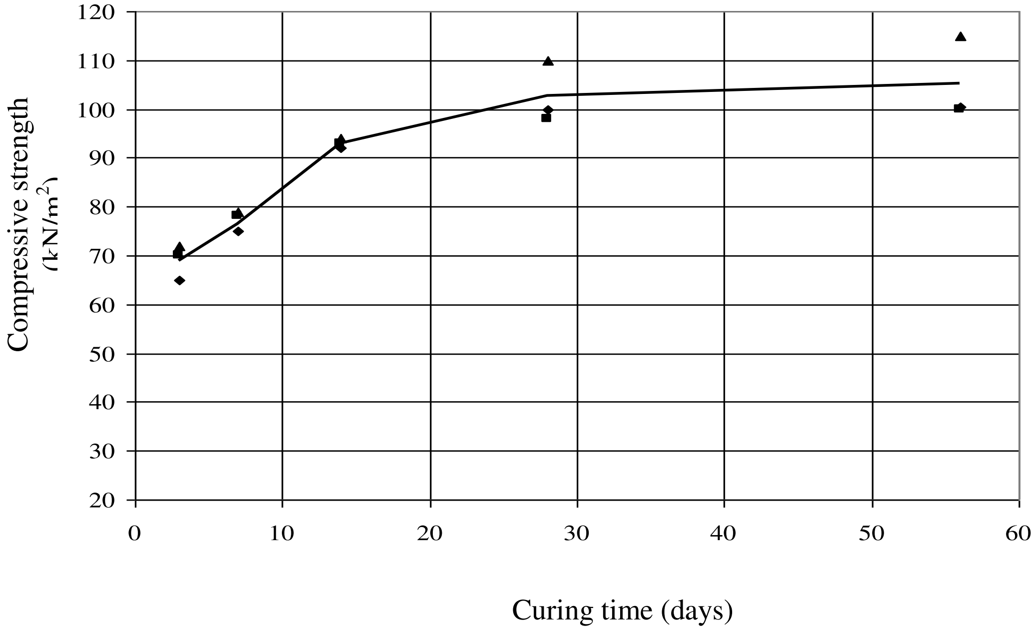


Fig. (9) Relation between curing time and compressive strength for ***Mixture (5)***

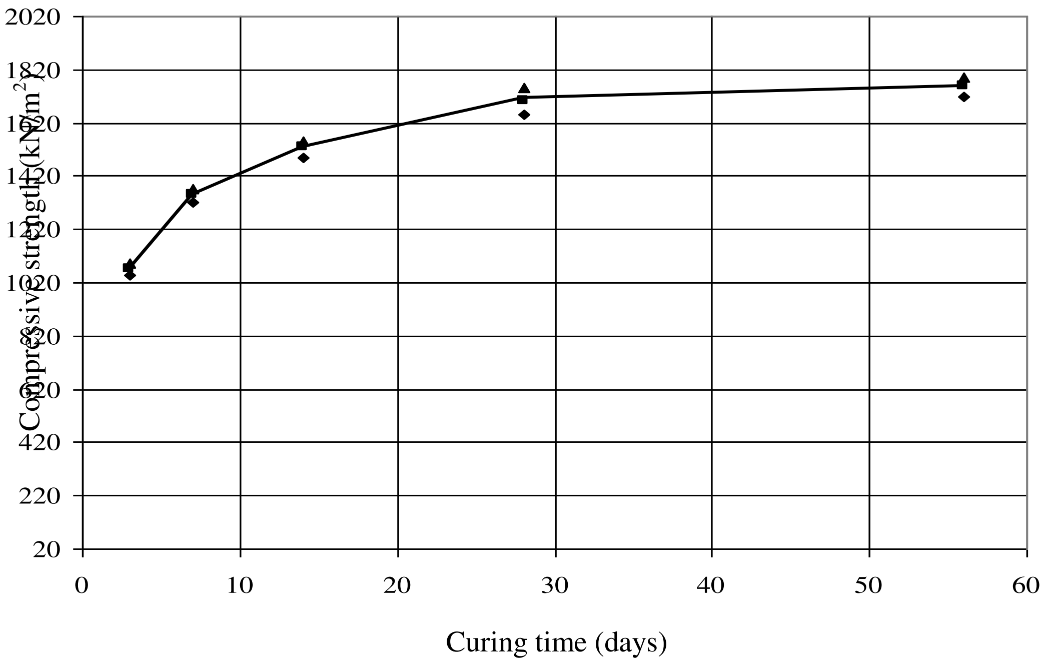


Fig. (10) Relation between curing time and compressive strength for ***Mixture (6)***

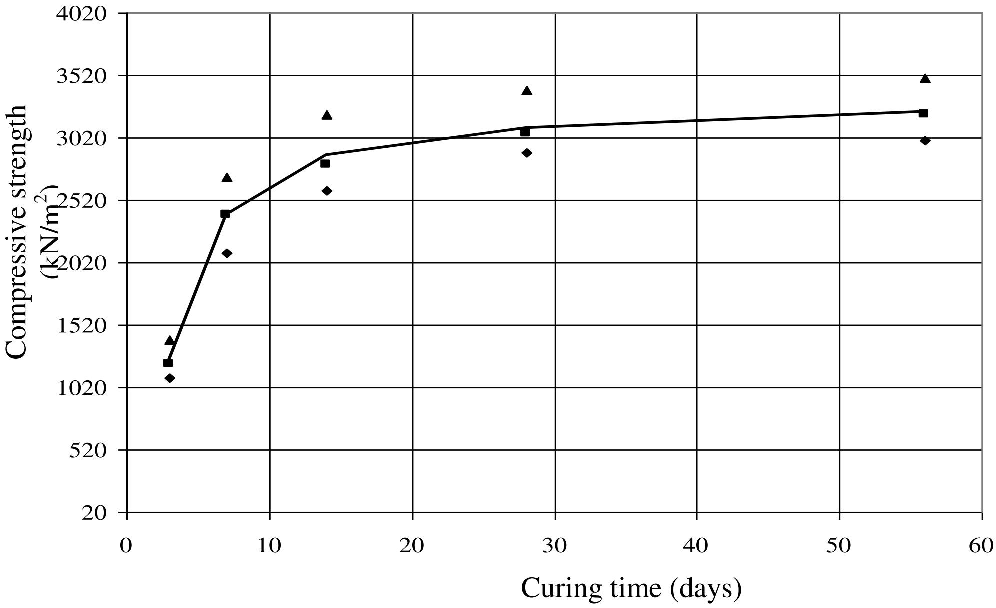


Fig. (11 Relation between curing time and compressive strength for ***Mixture (7)***

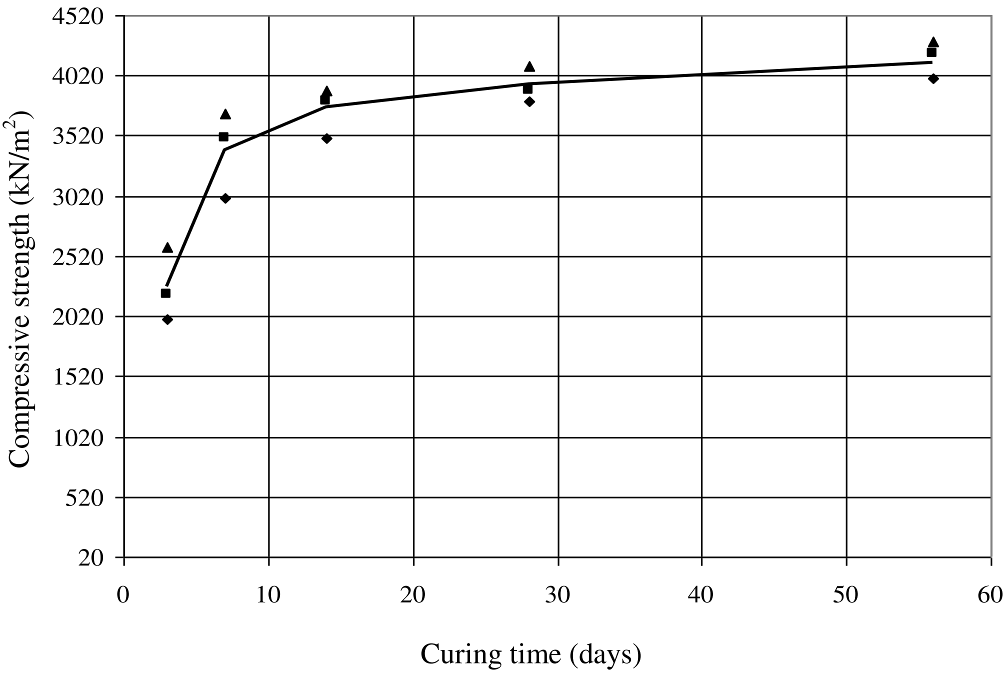


Fig. (12) Relation between curing time and compressive strength for ***Mixture (8)***

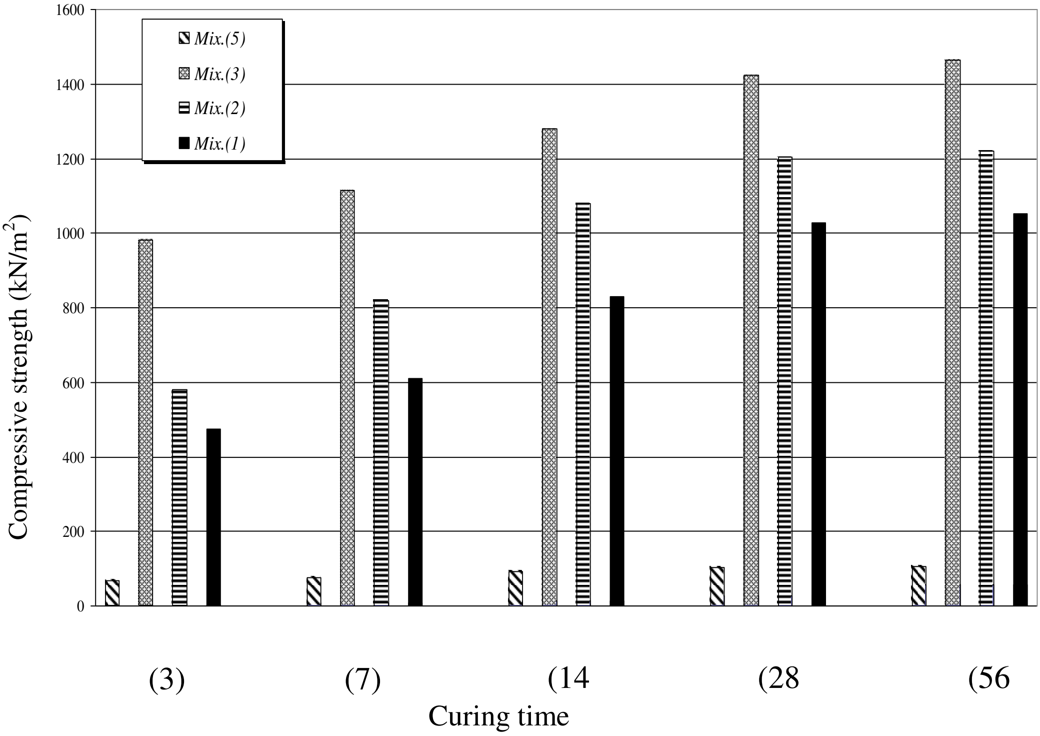


Fig. (13) Comparison between the effect of CKD-cement mixture on sand

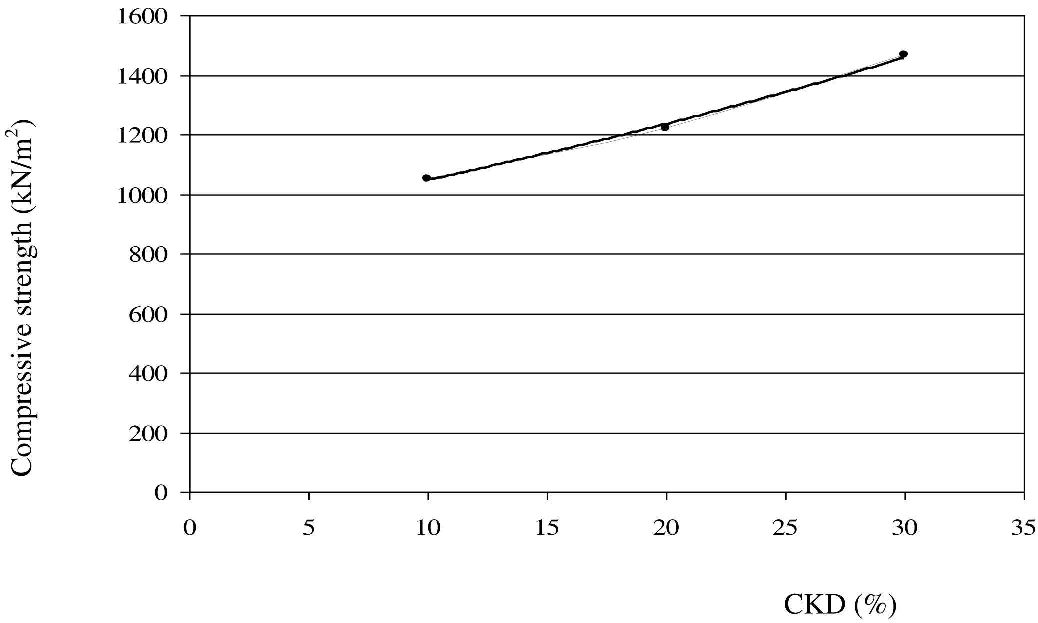


Fig. (14) Comparison between cumulative Compressive strength and CKD at time 56 day

4. CONCLUSIONS

The conclusions can be summarized as follows:

1. The optimum moisture content of mixture (sand-CKD) increase with increasing of CKD content.
2. The compressive strength of mixture (1) increases with increasing curing time and the rate of increasing is large from 7 to 28 days until that relation was slightly increasing.
3. The compressive strength of mixture (2) increases with increasing curing time and the rate of increasing is large from 7 to 28 days until that relation was slightly increased.
4. The compressive strength of mixture (3) increases with increasing curing time and the rate of increasing is large from 7 to 28 days until that relation was slightly increased.
5. The smallest percentage of cement to cohesion as improves the sand more less 2%.
6. The compressive strength of sand-CKD mixtures increases approximately linearly with CKD content. the relation can be represented as:

$$q_u(t) = 886.3\chi^{0.0166CKD}$$

Where: $q_u(t)$= Compressive strength at 56 days, kPa

χ **= exponential term**

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بعض الخواص الفيزيائية والكيميائية للرمل المثبت بإستخدام غبار الفرن الأسمنتي

يهتم عديد من الباحثين في مجال هندسة البيئة وبعض المجالات الأخري بكيفية إستخدام بعض المخلفات الصلبة الناتجة من الفرن الأسمنتي والتي تسبب بعض المشاكل البيئية والصحية وتؤثر علي البيئة الحيوية المحيطة ومن أهم هذه المخلفات هو غبار الفرن الأسمنتي.

غبار الفرن الأسمنتي عبارة عن ناتج ثانوي من عمليات تصنيع الأسمنت البورتلاندي ويتكون أثناء حرق المواد الخام في الفرن المخصص لإنتاج الخبث. وهذه الدراسة تتمثل في تأثير إضافة نسب مختلفة من غبار الأسمنت علي التربة الرملية بأنواعها و من النتائج المعملية لوحظ تحسن خواص التربة الرملية الفيزيائية والكيميائية والميكانيكية وكذلك لوحظ أن قدرة تحمل التربة تزداد بزيادة نسب غبار الفرن الأسمنتي في الرمل وأيضا تحسنت خواص الدمك للتربة الرملية بزيادة القيمة العظمي للمحتوي المائي والقيمة العظمي للكثافة الجافة وزادت قدرة تحمل التربة بزيادة المعدل الزمني.