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Characteristics of Cohesive Soils Stabilized by Cement Kiln Dust

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Abstract— Cement kiln dust CKD is a waste by-product from the manufacture process of the cement, which contributes to environmental pollution. This study has been conducted to investigate the feasibility of utilization the cement kiln dust for the soil stabilization. The characteristics of two types of cohesive soils of different clay content treated by cement kiln dust were studied. The direct shear test / unconfined compression tests, the coefficient of permeability, and durability tests (freezing-thawing and wetting-drying) were reported. Several tests were carried out to investigate the effect of curing age on the unconfined compression and coefficient of permeability. Treatment with cement kiln dust was found to be an effective option for improvement of soil properties, based on the testing conducted as a part of this research. Strength was improved and plasticity and coefficient of permeability were substantially reduced. Also, the treated samples showed a reasonable durability for both wetting-drying, and freezing-thawing.

Index Terms— By-products, Cement Kiln Dust (CKD), direct shear test, unconfined compression test, coefficient of permeability test, durability test.

1 Introduction

THE growth in demand of cement over the world, results large quantities of cement kiln dust (CKD). Sustainability is the cornerstone of the cement industry, not only in the products that use cement, but also in its manufacturing process. Cement dust is a significant by-product material of the cement manufacturing process, which is poses an environmental threat. To deal with this problem, researches are being carried out in different parts of the world to find out efficient ways of using cement dust in various applications such as soil stabilization.

Any potential application of CKD, including sand and clay stabilization, is governed by the physical and chemical composition of the dust. In practical terms, the dusts vary markedly from plant to plant in chemical, mineralogical, and physical composition, depending upon the feed raw materials, type of kiln operation, dust collection facility, and the fuel used [1].

A number of CKDs and clay-type soils were used by [2]to study the soil stabilization, soil-cement dust mixes containing 3, 8, and 10% of CKD were tested for various engineering properties, such as the unconfined compressive strength, moisture-density relationship, liquid limits (LL), plastic limit (PL), plasticity index (PI), and shrinkage limit.

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The study found that the use of CKD was potentially promising in stabilizing soils for subbase applications. [3] reported that CKD with high free lime (26.6%) and moderate alkalies (≈ 4.6%, expressed as Na2O equivalent) produced mixtures with compressive strengths comparable to those obtained with cement and lime. CKD having low free lime (0.5%) and low alkalies (2.2% Na2O equivalent) gave lower strengths. In general, CKDs with high free lime and moderate alkalies gave enhanced stabilization in terms of improved compressive strengths and reduced plasticity. It might also be pointed out that higher alkalies in CKDs can counter the stabilization reactions because of the ionic interference.

A study on the use of CKD in clay stabilization was also reported by [4] and [5]; they established potentially useful correlations among the engineering properties of the clays and their stabilized counterparts. However, their investigations were based on only one CKD and primarily one clay soil, a dark grey "fat" clay, although, at times, some selected tests were also carried out on other potentially expansive clays. The primary clay used in the investigations belonged to the CH group [6].The clay-CKD mixtures containing 5% to 40% CKD by weight were cured for up to 56 days. The results showed that, with the exception of the dry densities, the engineering properties of the CKD-clay mixtures were comparable to those of fly ash-soil and cement-soil mixtures. According to [7], the CBR test also positively correlates with the modulus of elasticity and strength of the stabilized soils.

Voids in the CKD-stabilized clay samples, measured optically, decreased with CKD additions. The raw clay soil had 7% void space whereas the samples with 25% CKD gave a void space between 1 and 2.3% [5]. This may explain the strength gain as a consequence of decrease in voids. This phenomenon does not appear to be time dependent; it rather appears to be CKD-

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dosage dependent. The decrease in voids may result from a combination of processes occurring simultaneously, i.e., the hydration products developing early on, and the placement of CKD particles filling the voids to modify the morphology of the stabilized mass.

CKD also increased the permeability of cohesive weathered shales giving increased coefficients of permeability from 3 x 10-8 to 1 x 10-5 cm/sec. The permeability of silty fine sand, however, somewhat decreased from 3 x 10-3 to 1 x 10-4 cm/sec when treated with 20% CKD. It might be important that if the CKD-soil mixtures were cured for longer periods, say 14 days, their permeability could decrease even further because of the growing reaction products and reduced connected voids [8].XRD (x-ray diffraction) and SEM (scanning electron microscopy) investigations conducted on the CKD-stabilized clays showed the presence of hydration products and a subsequent decrease in void space, which resulted in increased strength and a reduction in the plasticity indices with curing times. This appears to be in line with an earlier hypothesis that CKD mechanistically functions similarly to cement [9] in stabilizing soils as it forms hydration products in the system and reduces the total porosity to promote compaction.

Azad [10] found that an increases in the unconfined compressive strength (UCS) of soil occurred with the addition of CKD. Furthermore, the 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. Mohamed, 2002[11] evaluated the potential use of cement- dust (CKD) for enhancing the mechanical as well as the hydraulic properties of soils in arid lands. Various tests were conducted to determine the different physical properties of the stabilized matrix and the optimum mixture that produces maximum internal energy and minimum hydraulic conductivity was selected. The analysis showed that 6% by weight of CKD is the optimum mix design, which increases the shear strength and decreases the hydraulic conductivity to less than 10 super (-9) m/s. Therefore, the treated soil could be used as a soil-based barrier layer for containment of hazardous waste, [11].

The purpose of using CKD, and the other additives, is to improve the texture, increase the strength and reduce the swell characteristics of the various soils. When the additives containing free calcium hydroxide are mixed with the soil, the calcium causes the clay particles to flocculate into a more sand-like structure reducing the plasticity of the soil [12]. This reduction in plasticity, which is called modification, reduces the shrink/swell characteristics of the soil. Soil stabilization includes the effects from modification with a significant additional strength gain. The soil must be able to react with the chemical additives to achieve the soil stabilization or modification that is desired.

2 .MATERIALS AND TEST METHODS

2.1 Materials

The soil sample was locally collected from Al-Meshkab town in Najaf. The soil lumps were broken into small pieces and passed through 4.75 mm size sieve to make it free from roots, gravel etc. The soil was sieved to have a homogeneous mass containing sand to clay. Cement dust were obtained from Al-Najaf cement factory and used for soil stabilization. As well as distilled water used in all mixes.

2.1.1 Properties of Soil

The two types of soil used in the investigation were classified as CL (denoted as soil A), and ML (denoted as soil B) according to Unified Soil Classification System. The engineering properties of these soils are shown in table (1). The grain size distribution curves shown in Fig. (1) 1indicated that the soil (A) composed of 10% sand, 59% silt and 31% clay, while soil (B) composed of 6% sand, and 94% silt.

2.1.2 Properties of cement dust

The cement dust used in this study sieved through sieve No. 30 (0.6 mm) before adding it to the soil. The physical properties and the chemical composition of the dust is reported in Table 2.

2.2. Sample preparation

The soil was dried in an oven at approximately 105±°C for 24 h. The required amount of soil was mixed with cement dust under dry conditions. The content of the cement dust was chosen as 0%, 5%, 10%, 15%, and 20% by dry weight of soil. The maximum dry density (MDD) and optimum water content (OMC) of all the soil-cement dust mixtures were obtained from Standard Proctor compaction test. To control the density of all specimens, the specimens were prepared to a desired MDD and OMC by static compaction method. The specimens which prepared to study the effect of curing age, kept in sealed plastic bags and placed in moist room having a temperature of 21 C and a relative humidity of 70% until tested. The mix thus obtained was used for preparation of triaxial test, unconfined compression, and permeability test specimens. The above tests were conducted on both untreated and treated soil specimens to make a comparison between them.

2.3. Compaction test

Standard compaction tests were conducted on 30 samples according to ASTM D 558-76. The results of maximum dry density (MDD) and optimum moisture content (O.M.C) are shown in table (3), each value represented an average of three tested samples. The relationship between (MDD), and (O.M.C) with cement dust ratio are shown in figures (4) & (5).

2.4. Unconfined Compression Tests

The unconfined compression test achieved according to ASTM D 2166-72 for 150 specimens. The effects of cement dust content, and curing ages (1, 4, 7, 30, 60, and 90 days) on the unconfined compressive strength of the two cohesive soils were considered. Soil specimens, with and without treatment, were compacted in a cylindrical mould of 50 mm diameter and 100 mm high to standard Proctor's maximum density and opti-

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mum moisture content. Three specimens were tested for each combination of variables as shown in table (4). The relation between unconfined strength and cement-dust ratio are shown in figures (2) & (3).

2.5. Direct Shear Tests

Direct shear tests were conducted on 90 specimens with normal stresses (69 kN / m2), (128 kN / m2), and (276 kN / m2). Soil specimens with and without cement kiln dust were tested in 64mm square shear boxe (plan dimensions). The specimens were prepared at the maximum dry unit weight and optimum moisture content obtained from Standard Procter test. Three specimens tested for each selected cement kiln dust content. The testes were performed for the specimens of soil-cement dust mixture after 7 days of curing in humidity room. The relationship between normal stress and shear stress for each cement dust ratio is shown in figures (10) and (11).

2.6. Permeability Tests

To study the effect of cement kiln dust on the value of coefficient of permeability of the soil (k), fifty specimens were prepared and tested according to ASTM D 2434-68. The coefficient of permeability determined by using a falling head permeability test method after variable curing ages, the results were recorded in table (3). The variation of coefficient of permeability with the curing age at specified cement dust ratio shown in figures (6) and (7), also the relationship between (k) and cement dust ratio is shown in fig. (8).

2.7. Durability Tests

2.7.1. Freezing –Thawing Tests

Two specimens prepared and tested for each cement dust content, the freezing –thawing testswere conducted according to ASTM D 560. The specimens were placed in a moist room having a temperature of 21 °C and a relative humidity of 70% for a period of 7 days. At the end of the storage in the moist room, water-saturated felt pads were placed between the specimens and the carriers, and the assembly was placed in a freezing cabinet having a constant temperature not warmer than−23 °C for 24 h. Then, the assembly was removed and placed in a moist room with a temperature of 21 °C and a relative humidity of 100% for a period of 23 h. At the end of this period, the specimens were removed and firm strokes were applied to the full height and width of the specimen with a firm stroke corresponding to approximately 1.4 kg force. Eighteen to twenty vertical brush strokes are required to cover the sides of the specimen twice and four strokes are required on each end. After 12 cycles, the test samples were dried in an oven at 110±5 °C for 12 h. Then, volume and moisture change, were calculated for one specimen and the soil-cement dust losses for the other. The results are shown in table (3).

2.7.2. Wetting – Drying Tests

Wet-dry tests were conducted according to ASTM D 559. Two identical samples of each soil / additive combination were prepared at the optimum moisture content. Each wet-dry cycle consisted of submerging the two soil samples in water for 5 hours and then placing them in a 71^0 C oven for 42 hours. After removing the sample from the oven, the first sample was measured for volume change and weighed to determine any change in moisture content. The second sample was brushed and weighed to determine the soil loss. The test was continued until 12 wet-dry cycles were completed or until the sample failed. The results are shown in table (3).

TABLE (1)
ENGINEERING PROPERTIES OF THE SOILS

Soil	L.L	P.I	Gs	USCS	Particle grain size			Compaction characteristics	
					Sand%	Silt%	Clay%	MDD kN/m3	OMC%
A	38	19	2.73	CL	10	59	31	16.45	20.5
B	32	7	2.69	ML	6	94	----	16.52	21

TABLE (2)
CEMENT KILN DUST (KCD) PROPERTIES

Color	shape	Gs	Sio_2	$Al2O_3$	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl	L.O.I
Light brown	Semi-circle	2.85	14.1	4.7	1.97	40.17	2,79	5.85	3.13	1.55	1.83	24.25

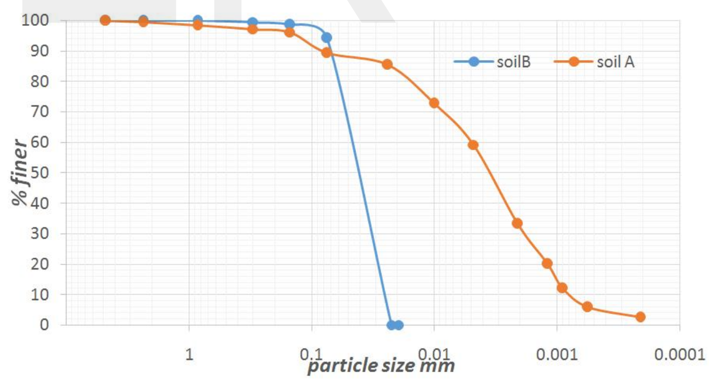

Fig.1 Grain- size distribution curve

TABLE (3)
TESTS RESULTS

Properties	Type of soil	Cement dust content (% by dry weight)				
		0	5	10	15	20
Max.dry density kN/m	A	16.45	16.51	16.35	16.23	16.15
	B	16.52	16.7	16.31	16.11	16.03
Optimum moisture content %	A	20.5	19.5	20.8	21.5	21.8
	B	21	19.4	22	22.5	22.75
Permeability(k)×10^{-8} cm/sec	A	5.0	3.4	2.8	2.2	2.0
Permeability(k)×10^{-6} cm/sec	B	13.0	8.7	5.4	5.0	3.7
Freezing – Thawing: (Max.loss in weight after 12 cycle %)	A	5.1	4.9	4.3	4.1	3.8
	B	8.4	7.8	7.7	7.2	6.5
Freezing –Thawing (Max.volum change after 12 cycle %)	A	1.6	1.3	1.0	0.8	0.6
	B	1.4	1.2	1.1	0.8	0.5
Wetting – Drying (Max.loss in weight after 12 cycle %)	A	3.5	3.2	2.8	2.5	2.1
	B	3.3	2.9	2.4*	2.0	1.9
Wetting – Drying (Max.volum change after 12 cycle %)	A	0.9	0.7	0.3	0.2	0.2
	B	0.8	0.5**	0.3	0.2	0.1

* The samples collapsed after 10 cycles.** The samples collapsed after 11 cycles.

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TABLE (4)
RESULTS OF UNCONFINED COMPRESSION TESTS

Cement dust content %	curing age / Type of soil	Unconfined compression strength kN/m³					
		1 day	4 day	7 day	30 day	60 day	90 day
0	A	310	***	***	***	***	***
	B	185	***	***	***	***	***
5	A	450	513	601	785	940	1050
	B	315	350	400	580	590	750
10	A	415	475	530	740	900	910
	B	295	330	385	520	660	700
15	A	395	455	490	660	780	860
	B	280	315	480	485	575	510
20	A	387	420	470	598	680	745
	B	275	310	340	430	510	545

***The study of curing period effect was achieved for tests of soil stabilized with cement dust

TABLE (5)
SHEAR PARAMETERS OF TREATED AND UNTREATED SOIL OBTAINED FROM DIRECT SHEAR TESTS

CKD%	Soil type	Cohesion C (kN/m²)	Angle of internal friction,Ø°
0	A	160	9.5
	B	90	15
5	A	120	28.6
	B	50	23
10	A	60	20.5
	B	40	20
15	A	33	25
	B	32	20
20	A	32	24
	B	30	19

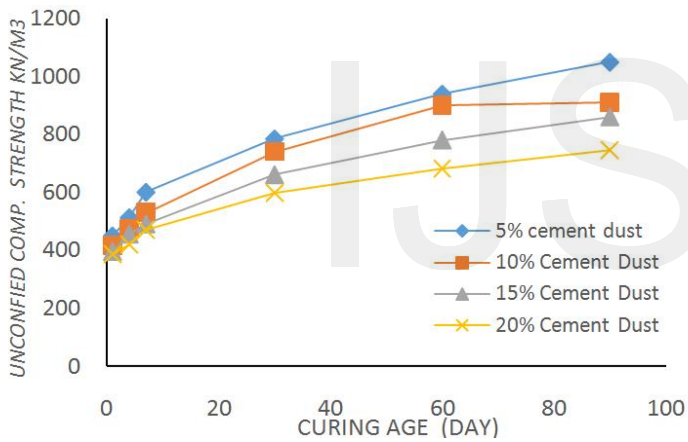

Fig.2 Effect of CKD content on unconfined compression at several curing age for clayey soil

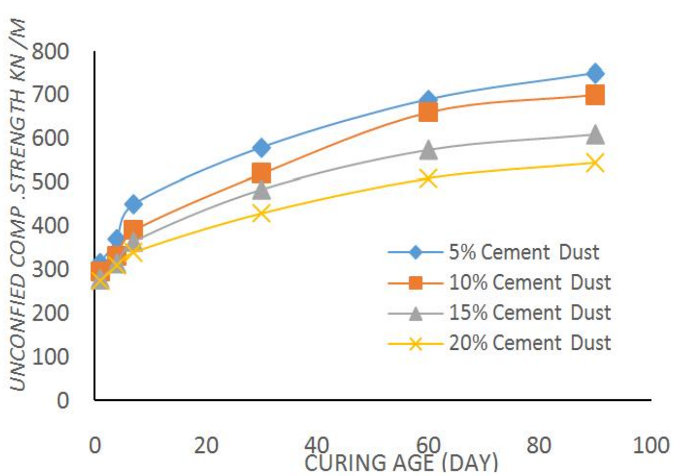

Fig. 3 Effect of fiber content on unconfined compression at several curing age for salty soil

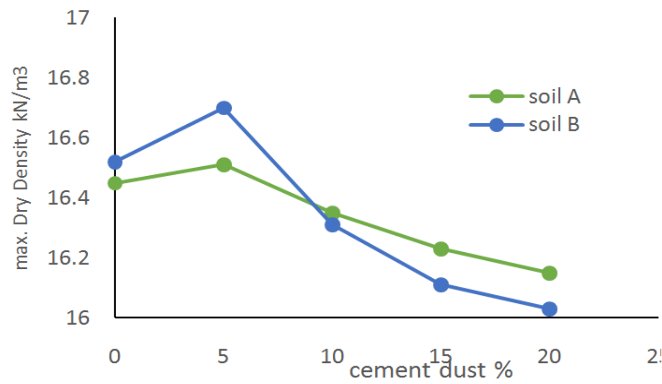

Fig. 4 The relation between CKD% and MDD for the two soils

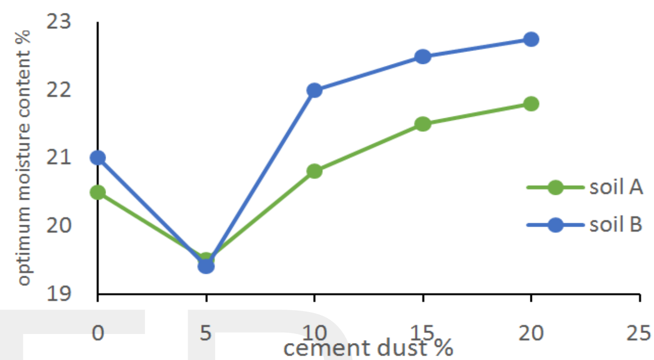

Fig. 5 The relation between CKD% and OMC for two soils

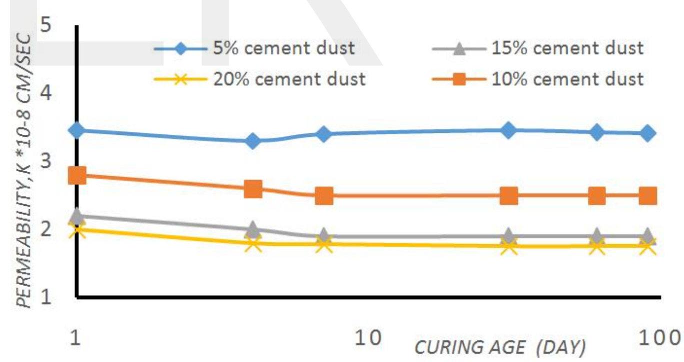

Fig. 6 Variation of permeability of clayey soil for different CKD with curing age

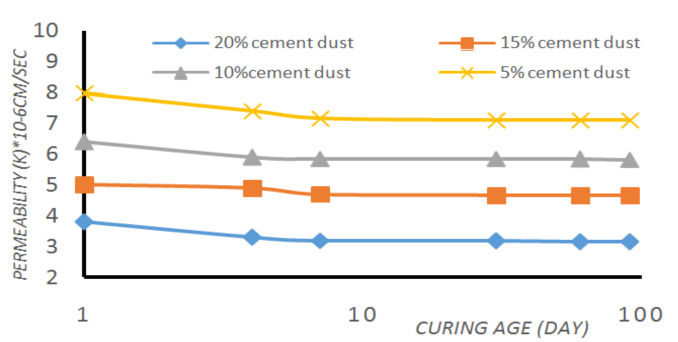

Fig. 7 Variation of permeability of silty soil for different CKD with curing age

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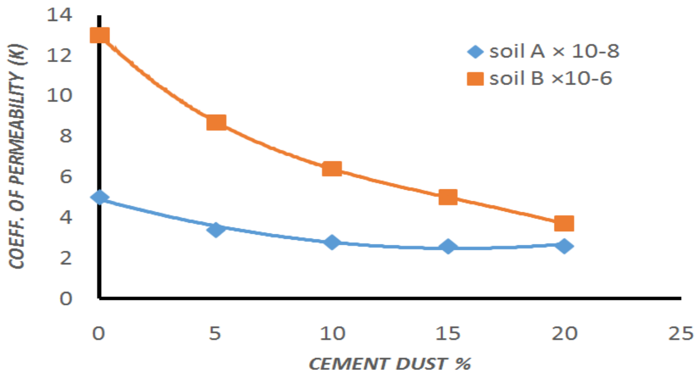

Fig. 8 Variation of coeff. of permeability with CKD content

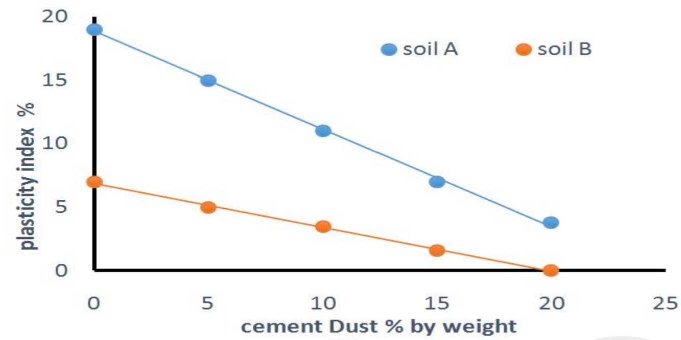

Fig. 9 Variation of plasticity index with CKD content

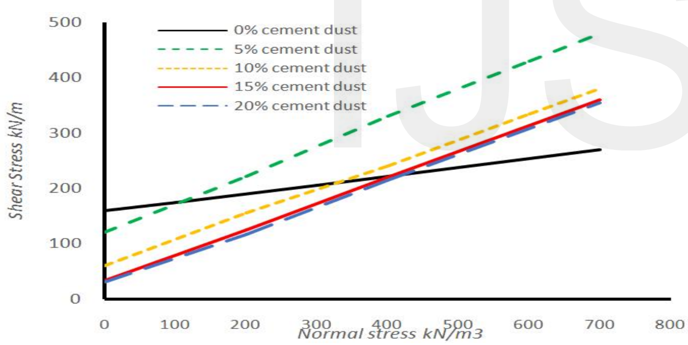

Fig.10 Mohr-Coulomb failure envelopes for treated anduntreated clayey soil specimens

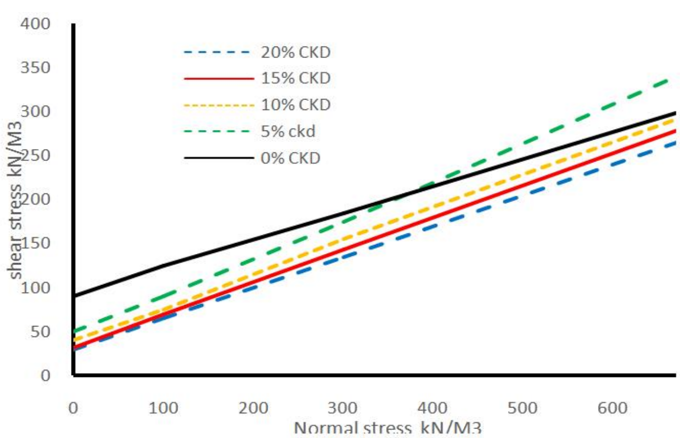

Fig.11Mohr-Coulomb failure envelopes for treated and untreated silty soil specimens

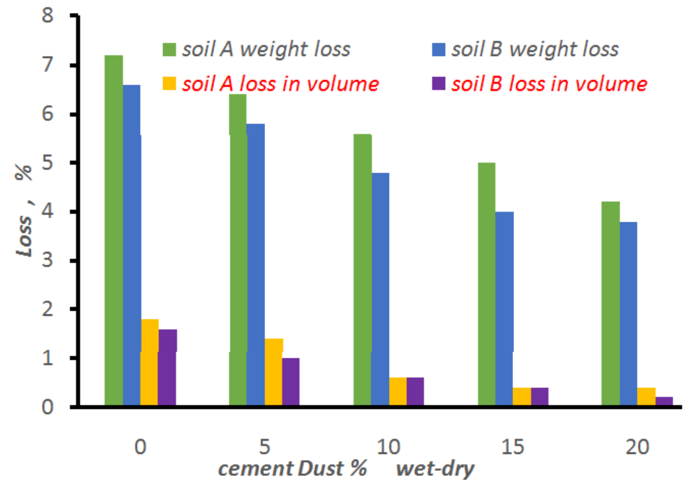

Fig.12 results of wetting-drying tests for different cement dust content

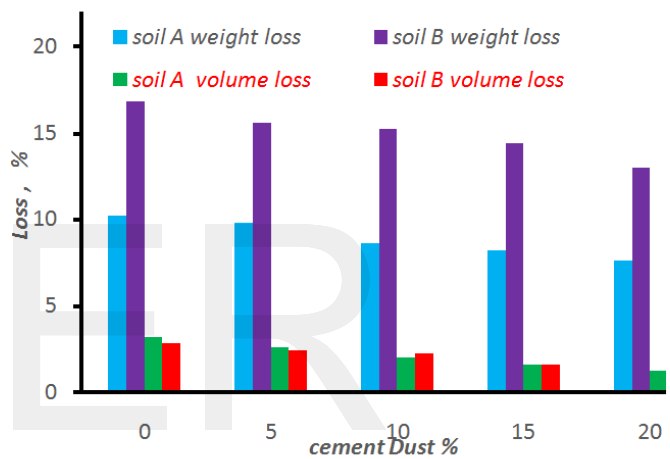

Fig.13 results of freezing-thawing tests for different cement dust content

3 Discussions

Effect of CKD on the unconfined compressive strength (UCS) was determined as function of CKD content and curing age for the two soil types as presented in table (4). The results show that the inclusion of CKD increase the unconfined compressive strength (qu). It is observed that the UCS is increased 45% and 70% for clayey and silty soil respectively when compared with that of untreated soil and occurs at a CKD content of 5%. Thus, the unconfined compressive strength increase up to 5% cement kiln dust and decrease thereafter. Figure 2and 3 show that the treated samples gain higher strength with increasing the curing age, this due to both inclusion ratio and curing age contribute to the production of more cementing bonds within the soil body, and this confirms the previous findings of many other researchers (e.g. Nagaraj et al. 1996) [13]. Hence, the optimum cement kiln dust content is observed to be 5% for the soils considered in the study.
The role of cement content and water content on the unconfined compressive strength can be illustrate this result which is expressed as novel parameter. The novel parameter govern-

ing the strength and deformation characteristics of clay-cementmixtures wherein the water content and cement content vary over a wide range has been successfully introduced [14], [15]. It is designated as clay-water/cement ratio, wc/C, which is the ratio of clay water content (%) to cement content (%). It is the structural parameter since the clay water content, wc, controls the clay fabric and the cement content, C, reflects the degree of cementation. For a given soil admixed with cement, the lower the wc/C, thegreater the strength. The application of this proposed parameter has been incorporated with Abrams' Law to predict the strength development [16].

Table 3 shows the effect of CKD on compaction characteristics of the two soils investigated. It is evident from figure 4&5 that the 5% CKD provides the largest values of maximum dry density and the minimum value of optimum moisture content. This may be because; at low values of CKD there is insufficient content of cement dust available to bond soil particles. At higher values of cement dust content it is likely that the soil particles are cemented together, and a continuous structure with harder contacts is formed by the hydration products and secondary reactions. As the result, soil particles are fixed together and their movement is restricted leading to a substantial decrease in density [17].

The relationship between the coefficient of permeability and CKD content is plotted in fig. (8) and (9). The relation indicates that the permeability coefficient decreases considerably with increasing the CKD content and the reduction are more obvious with silty soil. Curing age shows insignificant effect on the coefficient of permeability. This may be due to, the voids in the CKD-stabilized clay samples, decreased with CKD additions.This phenomenon does not appear to be time dependent; it rather appears to be CKD-dosage dependent [5].

Figure (9) show the effect of cement dust content on the plasticity indices of each soil. It is observed from this Figure that the plot of variation of plasticity index with respect to CKD content is a linear reverse relationship and, silty soil loss the plasticity property at 20% cement kiln dust. This result is matching with the illustration reported by (Little, D.N. 1995) [12],"When the additives containing free calcium hydroxide are mixed with the soil, the calcium causes the clay particles to flocculate into a more sand-like structure reducing the plasticity of the soil". This reduction in plasticity which is called modification reduces the shrink/swell characteristics of the soil. Soil stabilization includes the effect from modification with a significant additional strength gain

The results of direct shear test represented by the relation between normal stress σ_n and shear stress τ shown in figures (10) and (11). The figures illustrate that the cohesion C decrease with increasing the CKD content and this reduction be greater in clay soil, while the friction angle increasing with CKD content with maximum value at 5% cement dust.

Wetting-Drying testing conducted on treated samples prepared at optimum moisture content. The number of cycles survived prior to sample failure is reported in table 3. As this table shows most samples survive a 12 cycles of wet-dry testing. Fig (12) clarify that is a significant improvement in performance against wetting and drying with increasing the cement kiln dust content.

A series of freezing-thawing test were performed for treated samples of each soil at different CKD content. The results are reported in table 3. As this table shows, all samples survived the 12 cycles test. Figure (13) shows that the increasing in CKD content experienced a significant decrease in weight and volume losses.

4 Conclusions

1. CKD is an effective soil stabilization agent, based on the results observed and described in this study. It is recommended that it be considered for use in the stabilization of subgrade soils.
2. Atterberg limits are commonly used to determine the plasticity of a soil and as an indicator of the potential for volume change. CKD was effective in reducing the plasticity of two soils.
3. The strength of all samples treated with CKD was improved with the addition of CKD. The optimum cement kiln dust content is observed to be 5% for the soils considered in the study.
4. CKD improved the durability of the soil as evaluated by wetting-drying and freezing-thawing testing.
5. The increases in UCS were inversely proportional to the plasticity index (PI) of the untreated soil.

5 Recommendation

It is recommended based on the results of this research that cement kiln dust be considered a viable option for the stabilization of subgrade soils. As with all additives, it is recommended that a mix design be conducted prior to selection to confirm the CKD selected and the amount specified will provide satisfactory performance

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