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Research paper

Assessment of Using Cement Kiln Dust Stabilized Roads Subbase Material

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Abstract

The increase in the demand for cement to produce large quantities for the purpose of reconstruction produce a large amount of cement kilns dust accordingly. The cement kilns has a cementations property and it's using to treats soil. In this study, sand gravel soil (roads subbase) materials has been used to study the effect of the cement kiln dust (CKD) as a partial replacement with the natural dust of subbase till 20% by weight. Three tests procedures have been adopted which are density-moisture relationship, California bearing ratio (CBR), and unconfined compression strength (UCS). The results show significant increasing in density and optimum moisture content, CBR, and UCS with the increasing of CKD content. Bonds induced by the pozzolanic reaction and the absorption of the free water on particles surfaces approaching each other could the cause of increasing density, forming tighten structure, and raising the CBR% values, this reaction needs more water with increasing of CKD that could be caused increasing in the optimum moisture content. The increasing in UCS results due to stabilizing the materials by CKD increased the ability to use the CKD as alternative material for Portland cement.

Keywords: *CBR, Cement Kiln Dust (CKD), Natural Aggregate, natural Dust; subbase layer.*

1. Introduction and literature review

Cement kiln dust (CKD) is by-product material produced in Portland cement plants in large quantities, the high alkaline of CKD is preventing its reuse in cement manufacturing [1]. In Iraq, Portland cement plants produced annually about 350000 tons and available for free [2]. It is an effective alternative to cement in stabilizing soils, and the cement is more expensive than finer CKD [3], it has a cementations property which makes it an effective binder in soil. It used increasingly for stabilizing soil, and used also as additive in improvement shear strength and changing plasticity of soils [4]. For soil treatment; when increasing CKD, the maximum dry density and swell decrease while CBR values and the pH increase [3] also increasing in soil elasticity modulus and lowering water absorption and sorptivity [4]. Mosa et al [2] found in their research that the optimum percent of CKD to stabilize soil is 20% by soil weight which it gave optimum swelling.

Elmashad studied the effects of cement dust and the cement on compressive strength and permeability of the sandy soil, his research results show improvement of the compressive strength and durability under environmental condition, improvement of compaction, reduction of the sand permeability, and low cost of using CKD, Baghdadi et al, showed in their research the specimens of 75% and 100% CKD to sand dunes failed in the durability although it gave high strength [5].

Blending CKD with aggregate shows increasing in resilient modulus with increasing time of curing and its amount, also show a higher strength than a new constructed aggregate as subjected to repeated loads, also improvement in flexural strength [6].

2. Materials and methods

Materials used in this research were the whole aggregate or natural aggregate compose of sand-gravel soil, and the cement kiln dust (CKD).

The natural aggregate was limestone brought from Al-Najaf city quarries (western south of Iraq), Figure (1) exhibit the particle size distribution which is comply with the subbase layer materials specifications type "B" according to Iraqi specifications (Table R6/1) [7] as shown in Table (1), Table (2) shows the physical properties.

Cement kiln dust brought from Al-Kufa Cement factory in Al-Najaf city, chemical composition shown in Table (3), the sulphate content (SO_3) was found 15.7% thus percent's of CKD added must not exceed 32% of total mix to satisfy the specifications requirements [7]. And when used as fines (15% upper limit), it will be satisfied. In general, kiln dust has a larger surface area than cement due to its finer particle size distribution [1].

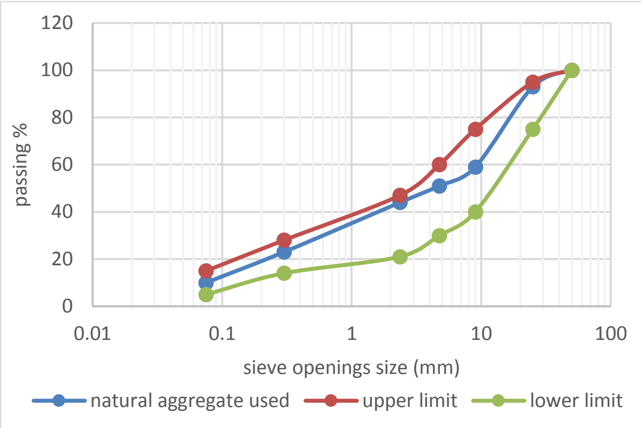

Fig.1: Particle Size Distribution of Natural Aggregate and the Limits of the Specification [7]

Table (1): The Iraqi standard specifications requirement of subbase layer materials [7]

	Sieve size	Percent of passing			
		Type A	Type B	Type C	Type D
Gradation	75mm	100	-	-	-
	50mm	100-95	100	-	-
	25mm	-	95-75	100	100
	9mm	65-30	75-40	85 -50	100-60
	4.75mm	55-25	60-30	65-35	85 -50
	2.36mm	42-16	47-21	52-26	72-42
	0.3mm	18 -7	28 -14	28 -14	42-23
	0.075mm	8 -2	15 -5	15 -5	20 -5
CBR (minimum)		45	35	30	20

Table (2): The physical properties of used natural aggregate with standard specifications of tests

property	Result	Specifications value	Standard tests[8]
Liquid limit %	23	25 max	ASTM D 4318
Plastic limit %	19		
Plasticity index	4	6 max	
Density (Gm/cm^3)	2.21		ASTM D 1557
Optimum moisture %	5.3		
CBR%	37	35 min	ASTM D 1883
UCS (Mpa)	6.7		ASTM D 1633

Table (3): Chemical Composition of CKD*

Components	Percentage
$CaCO_3$	49.5%
Na_2O	1.5%
K_2O	0.5%
CaO + free CaO	27.57%
SO_3	15.73%
SiO_2	12.58%
Al_2O_3	1.86%
Fe_2O_3	1.44%
Total Dissolved Solids (TDS)	6.13%
Loss On Ignition (LOI)	15.82%
Free CaO	13%

*A.M. Mosa et al. [2]

In this paper, sand-gravel soil (roads subbase) materials has been used to study effect of the cement kiln dust as a partial replacement with the natural dust (fines or materials finer than 0.075mm) of subbase in 5, 10, 15, and 20% by weight. Three tests procedures have been adopted which are compaction, CBR, and unconfined compression strength.

Paper aims to make use of wastes by-products materials in strengthen the subbase and to find alternatives to use as base layer.

3. Results and discussion

3.1 Maximum density and optimum moisture content

Figure (2) illustrates the maximum dry density of natural aggregate mixed with different CKD content, there is a significant increasing in density as comparing with the content of CKD this could be attributed to some reasons, 1-the high surface area and fineness of CKD to fills the voids [1, 2], 2-specific gravity of CKD as compare it with clays specific gravity, 3-reduction the plasticity, and 4-adsorption by the pozzolanic reaction absorb the free water on particles surface approaching each other. The pozzolanic reaction and the high surface area and fineness of CKD, the water absorption increased with the increasing of binder to maintain consistency in a constant that is caused increasing the in optimum moisture content [1] as shown in Figures (3) and (4).

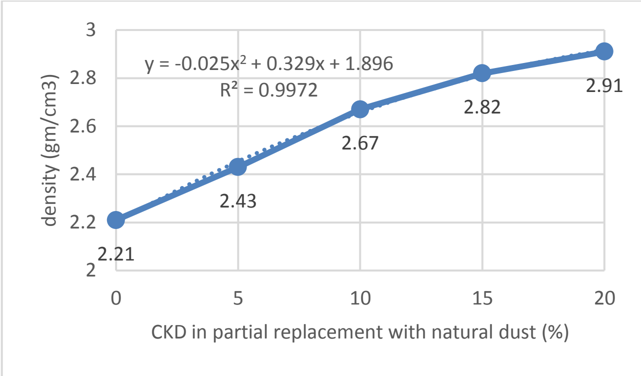

Fig. 2: Relationship between the maximum dry density and CKD Content

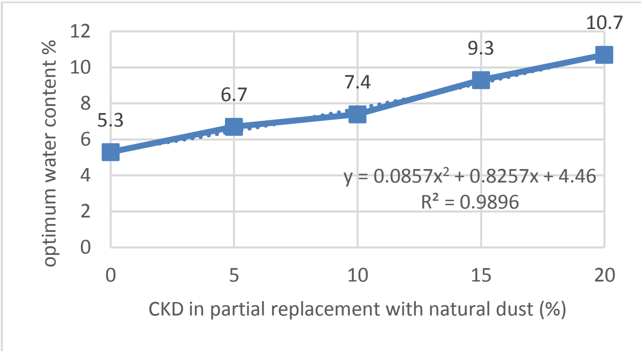

Fig.3: Illustrates the effect of the CKD content on the optimum moisture content values

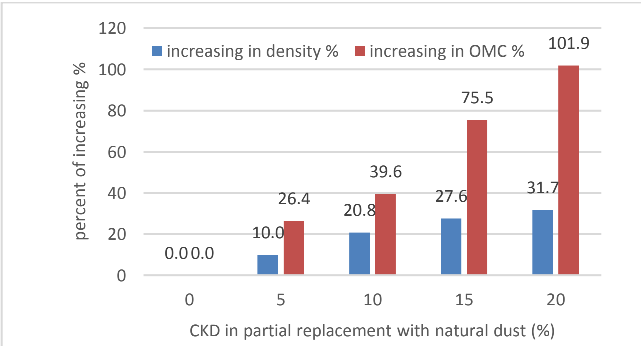

Fig. 4: Percent of Increasing in Both Density and OMC Influenced By CKD Content.

3.2 California Bearing Ratio (CBR %)

The CBR% values were clearly increased with CKD increasing as shown in Figures 5 and 6, that is attributed to forming bonds by the pozzolanic reaction given strength and tighten structure due to some reasons like 1-presence of free lime and low alkalis [2], 2-increasing in density, 3-absorbing water by CKD reactions and cation exchanges reforming structure [1], and 4-the plasticity reduction induced to the effect of high lime with low alkalis [2] and effect of silica which works as sand. Moreover, CKD has amount of alkalis which contains the major stabilizing agent is the calcium required for stabilizing the aggregates [6] which reduce the deflection during applying loads [10].

Little amount of CKD (about 16% from natural fines which was 10% from total sample weight) make the mix accepted as base layer from CBR% point of view according the Iraqi specifications requirements as shown in Figure (5). As the CBR value increasing, the layer coefficient (a_i) will increase consequently and the layers thickness decreases [9] this lead to enhancement the pavement performance and increasing service life, and reducing the deflection [10] after soil stabilized which leads to reduce the maintenance cost.
As comparing the CBR results with Mohsen and Jawad [11] and Ghani et al [10] researches which they had used the same subbase materials (natural aggregate type B from the same quarry have closely properties and particles gradation), their CBR results revealed that adding cement reached to 8% by the total weight was close to this research results although of high content of cement compare to with CKD used, it could be due to they left the natural dusts or fines, increased amount of fines, and the high surface area and fineness of CKD to fill the voids comparing to the cement.

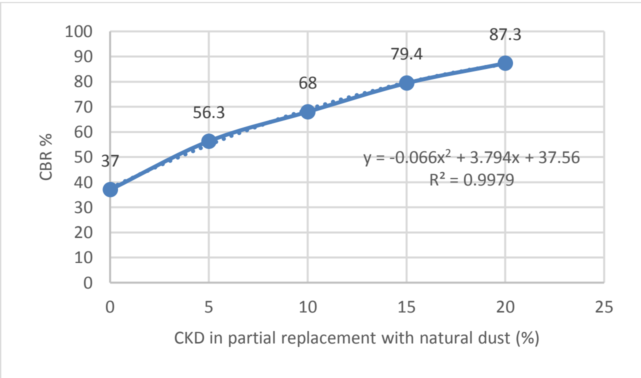

Fig. 5: The effect of CKD content on CBR values

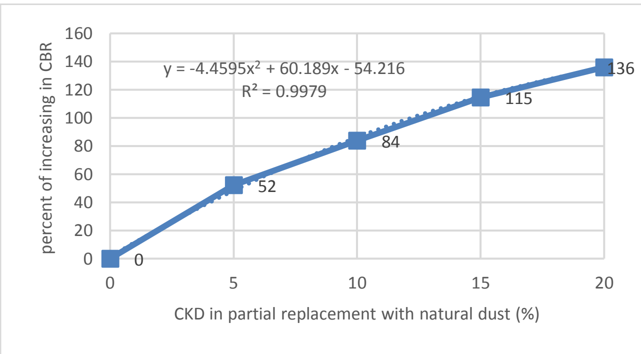

Fig. 6: Percent of increasing in CBR values as influenced by CKD content

3.3 Unconfined Compression Strength

Under unconfined situations of subbase materials, the results of the UCS assessment revealed increasing in the strength by increasing in CKD content as shown in Figure (7), it's due to the pozzolanic reactions forming bonds with presence of the calcium agent in CKD and high free lime in CKD with low alkalis [2], this result reveals that there is ability to use the CKD as alternative material for cement. Figure (8) shows a significant increasing in UCS values especially with more than 10% CKD.

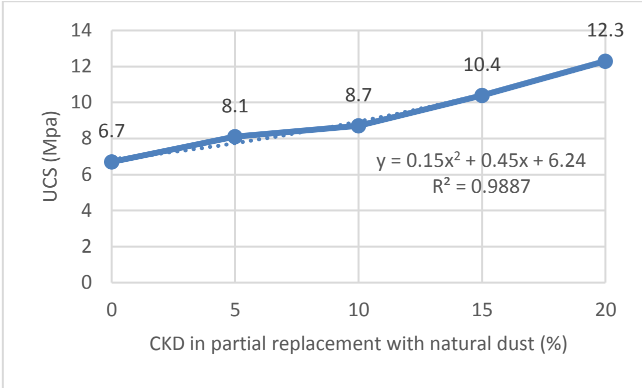

Fig. 7: UCS values as influenced by CKD content

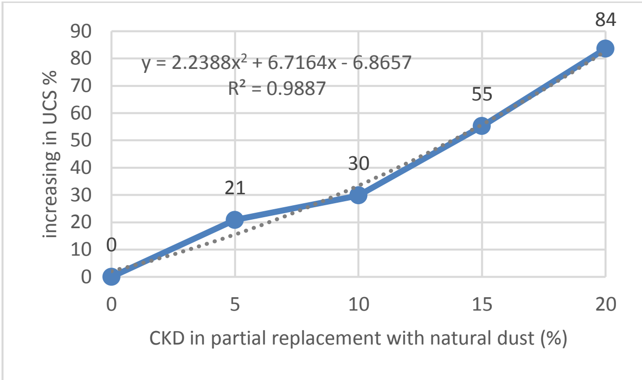

Fig. 8: Percent of increasing in UCS as influenced by CKD content

4. Economic evaluation

To evaluate the adding CKD to natural aggregate from economical point of view the selecting the most economical design and fixing some variables when comparing as shown in Table (4), taking the modulus of asphaltic surface and base layers, and the two cases of subbase (natural and treated with CKD in 20% from fines content) then using the AASHTO method to find thicknesses of the layers by adopting the design structural number is 5.

Table (4): Comparison between two designs structures

	Case 1: not stabilized subbase		
layer	Modulus (psi)	Layer coefficient (a)	Thickness (inch)
Surface	340*	0.38	2**
Base	230*	0.32	4**
Subbase	CBR=37%	0.12	25
	Case 2: stabilized subbase		
layer	Modulus (psi)	Layer coefficient (a)	Thickness (inch)
Surface	340*	0.38	2**
Base	230*	0.32	4**
Subbase	CBR=87%	0.136	22

* From Mutlag [12] and Jasim [13]
** recommended by AASHTO as minimum limits [14]

Table (5): The materials price in Iraq [15]

Material	Cost (IQD/m^3)
Asphalt concrete surface	300,000
Asphalt concrete base	200,000
Subbase	21,000

Because the CKD is priceless and used in very little amount (about 2% from of total sample) it has the same price as natural aggregate subbase material as shown in Table (5). Table (6) shows the construction cost, thickness, and reduction in cost. Reduction in total thickness was 9.6%, and in subbase thickness 12%, while the reduction in total initial cost 1.9% and 12.7% reduction in subbase cost.

Table (6): Shows the construction cost and thickness

layer	Cost (IQD)		Thickness (inch)
Case 1: not stabilized subbase			
Surface	15,000	41,300	31
Base	20,000		
Subbase	6,300		
Case 2: stabilized subbase			
Surface	15,000	40,500	28
Base	20,000		
Subbase	5,500		

5. Conclusions and recommendations:

The replacement of natural dust with by CKD has a positive result in improvement of strength of natural aggregate subbase materials such used, it's clearly improves the unconfined compression strength and California bearing ratio. The percent more than 15% of CKD make increasing in CBR and UCS to more than 115% and 55% respectively. Little amount of CKD (about 16% from natural fines which was 10% from total sample weight) make the mix accepted as base layer from CBR% point of view according the Iraqi specifications requirements, results refer that there is ability to use the CKD as alternative material for cement. Both density and optimum moisture content were clearly increased when the CKD content increased with little amounts.

Moreover, it raises the layer coefficient which led to decrease the layer thickness, this reduction was 12% in subbase thickness while the reduction in subbase cost was 12.7%. It recommended to use CKD to stabilize and improve the subbase materials and study effect of raising its percent.

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