Iraqi Journal of Science
ISSN: 0067-2904

The effect of CKD fineness on the consistency and setting time of cement paste when adding it as a partial replacement of cement

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Abstract

Cement kiln dust (CKD) is a waste of cement manufacture. The disposal dust becomes an environmental threat. In order to overcome this problem, researchers are carried out to find out the economical and the efficient means of utilizing it in various applications .One of these applications is adding it as partial replacement of cement. The aim of present work is investigating the effect of CKDs fineness on the consistency and setting time of cement, when utilized as a partial replacement. the CKD was grind by jet mill and classify into 7 groups according fineness (3000 , 6000 , 7000 , 8000 , 9000 , 10000 , 11000) cm^2/gm then prepared blends with (5 ,10 , 15 , 20 , 25 , 30 , 35 and 40) % replacement by CKD for each fineness ,and compare between two sources of CKD (kufa and Bazian cement plant) which different in location and manufacturing process .The results showed that increasing of fineness lead to increasing of water demand for consistency for each CKD, with different in water amount between types of CKD. Setting time(initial and final) retarded with increase fineness of CKD of kufa plant while accelerated setting time with increase fineness of CKD of Bazian plant .where the results indicated that increasing of CKD fineness lead to increasing activity of CKD compounds which affected on cement hydration according to its activity and percent's presence of each type of CKDs .

Keywords: Cement, CKD, fineness, consistency, setting time

تأثير نعومة غبار افران الاسمنت على القوام القياسي وزمن التصلب لعجينه الاسمنت عند اضافته كبديل جزئي للإسمنت

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الخلاصة

غبار افران الاسمنت هو نفاية من نفايات صناعة الاسمنت ، والذي اصبح يهدد البيئة، وللتغلب على هذه المشكلة، بدء الباحثون بإيجاد طرق اقتصادية وكفوؤه لاستخدامه بعدة مجالات ، من هذه المجالات استخدامه ليحل محل جزء من الاسمنت . هدف الدراسة الحالية تحري تأثير نعومة الغبار المضاف وبنسب مختلفة كبديل جزئي للإسمنت على خواص القوام القياسي وزمن التصلب ،حيث طحن الغبار بطريقة الطحن بالعصف ثم صنف الى سبعة مجاميع اعتمادا على نعومته (3000 ، 6000، 7000، 8000، 9000، 10000، 11000) سم^2/غم ثم حضرت خلطات تحوي على نسب استبدال (5، 10، 15، 20، 25، 30، 35، 40) % وزنا" من كل نعومة من النعومات ، ،وتم مقارنة النتائج بين مصدرين مختلفين من ناحيه الموقع وطريقة الانتاج وهما معمل سمنت الكوفة و بازيان . أظهرت النتائج بان زيادة نعومة الغبار ادت الى زيادة بكمية الماء للوصول للقوام القياسي ولكلا النوعين من الغبار مع كون غبار بازيان كان اكثر حاجه للماء من غبار

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الكوفة ، اما زمن التصلب(الابتدائي والنهائي) فقد ازداد (تأخر) بزيادة نعومة غبار الكوفة بينما زيادة نعومة غبار بازيان ادت الى نقص (تسريع) في زمن التصلب . ان زيادة نعومة الغبار ادت الى زيادة المساحة السطحية لمكوناته وبالتالي ازداد تأثير المركبات الفعالة فيه على اماهة الاسمنت وحسب درجة فعاليتها و نسبة تواجدها في كل نوع من انواع الغبار المستخدم .

Introduction

Cement kiln dust is a waste of cement manufacturing which is collected at kiln exhaust gases of cement plant and disposal and accumulation in irregular piles in open land. In Iraq cement kiln dust accumulates usually around the plants, most of these piles are unlined and uncovered [1] as explain in plate-1.

Plate 1- Cement kiln dust disposal (kufa cement plant)

The significant properties of CKD are affected by design of kiln ,raw materials and the used fuel in the cement plant [2,3], therefore the chemical and physical characteristics of CKD varies from one plant to another and must be evaluated as individual basis [4].The consistence of CKD are generally silicates, chlorides , carbonates ,various metal oxides and oxides of potassium ,calcium and sodium [5]. In construction works , CKD are used in various engineering purpose, one of these is the partial replacement of cement to produce cement mortars and concrete to benefit and reduced of negative effects of high quantities of CKD on environment.

In this study CKD is used in differences percentages as partial replacement after grinding to reach for advance fine of grain size of CKD .

Aims of study

The aims of this study are to investigate the effects of using different fineness of CKD in different percentages added as partial replacement of cement on some physical properties of cement (consistency , initial and final setting) using two sources of CKD from Kufa and Bazian cement plants. The Figure -1 shows locations of cement plants which selected in Iraq.

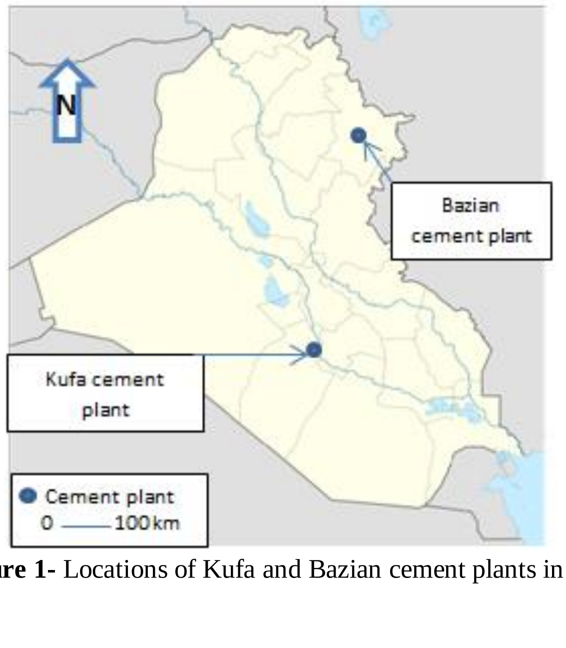

Figure 1- Locations of Kufa and Bazian cement plants in Iraq

Previous studies

Many of researchers are studied the utilizing of CKD as a partial replacement of cement using the original grain size of the CKD where the producal CKD fineness are similar to thegrain size of cement (2500 – 3000 cm^2/gm). Some of these studies which focus on setting time and water demand are:

Bhatty (1984)[6] studied the replacement effect of CKD on the setting time ,he chose five types of CKDs from five different sources of CKD where the CKD replacement of the cement was 0%, 10%, 15%, and 20% at a w/b ratio of 0.50 . He found that four CKDs affected decreased the setting time with increasing replacement while one remaining of CKD had the opposite effect and increased setting time.

Ramakrishnan (1986) [7] found that the addition 5% of CKD slightly retarded the setting time of cement by 22 minutes for initial and 40 minutes for final setting .

El-Aleem et al. (2005)[8] found that the increase replacement of CKD at 0%, 2%, 4%, 6%, 8%, and 10% by mass in pastes CKD leads to increase water demand and decrease setting time .

Maslehuddin et al. (2008) [9]studied the setting time effect of replacement CKD at 0%, 5%, and 10% by mass .They found that increasing CKD replacement 5 and 10 % lead to decreasing in initial setting by (6% , 11%) and final setting time by (2 % , 7 %) respectively.

Heikal et al. (2002)[10] explain that the setting time of three blends (slag cement 70/30%, 50/50%, and 30/70% by mass of OPC and granulated slag which is each blend was mixed with 2.5%, 5.0%, 7.5% and 10% by mass of CKD) indicated that the increase in CKD content increased the water requirement for normal consistency. The addition of 2.5% CKD by mass to mixes (70/30%) and (50/ 50%) increased setting time, whereas it accelerated the final setting time of mix (30/70%).

Marku at el (2012)[11] replacement 15% , 30% and 45% of PC by CKD and found that the water demand is increased with the increase CKD replacement and the increasing of CKD replacement lead to decrease setting time .

Methodology

Two sources of CKD are used in this study, the first source is from Kufa cement plant and the second source from Bazian cement plant, The chemical analysis of CKD is carried out as the first step in this study as shown Table-1 .

Table 1- Shows chemical composition of CKDs samples

Oxides / Sours	L.O.I	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	K_2O	Na_2O	CL
CKD from Kufa	22.51	9.82	5.66	1.94	8.73	42.92	2.62	2.01	3.07	0.71
CKD from Bazian	29.01	7.54	3.07	3.60	2.20	45.59	1.90	2.70	3.47	0.91

Table-2 shows the physical analysis and chemical composition of Ordinary Portland Cement OPC (AL-Mass) these results are conformed to IQS, No.5 /1984.

Table 2- Physical analyses and chemical composition of OPC (Al- Mass)

		Test result	I .Q .S , No.5 /1984 limits
Setting time	Initial	132	≥ 45 min
	Final	270 min	≤ 10 hours (600min)
Compressive strength(MPa)	3 days	22.52	≥ 15
	7 days	30.24	≥ 23
Fineness(cm^2/gm)		3160	≥ 2300
Soundness		conform	< 0.8
Chemical composition	CaO	62.21	-
	SiO_2	20.76	-
	$Al2O_3$	4.10	
	Fe_2O_3	3.30	
	MgO	2.46	< 5.0
	K_2O	-	
	Na_2O	-	
	SO_3	2.76	< 2.8
	L.O.I	2.75	< 4.0
	L.S.F	o.94	0.66 – 1.02
	I.R	0.94	< 1.5%
	F .L	1.12	-
	C_3S	57.15	-
	C_2S	16.65	-
	C_3A	5.28	-
	C_4AF	10.03	-

The grinding CKD samples were carried out using jet mill grinder methods which depending on collisions granular of materials into each other to obtain finer grins size. The CKD samples are classifying into 7 groups according to the fineness test which is carrying out using Blain permeability method according to IQS ,No. 8/1984 . The groups are 3000 , 6000 , 7000 , 8000 , 9000 , 10000 , 11000 cm^2/gm .The preparation blends have OPC with replacement 5 , 10 , 15 , 20 , 25 , 30 , 35 , 40 % of CKD from each fineness group.

The effect of fineness and percentages of CKD replacement on water demand of cement paste is to reach the standard consistency, which means the degree paste plasticity [11] , The consistency test carried out for all blends (113) according to IQS, No 8 ,1984 using vicat apparatus .

The initial and final setting time are determined for all blends to evaluate the effect of CKDs fineness on these properties and indirect of development hydration reactions of cement, which is performed using vicat apparatus according IQS, NO. 8/1984

Results and Discussion

Consistency test

The amount of water demand for reach blend (cement) to normal consistency is 132 mLt while the other blends which have CKD are show below:

1- Cement with CKD of kufa cement plant

The amount of water demand for reach blend (cement + CKD) to normal consistency are shown in Table-3.

Table 3 - Shows the consistency test results (cement + CKD of Kufa cement plant)

Fineness of CKD cm^2/gm / CKD percent	Water demand (mLt)						
	3000	6000	7000	8000	9000	10000	11000
5%	135	135	132	137	137	140	140
10%	138	140	145	155	150	157	155
15%	143	148	155	160	163	160	160
20%	148	155	155	155	160	167	165
25%	145	155	153	160	158	165	165
30%	150	160	160	168	165	165	168
35%	150	160	168	170	170	172	172
40%	153	163	170	172	172	173	172

The maximum value is (173 mLt) when replacement of CKD equals 40% (by weight) at 10000 cm^2/gm of CKDs fineness, while the minimum value was (132 mLt) when replacement of CKD equals 5% (by weight) at 7000 cm^2/gm of CKDs fineness .The relationship between fineness and water demand for normal consistency are shown in Figure-2 .which explain the increasing of fineness leads to increasing in water demand for all used replacement percentages.

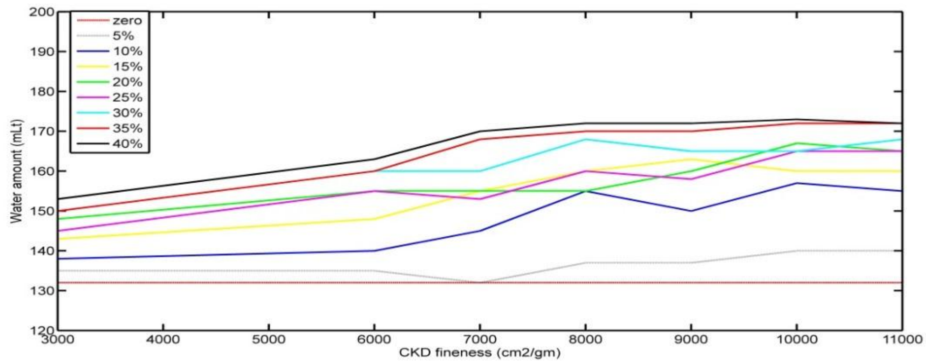

Figure 2 -Shows the effect of fineness of CKD (kufa cement plant) on water demand of consistency

The Figure-3 explains clearly that the increasing of CKD percentages replacement leads to more water requirement to reach for consistency for all CKD fineness used in this study.

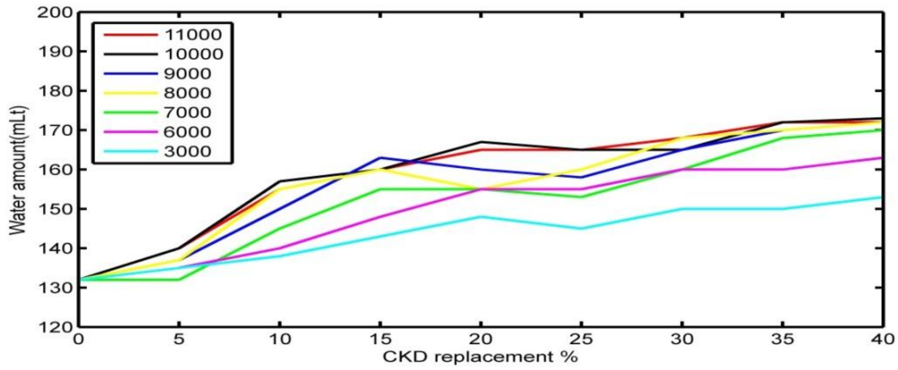

Figure 3-Shows the effect CKD (of Kufa cement plant) replacement (on different fineness) on water demand of consistency

These figures show that the water required for reach consistency are higher when the finer CKDs fineness are used .where the increasing of fineness may caused increasing in surface area of some CKD compounds which have high ability to water absorption and accordingly reduce the plasticity of paste.

2- Cement with CKD of Bazian cement plant

Table-4 shows the amount of water required to reach blend (cement + CKD) normal consistency where the maximum value was (193 mLt) in the replacement of CKD equals 35% and 40% (by weight) at 11000 cm^2/gm of CKDs fineness . While the minimum value was (132 mLt) when the replacement of CKD equals 5% (by weight) at 3000 cm^2/gm of CKDs fineness.

The relationship between fineness and water demand for normal consistency are shown in Figure-4 which shows the increasing fineness leads to increase water demand for all replacement percentages.

Table 4 – Shows the consistency test results of cement + CKD of Bazian cement plant)

Fineness of CKD cm^2/gm / CKD percent	Water demand (mLt)						
	3000	6000	7000	8000	9000	10000	11000
zero	132	132	132	132	132	132	132
5%	132	137	137	140	143	143	145
10%	143	145	145	147	145	153	160
15%	140	145	153	148	153	160	165
20%	145	152	158	155	165	170	175
25%	155	155	158	160	170	175	175
30%	153	160	160	168	173	185	188
35%	160	165	165	170	178	185	193
40%	165	170	170	176	183	190	193

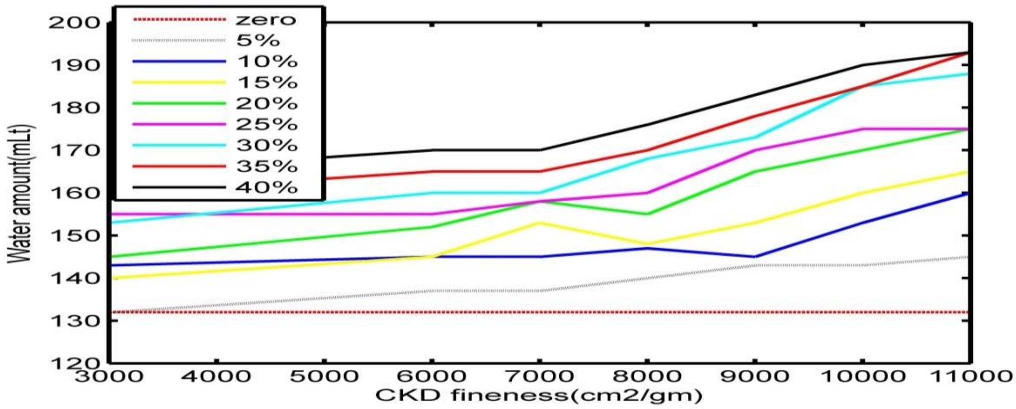

Figure 4 - Shows the effect fineness of CKD (Bazian) on water demand of consistency

Figure-5 explains clearly the increases of CKD replacement percentages leads to more water requirement to reach consistency for all CKD fineness used in this study.

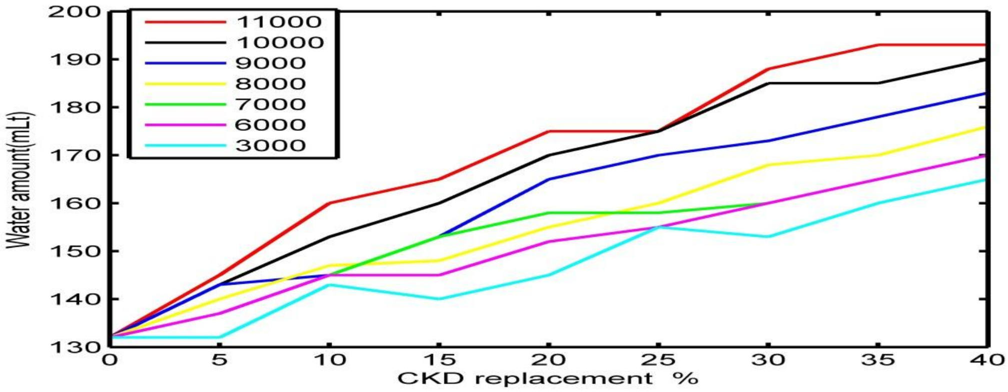

Figure 5- Shows the effect CKD (Bazian) replacement (in different fineness) on water demand of consistency

The two figures above show that water requirement to reach consistency is at high amount with use high fineness of CKD .where increasing fineness may caused by increasing in the surface area of some CKD compounds which have high ability to water absorption and reduce plasticity of paste.

The results that the blends which have CKD of Bazian cement plant demanded water more than blende's have CKD of kufa cement plant this is may be due to differences in chemical composition where the CaO ,Fe_2O_3 , alkalis , chlorides and L.O.I % are high in CKD of Bazian cement plant compared to CKD of kufa cement plant where these compounds are most probably responsible for the high water demand .

Setting time test results

The initial setting time of OPC paste is 132 minutes and final setting time is 270 minutes, which is within the limits of Iraqi standers IQS, No.5 , 1984 as shown in Table-2. While the initial and final setting time for samples containing CKD replacement are discussed below:

1- Cement with CKD of Kufa cement plant

The results of initial setting of blends (cement +CKD) are summarized in the Table-5. Where the maximum value of initial setting time appears at 35% CKD replacement of 10000 cm^2/gm of fineness and minimum value appears at 40% CKD replacement for 3000 cm^2/gm. The fineness 10000 & 11000 cm^2/gm for all CKD replacement showed maximum values.

Table 5 –Shows the initial setting time cement +CKD of Kufa plant

Fineness of CKD cm^2/gm / CKD percent	Time (minutes)						
	3000	6000	7000	8000	9000	10000	11000
5%	130	130	125	125	120	120	130
10%	120	120	125	120	110	115	125
15%	120	110	120	115	115	115	120
20%	110	110	115	110	115	120	120
25%	100	120	120	125	125	135	130
30%	80	100	125	130	130	140	135
35%	80	110	130	135	140	142	140
40%	75	115	133	135	138	140	140

The relationship between fineness and initial setting time Figure- 6 shows that percentages more than 20% is retarding the setting time. While the percentages of replacement less than 20% are slightly or not affected by increasing fineness, may be to low replacement percentages and consequently affect is limited.

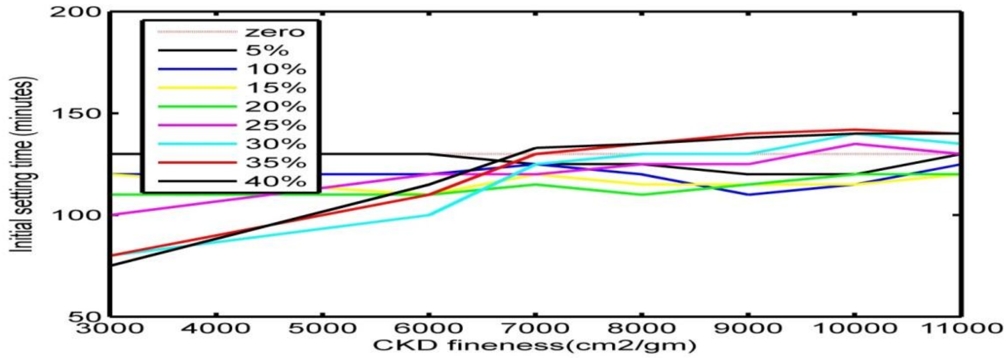

Figure 6 – Shows the relationship between fineness of kufa CKD replacement and initial setting time

Table-5 and Figure-7 shows that the fineness 3000 and 6000 cm2/gm are accelerating setting time with increasing of CKD replacement, while the fineness 9000 , 10000 &11000 cm^2/gm shows retarding behaviors with increasing of CKD replacement .The time retarder reach 12 minutes more than PC only which indicates that the fineness may be contributing the changes in effect of CKD on initial setting time of cement paste.

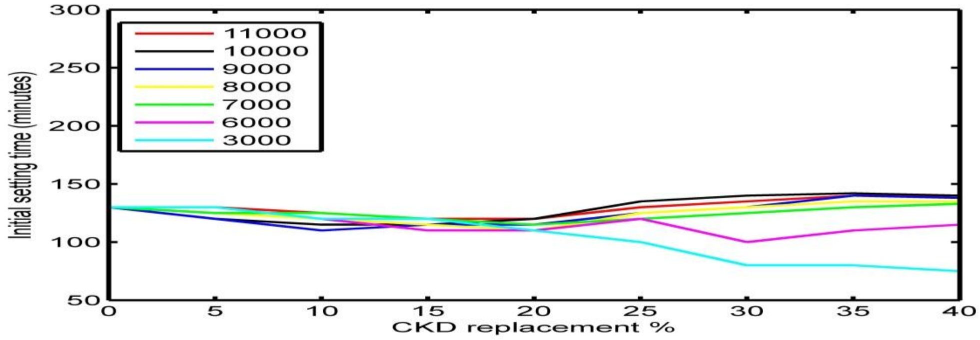

Figure 7 –Shows the relationship between CKD(kufa) replacement and initial setting time

The final setting time of (cement + CKD of Kufa cement plants) is shown in the Table-6.

Table 6 - Shows finall setting time (cement + CKD of Kufa cement plant)

Fineness of CKD (cm^2/gm) / CKD percent	Time (minutes)						
	3000	6000	7000	8000	9000	10000	11000
5%	270	273	270	280	260	280	280
10%	240	275	265	265	260	270	285
15%	245	260	270	285	290	285	270
20%	225	265	270	290	290	300	330
25%	210	280	285	290	310	320	335
30%	210	275	290	285	320	350	350
35%	180	280	290	300	350	380	370
40%	180	290	298	350	375	383	385

The maximum value 385 minutes of the final setting time is appearing at 40% of CKD replacement at CKD fineness 11000 cm^2/gm and minimum value 180 minutes appears at 40% of CKD replacement of 3000 cm^2/gm of CKD fineness. Figure-8 shows the relationship between fineness and final setting time and effect of increasing fineness, which lead to retard the final setting time for all replacement percentages.

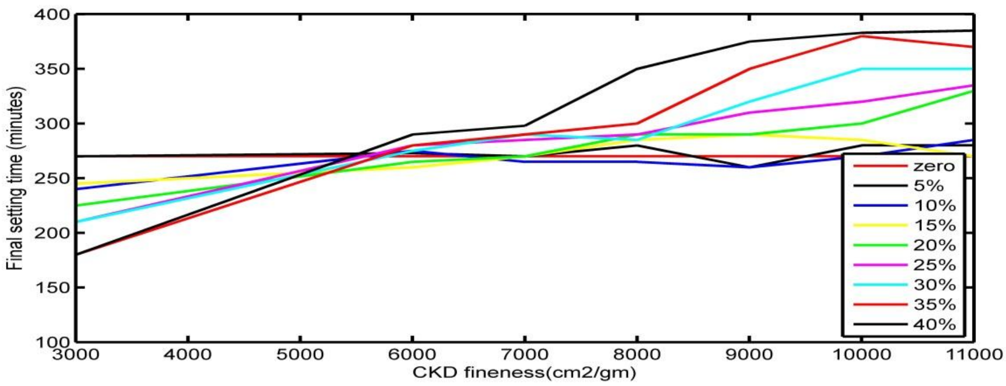

Figure 8- Shows the relationship between fineness of kufa CKD replacement and final setting time

Figure-9 explains the effect of CKD replacement in different fineness on the final setting time. All fineness except 3000 cm^2/gm are retarders (increasing time) with increasing CKD replacement while the fineness 3000 cm^2/gm is accelerated the final setting time with increasing of CKD .this indicate that the different affect of CKD with increasing fineness in which the fineness is changing the behavior of final setting time .

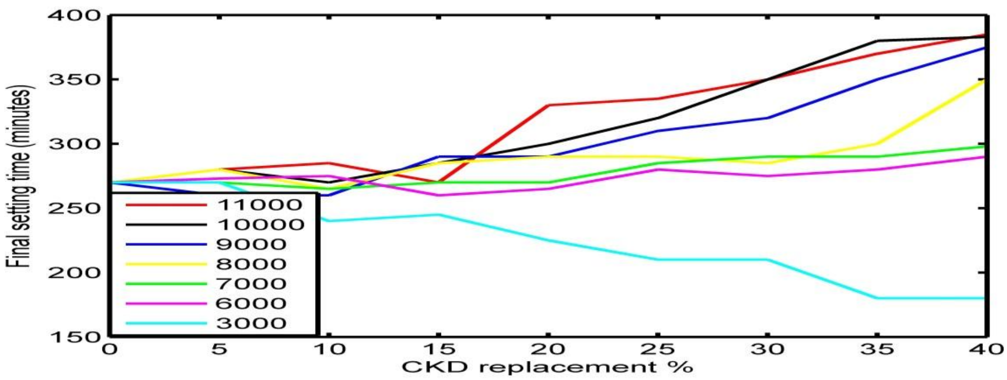

Figure 9 –Shows the relationship between kufa CKD replacement and final setting time

The results of setting time of blends (cement +CKD of kufa cement plant) indicates that effects of CKDs fineness retarded the setting time (initial and final). This may be due to increasing in the surface area activity for some CKD compounds, may be increasing activity pointes of SO_3 leaded to more ettringite compound production which is responsible for retarding of cement by prevents water to reach for cements compounds especially C_3A and prevent hydration .

2 – Cement with CKD of Bazian cement plant

The initial setting time of (cement +CKD) are shown in the Table-7 where the maximum value of initial setting time appears at 5% CKD replacement at fineness 6000 cm^2/gm , and the minimum values appear at 40% CKD replacement at fineness of 11000 cm^2/gm.

Table 7 – Shows the Initial setting time (cement + CKD of Bazian plant)

Fineness of CKD cm^2/gm / CKD percent	Time (minutes)						
	3000	6000	7000	8000	9000	10000	11000
5%	130	135	130	125	120	125	125
10%	130	130	130	120	125	120	115
15%	125	125	120	125	120	120	110
20%	130	125	120	120	115	115	110
25%	125	120	115	110	100	110	100
30%	110	125	100	100	110	90	80
35%	110	110	100	100	90	85	80
40%	105	100	90	90	80	85	75

The relationship between fineness and initial setting time in Figure-10 explain the increasing of fineness led to decreasing (acceleration) time of setting.

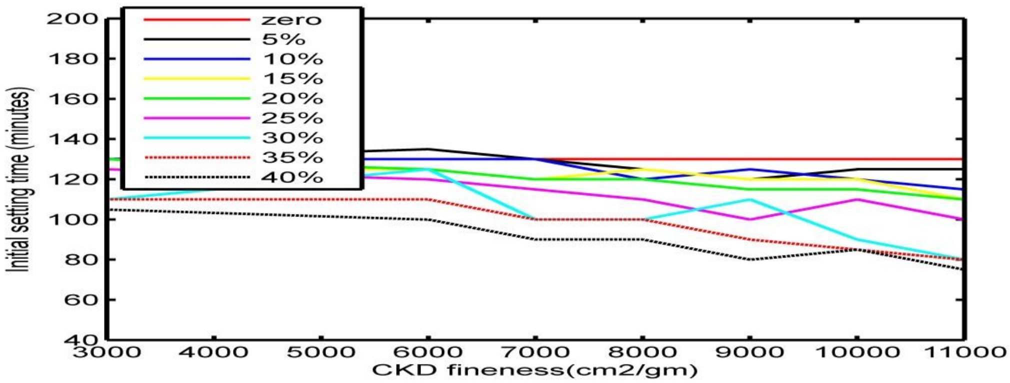

Figure 10 - Shows the relationship between fineness of Bazian CKD replacement and initial setting time

Table-7 and Figure-11 explain that CKD acts as accelerator with increasing of CKD replacement for all fineness **.**

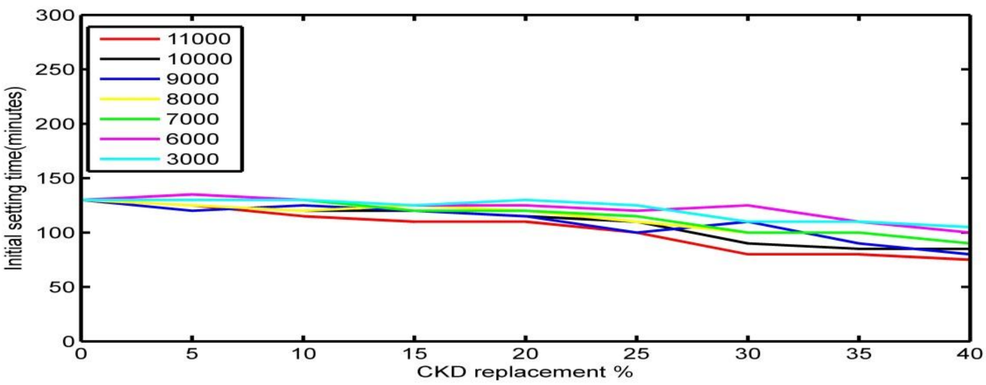

Figure 11 –Shows the relationship between Bazian CKD replacement and initial setting time

The final setting time results of (cement +CKD of Bazian cement plant) are shown in the Table-8.

Table 8 – Shows the finall setting time cement + CKD of Bazian cement plant

Fineness of CKD cm^2/gm / CKD percent	Time (minutes)						
	3000	6000	7000	8000	9000	10000	11000
5%	270	265	260	280	260	280	260
10%	250	240	265	255	240	250	245
15%	250	255	260	240	225	225	210
20%	255	235	225	220	230	220	210
25%	240	245	235	230	200	190	195
30%	225	220	220	200	185	195	185
35%	210	220	200	210	195	170	170
40%	190	195	190	190	198	173	175

The maximum value is 280 minutes for the final setting time appears at 5% of CKD replacement at CKD fineness of 10000 & 8000 cm^2/gm and minimum value is 170 minutes appears at 35% of CKD replacement of 10000 & 11000 cm^2/gm CKD fineness.

The relationship between fineness and final setting time Figure-12 shows the effect of increasing fineness which causing decreases of (acceleration) final setting time.

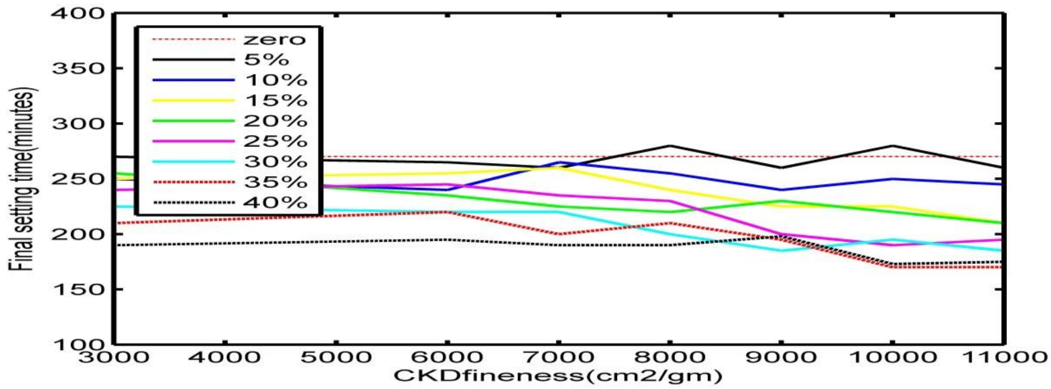

Figure 12 – Shows the relationship between fineness of Bazian CKD replacement and final setting time

The Table-8 and Figure-13 explains that all fineness are acting as accelerator with increasing of CKD replacement . This acceleration reaches up to 100 minutes less than OPC setting time .

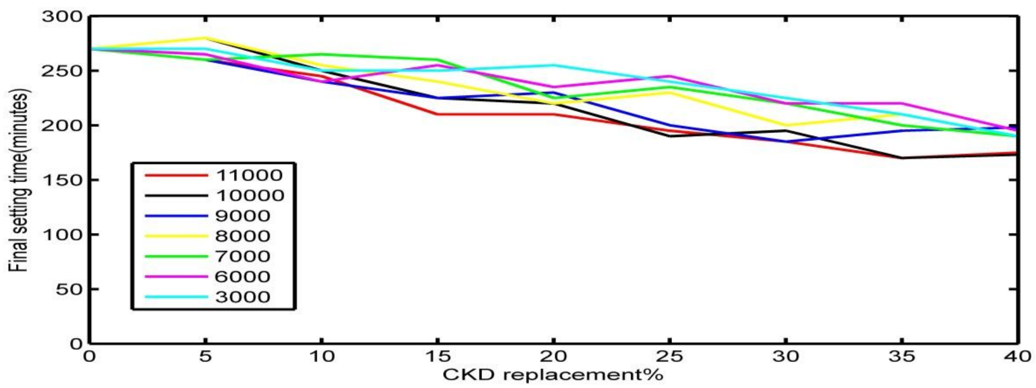

Figure 13 - Shows the relationship between Bazian CKD replacement and final setting time

The results of setting time of blends (cement +CKD of Bazian cement plant) indicates the effects of CKDs fineness by accelerating setting time (initial and final). These effect may be due to surface area for some CKD compounds, which enhanced cement hydration. In this case the K_2O and Na_2O may increasing in activity pointes that leads to enhance hydration and the low of $SO_{3\%}$ may limits effect .There for, the effected compounds which are responsible for enhancing hydration are main effect from the compounds that have ability to prevent and retarded the cement setting time.

The different effect the CKDs between the two plants may come mainly from the differences in chemical composition of CKDs , and the grinding which lead to increasing the active surface area of some active compounds such as SO_3 ,alkalis and CaO. The CaO and alkalis with increasing of fineness lead to more water demand for normal consistency there for the replacement by CKD of Bazian cement plant needed more water amount compared to kufa . Moreover the fineness lead to change behavior of setting of (cement + CKD of kufa plant) which have high percent of SO_3 that increasing of active surface area of SO_3 lead to changing the effect on reaction in first hydrations hours and later retarded of setting time with increasing of fineness.

Conclusions

- The CKD which is produced as waste from kufa cement plant are different in chemical composition from CKD of Bazian cement plant.
- The use CKD in different fineness as partial replacement in cement gave different results
- The water demand for consistency are increasing with increasing CKD fineness yet this water demand differs from plant to another .
- The setting time of blends (cement+ CKD of kufa) act as retarder with increasing of CKDs fineness.
- The setting time of blends (cement + CKD of Bazian) acts as accelerator with increasing of CKDs fineness.
- The fineness of CKD lead to increase in surface area of CKDs compounds which shows different effects on the cement paste according to the type , activity and percent of compounds .

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