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Influence of Using White Cement Kiln Dust as Mineral Filler on Hot Asphalt Concrete Mixture Properties

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ABSTRACT

The White Cement Kiln Dust (WCKD) is a byproduct material, formed in cement factory during the operation of cement production. In highway construction, the WCKD can be used in different ways such as stabilizing the subgrade of highway embankment and as mineral filler in Hot Mix Asphalt (HMA); the latter usage will give clean and healthy environment in addition to more economy. In Iraq, there are two common types of fillers, Portland cement and lime stone powder. In this research, WCKD taken from Fallujah cement plant used as mineral filler in addition to two common types. Various percentages , such as 100%WCKD, 50%WCKD + 50%Cement(C) ,100%C , 50%WCKD+50%Limestone (L), and 100% L, were used to prepare asphaltic concrete mixes. In general, five tests were used to evaluate the performance of these mixes. Standard Marshall Test procedure was applied under three different conditions, two of them at two temperatures at 60 ^{o}C and 70 ^{o}C and in the third one it was used to test samples immersed in water, at room temperature(24^{o}C), for four days. Indirect Tensile Strength Test (ITST) was used to evaluate conditioning and un-conditioning samples. All test results, when compared with controlled asphalt concrete sample (Sample contained 100% limestone as filler), were acceptable and within the AASHTO and Iraqi Standard Specifications of Roads & Bridges 2003. Stability values, at standard condition test, of samples containing 100% WCKD, 50%WCKD+50%C, and 50%WCKD+50%L are 11.9kN, 13.2kN, and 14.0kN respectively, while for controlled sample was 9.0kN. The Marshall stiffness values showed similar trends, for samples having 100% WCKD, 50%WCKD+50%C, and 50%WCKD+50%L giving 3.22kN/mm, 3.38kN/mm, 3.5kN/mm respectively but for controlled sample was 2.43 kN/mm. Same trends of results gained in ITST .The results showed the beneficial using of WCKD as filler that will conserve the environment and encourage the HMA producers to use this inexpensive material in their works.

Key wards: **kiln dust, Marshall Test, Hot mix asphalt, indirect tensile strength**

1. INTRODUCTION

All factories produce, in addition to their main production, different types of waste materials such as acids, alkaline, oils, scrap metals, slag ,fly ash, scrap rubber, stone pieces ,powders, etc. In general, the waste materials are divided into two main types, which are hazardous and non-hazardous waste. Non-hazardous industrial wastes are those do not meet the US Environmental Protection Agency (EPA)'s definition of hazardous waste and are not municipal waste [1]. The WCKD, well known as cement kiln dust(CKD), is a by-product material formed in cement factory during cement production operation which categorized by EPA as a special non-hazardous solid waste material[2] ,[3]. The WCKD is found in the exhaust gasses released by cement kilns and collected by fabric filters or electrostatic precipitators [4],[5].The CKD chemical and physical properties influenced by several factors such as, types of kiln feeding process (wet or dry), raw materials, fuel combustion, methods and facilities of dust collections, and others. The general properties of CKD are similar to Portland cement [5]. Some of CKD is recycled back again with the clinker but the amounts are limited by alkalinity requirements for Portland cement and kiln operation issues [5]. However, most of the material is disposed of on-site without any further reusing or reclamation [4]. Annually, considered volumetric quantities of CKD generated during cement production. In USA 1995, the amount of generated CKD, was 3798000 metric tons; 651000 metric tons of this amount were beneficially reused while 3147000 metric tons were sent to landfill. Corresponding quantity was decreased in 2006 to 2563000 metric tons ,1403000 metric tons beneficially reused while 1160000 metric tons sent to landfill due to applying plans and high efforts accomplished by Cement Manufacturing Sustainability(CMS) Program [6]. In Egypt there were 3million tons of CKD [7]. In Iraq, there were about 640000 tons [8]. In addition to the huge amounts of CKD which are disposed in landfill, the CKD affects human health in three ways: 1- Inhalation (lung diseases), 2- eyes (eye contact with cement dust), and 3- skin (irritating effect on most skin).[9],[10].

Although CKD has negative effects on the environment and human health, it has some different beneficial use. Such of these uses as in agriculture soil amendment and based on literatures, the following are general beneficial CKD uses in highway engineering:

1. As a mineral filler in asphalt concrete mixture (fully or partially use). [11], [12].
2. As an agent which can assist in promoting stripping resistance of asphalt concrete mixes (to replace hydrate lime or liquid anti-stripping agents) [6], [12].
3. CKD can be agglomerated or pelletized to produce artificial aggregates, which can be used in special applications to improve the rutting resistance. This type of artificial aggregate can absorb lighter fractions of excess asphalt cement binder during hot weather [12].
4. To stabilize: sub-grade soil, granular base, and subbase pavement applications [13], [14], [15].
5. To use in flowable fill applications such as in abutment construction, back fill of trenches, as a fill for abandoned pipelines, and in back fill of retaining walls [16], [12].
6. To use as asphalt cement modifier by adding CKD to asphalt binder (50/50) to produce low ductile mastic asphalt. The European use of mastic asphalts, with low ductility for bridge deck waterproofing and protection is well documented [4], [12].

2. AIM OF STUDY

The aim of the present work was to:

1- Investigate the possibility of using WCKD partially or fully as mineral filler in producing HMA.

2- Conserve the environment from these huge waste materials.

3. MATERIAL PROPERTIES

3.1 Asphalt cement:

40-50 Pen. asphalt cement type was brought from Baiji refinery , about 210km north of the capital Baghdad. Standard tests based on ASTM &AASHTO specifications procedures were used to determine its physical properties. **Table 1** shows the handled properties.

3.2 Aggregates:

The coarse and fine aggregates were supplied from Thumal quarry, about 60 km west of Ramadi city the capital of Anbar province. The midpoint of surface course type III A gradation of Iraqi Standard Specifications of Roads &Bridges [17], as seen in **Fig.1**, has been selected and incorporated in preparing all hot asphalt concrete mixes in this research.The mechanical and physical properties of used aggregates are listed in **Table2**.

3.3 Mineral Filler

Three types of mineral filler had been used in this study, two of them are commonly used in Iraq to produce HMA, which are Portland cement & crushed limestone in addition to WCKD. The Portland cement was brought from Kubaisa Cement Plant, 180 km to the west of the capital Baghdad, and the crushed limestone was from Fallujah city .The third one is WCKD from Fallujah White Cement Plant. All the physical specifications of these fillers had been examined and tested in the laboratory of Anbar University. The results are shown in **Table3**. The chemical contents of each type accomplished in the Chemical Analysis Laboratory of Fallujah cement plant. The results of all types of these fillers are listed in **Table 4.**

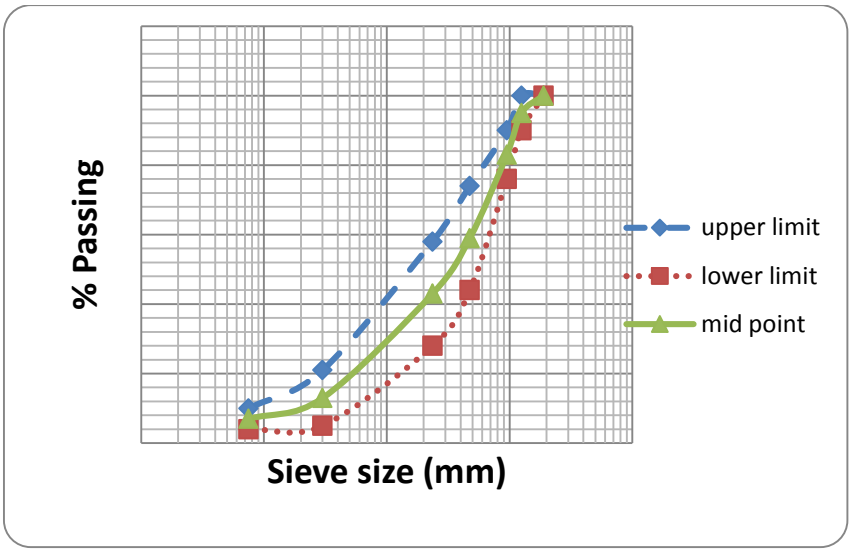

Figure1. Iraqi gradation of surface course type IIIA [17].

Table1. Physical Properties of Asphalt Cement [Anbar Un. Lab.]

Test	Unit	Asphalt cement grade 40-50 ISSRB2003 specifications	Test Result
Penetration,100gm,5sec,25 ^{O}C	0.1mm	40-50	46
Specific gravity 25 ^{O}C /25 ^{O}C	----	----	1.03
Ductility, 5cm/min., 25 ^{O}C	cm	100 min.	100+
Solubility in trichloroethylene. %	%	>99	99.1
Flash point, ^{O}C	^{O}C	232 min	232+
Residue from thin film oven test			
Retained Penetration,100gm,5sec,25 ^{O}C.	%	50 min	71.7
Ductility, 5cm/min., 25 ^{O}C.	cm	50 min	95+

Table 2. Mechanical and Physical Aggregate Properties [Anbar Un. Lab.]

Test	ISSRB	Coarse agg. (12-19)mm	Coarse agg. (5-12)mm	Fine aggregate
Los Angeles Abrasion value, %	< 30	21.6	19.5	----------
Bulk Specific gravity		2.609	2.620	2.694
Degree of crushing %	> 90	96	97	---------

Table 3. Physical Properties of Mineral Fillers [Anbar Un. Lab.]

Properties	% Passing			
Sieve Size Inches (mm)	ISSRB& AASHTO	Lime stone	(WCKD)	Cement
No.30 (0.6)	100	100	100	100
No.50 (0.3)	95-100	100	100	100
No.200(0.075)	70-100	94	89.5	97.5
Plasticity Index	< 4	3.52	1.8	0
Specific gravity	---	2.57	2.93	3.15
Blaine fineness (cm^2/g)	----	4770	3630	3400

Table4. Chemical compositions of Used Mineral Fillers. [Laboratory of Fallujah cements plant].

Filler type	Chemical compositions								
	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	Na_2O	K_2O	MgO	Loss due to ignition
(WCKD)	51.96	16.9	4.58	0.4	2.41	0.70	1.12	1.95	19.5
Limestone (L)	51.0	2.7	1	0.16	1.16	---	----	1.2	42.6
Cement (C)	62.74	22.68	5.06	3.24	2.2	----	---	2.36	1.2

Table5. General Marshall Test Results (ASTM 1559)

Test condition	Stability (kN)			Flow(mm)			Air voids (%)		
	at 60 ^{O}C	at 70 ^{O}C	4 days in water	at 60 ^{O}C	at 70 ^{O}C	4 days in water	at 60 ^{O}C	at 70 ^{O}C	4 days in water
ISSRB	**Min. 8**	**#**	**#**	**2- 4**	**#**	**#**	**3 -5**	**#**	**#**
%100 WCKD	**11.9**	**10.8**	**12.1**	**3.7**	**4.0**	**4.85**	**4.95**	**4.41**	**5.47**
100% C	**11.2**	**10.85**	**13.8**	**3.0**	**3.85**	**4.75**	**4.90**	**3.52**	**3.76**
100% L	**9.0**	**8.1**	**9.75**	**3.7**	**3.75**	**5.1**	**4.48**	**4.28**	**3.08**
50% WCKD + 50% C	**13.2**	**10.4**	**13.4**	**3.9**	**3.85**	**4.6**	**3.80**	**4.25**	**4.08**
50% WCKD + 50% L	**14.0**	**10.2**	**11.2**	**4.0**	**3.95**	**4.7**	**4.32**	**5.01**	**5.58**

ISSRB=Iraqi Standard Specifications for Roads and Bridges, **WCKD**=White Cement Kiln Dust, **C**=Cement, **L**=Limestone**, # =** No specification

Table 6. Marshall Stiffness of samples under different test conditions

Components	Marshall Stiffness (kN/mm) at(60 ^{O}C) Controlled Sample	Marshall Stiffness (kN/mm) at (70 ^{O}C)	Marshall stiffness (kN/mm)(4days immersed in water)
100% WCKD	**3.22**	**2.7**	**2.49**
100% C	**3.73**	**2.82**	**2.90**
100% L	**2.43**	**2.16**	**1.91**
50%WCKD+50% C	**3.38**	**2.7**	**2.91**
50% WCKD+50% L	**3.5**	**2.58**	**2.38**

WCKD=White Cement Kiln Dust, **C**=Cement, **L**=Limestone

Table 7. The ITST Results of Conditioning and Un-Conditioning Samples

components	ITST (Un-conditioning) (N/cm2)	ITST (Conditioning) (N/cm2)	Retained tensile Strength (%)
100% WCKD	171	157.51	92.11
100% C	165.7	137.23	82.82
100% L	141.5	126.68	89.52
50%WCKD+50% C	143.05	134.31	93.89
50% WCKD+50% L	165.76	130.43	78.68

WCKD=White Cement Kiln Dust, **C**=Cement, **L**=Limestone

4. EXPERIMENTAL STUDY

In this research, two standard test methods are followed. The first one is Marshall Test Method, designated as ASTM D1559, used to design and evaluate asphalt concrete mix, and the second test is Indirect Tensile Strength Test Method (ITST), designated as ASTM D4123, used to find the tensile strength of asphalt concrete mix samples and its fracture resistance. In general, the average of three specimens had been dependent for any test results.

Five different types of mixtures were prepared and tested. Each mix had; same type of aggregate, same asphalt content of 4.9% weight of total mix, which represents optimum asphalt content obtained from job mix preparation of mixtures related to controlled HMA samples in which the limestone (L) had been used as mineral filler, and same aggregate gradation taken from the midpoint of Iraqi gradation of surface course type IIIA. The only variable subject in theses mixes was the filler type and filler amount. The filler type and amount differs from one mix to another as follows 1-100%WCKD, 2-100%C, 3- 100% L, 4- 50% WCKD+50% C, and 5-50% WCKD+50%C. (the percentage indicates the filler amount in each mix).

5. MARSHALL TEST:

Standard Marshall Test designated, as ASTM D1559, is an appropriate test method, which used to design and evaluate the HMA. In this test, Marshall Specimen size is of 63.5 mm (2.5 inches) height and 101.6 mm (4 inches) diameter was compacted 75 blows for each face by Marshall automatic compacter. The Marshall stability value accomplished by immersing the compacted asphalt concrete samples in hot water at standard test temperature of 60 ^{o}C for 30 to 40 min.; then applying diametrical loading on sample at rate of 51mm/min.

According to a research results that applied on the Iraqi Express Way No.1 from 14/8/1989 to 31/8/1989 (the Iraqi hottest days in every year) by Iraqi State Organization of Roads and Bridges - Resident Engineer Directorate -Part- T9. In this research, they found that the mean temperature value of asphalt concrete surface course from 12 a.m. to 3 p.m. was 68.88 ^{o}C [18].

In this research ,Marshall Test procedure was applied under three different conditions, two of them at two temperatures at 60 ^{o}C and 70 ^{o}C The reason for choosing 70 ^{o}C is; firstly due to the hot weather, which prevalent in Iraq, as indicated by Tawfeeq1989 above, and secondly due to the high sensitivity of asphalt cement to temperature variation. The third time, Marshall Test had been executed on asphalt concrete samples that immersed in water at room temperature (24 ^{o}C) for four days. The main reason for the later test was to simulate the effect of water on roadway when it was over flowed for four days.

6. INDIRECT TENSILE STRENGTH TEST:

The Marshall machine had been used to apply a compression load on asphalt concrete specimens at rate of loading 51 mm/min. along a diametrical plane through two opposite loading curved strip heads of 12.5mm width. This type of loading leads to apply perpendicular stress acting on applied load plane causing the specimen to fail by splitting along the loaded plane. The aim of this test was to know the resistance of samples to fractures and to determine its tensile strength property. The maximum load that caused failure was determined and used to calculate the indirect tensile strength.

Two times ITST was executed to test asphalt concrete samples, one of them for un-conditioning (by immersing it in water at 25 ^{o}C for one hour) and the second for conditioning samples. The conditioning process was down by immersing samples in hot water of 60 ^{o}C for 24 hours. The samples removed from hot water and immersing it again in water of 25 ^{o}C for one hour and finally testing it in ITST. The Retained Tensile Strength (RTS) was computed by following the test procedure namely STP204-15 which had been adopted by Saskatchewan state [19].

$$\%RTS=\frac{Tensile\ \ Strength\ (water\ \ cured\ \ at\ \ 60^{o}C\ \ 24hours)}{Tensile\ \ Strength\ (air\ \ cured\ \ at\ \ 25^{o}C)}\times 100$$

Marshall Test Results:

The Marshall test under three different conditions, explained above, was done and its results shown in **Table 5 and Figs. 2, 3, and 4.** They are encouraging results because they indicate that the values of stability and flow of samples having 100%WCKD and other percentages are within the specifications of Iraqi roads (ISSRB2003). Therefore, WCKD can be used fully or partially as mineral filler instead of the common mineral filler in producing asphalt concrete mixture. In **Fig.4**, the air void property of all samples revealed satisfied results except for the immersed samples in water for 96 hours which contained 100% WCKD and 50% WCKD+50%L, they pointed out that their air void percentages were 5.47% and 5.58% respectively which are larger than Iraqi standard upper limit value which is 5%. This result may attribute to diluting some

parts of WCKD in water during the soaking of these samples for four days in water.

The Marshall Stiffness (MS), stability divided by its flow, is an empirical stiffness value that used by some European engineers to evaluate the strength of asphalt mixture. A higher value of MS indicates a stiffer mixture and, hence, it indicates that the mixture had high resistance to permanent deformation [20]. The MS values of each sample were computed and compared with the MS values related to controlled sample and the results are listed in **Table 6**. In order to know the ability of samples against permanent deformation under high stress their MS value should be greater than 2.1 (kN/mm) [21]. From **Table 6**; all samples gave MS values more than 2.1 (kN/mm) excluding one sample that contained 100%L and immersed four days in water, which gave 1.91 kN/mm. The reason of this reduction in MS value may due to that; this sample was free from any cementing material like C or WCKD leading to give highest reading value of flow (5.1mm) and lesser stability reading as compared with other results of stability and flow of samples that immersed in water.

7. ITST TEST RESULTS:

The ITST results of conditioning and un-conditioning samples and the RTS are presented in **Table (7)** .The mixtures containing 100%WCKD and 50%WCKD+50%C provided higher values of RTS which are 92.11% and 93.89%, respectively .The other results are lesser but they are still acceptable and within the Iraqi specification value of (70%).

8. CONCLUSIONS AND RECOMMENDATIONS:

The WCKD as a by-product material was tested. The results indicate that this material had acceptable gradation and had similar properties to what needed from filler specifications and within the Iraqi roads specifications2003 and AASHTO M17 requirements. The WCKD as a filler was used fully and partially to prepare hot mix asphalt samples. The samples were tested by using two standard test methods furthermore; testing samples under special test conditions such as running Marshall test at 70 ^{O}C and applying same test for immersed samples. For Marshall test, in general all the stability test values of mixes containing WCKD was increased when they immersed in water. This may be due to setting and hardening parts of WCKD and C. The flow reading results are within the Iraqi roads specifications2003 exclude the immersed samples which they gave more than the specification and especially for samples contained 100%L which, gave the highest deviation of about 27.5% more than upper specification limit (4mm). The result of sample containing 100%L indicated that the use of limestone as filler might give mixture having weakest ability to the effect of water presence while samples made by WCKD, as filler, gave higher resistance to the presence of water . For ITST test results, the percentages of retained tensile strength indicated that all samples were within the ISSRB but the samples of 100% WCKD and 50% WCKD + 50%C, gave the best results of 92.11% and 93.89% respectively. From the above conclusions, the following recommendations achieved:

1- WCKD can be used successfully as mineral filler (fully or partially) in producing hot mix asphalt in addition to conserve the environment from these waste materials. The best results handled for mixtures contain 50%WCKD+50%C and 50%WCKD+50%L.

2- Due to good resistance of mixture containing WCKD fully or partially to the presence of water and their best results, so using of cement or WCKD as mineral filler in producing HMA is strongly recommended in locations which having highly expectation to rain falling and in where the surface water was presence.

3- It is worthwhile to construct a highway trial section paved by hot mix asphalt containing WCKD as filler (fully or partially) in its mixture and then studying its behavior for long time under actual traffic motion, and environment conditions.

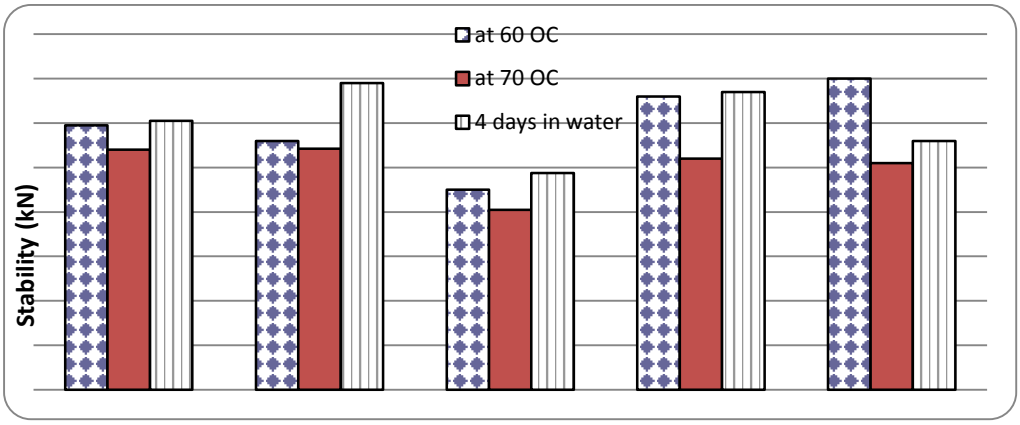

Figure2. Stability Values of Mixtures Having Different Components of WCKD

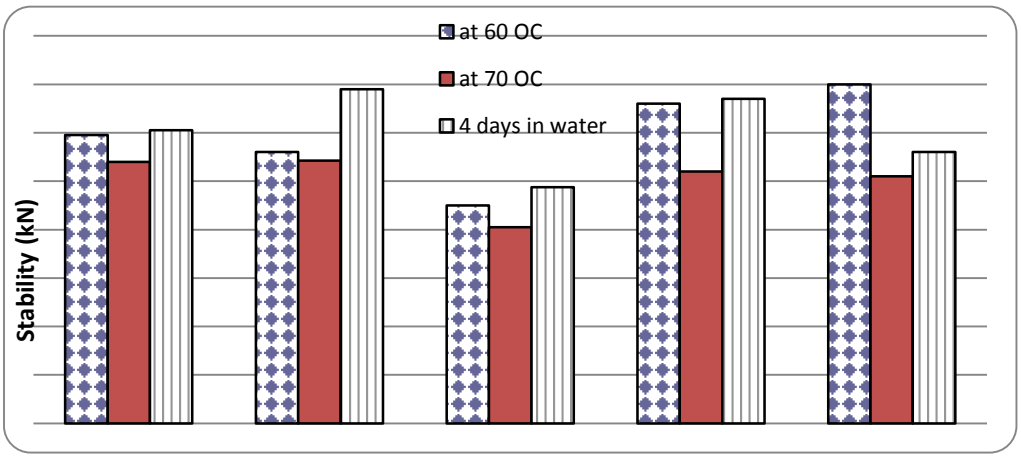

Figure3. Flow Values of Mixtures Having Different Components of WCKD

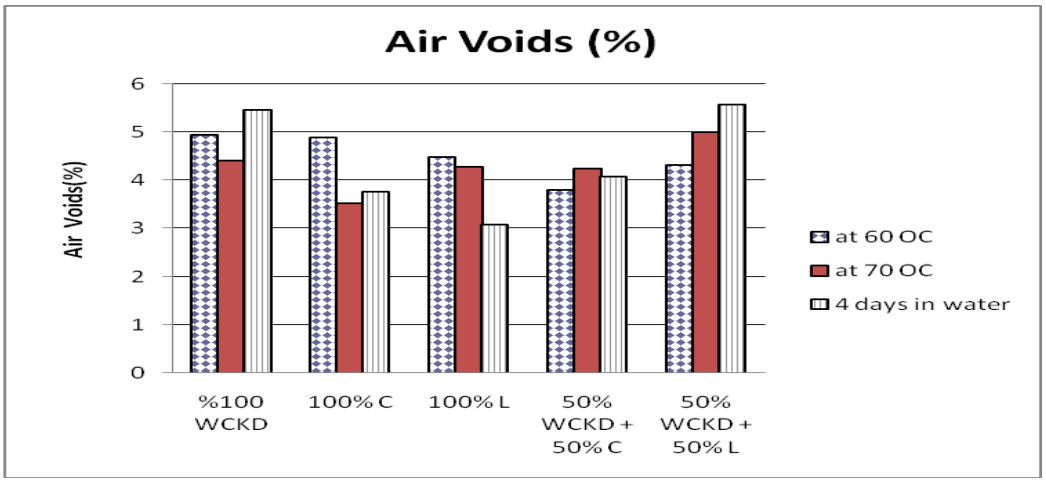

Figure 4. Percent of Air Void of Mixtures Having Different Components of WCKD

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(اثر استخدام غبار فرن الاسمنت الابيض كمادة حشو معدني (فلر) على مواصفات الخلطة الكونكريتية الاسفلتية الساخنة)

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جامعة الانبار/الهندسة مختبر الانبار الإنشائي جامعة الانبار/الهندسة معمل سمنت الفلوجة

المستخلص:

إن غبار فرن الإسمنت الأبيض (White Cement Kiln Dust (WCKDهو مادة عارضة ، تتشكل في مصنع الاسمنت خلال عملية الأنتاج. يستخدم كمادة فلر في إنتاج مزيج الخلطة الإسفلتية الساخنة (HMA). عند استخدامWCKD في انتاج المزيج الاسفلتي سيساهم في توفير بيئة نظيفة وصحية اضافة إلى كونها مادة رخيصة واقتصادية . في هذا البحث تم استخدام مادةWCKD والتي تم الحصول عليها من معمل اسمنت الفلوجة كمادة فلر في حالتين احدهما كليا والأخرى جزئية بالإضافة إلى السمنت ومطحون حجر الكلس. تم استخدام عدة نسب مئوية مختلفة , كالأتي: 1- (WCKD) 100%, 2- اسمنت اعتيادي(C) 50% + 50% (WCKD) ,3- اسمنت (C) 100 % ، 4-ومسحوق حجر الكلس(L) 50 % + (WCKD 50 % ، و أخيرا مسحوق حجر الكلس(L) 100 %. تم تقييم الخلطات الإسفلتية الساخنة المعدة من النسب اعلاه من خلال خمسة اختبارات , ثلاث منها بطريقة مارشال ،فحصين منها في درجتي الحرارة 60 و 70 درجة مئوية و الفحص الثالث تم فحص العينات المغمورة في الماء في درجة حرارة الغرفة (24 درجة مئوية) لمدة أربعة أيام. تم إجراء اختبارين آخرين لفحص قوة الشد غيرالمباشرة (ITST)الاول للعينات غير المكيفة و الثاني للعينات المكيفة. كانت جميع نتائج الاختبارات ضمن مواصفات هيئة الاشتو و مواصفات الطرق والجسور العراقية2003. ان قيم الثبات ب(kN) للنماذج في الظروف القياسية كانت 11.9 و13.2 و14 للنماذج المصنعة من WCKD100% وL50%+WCKD50% و C50%+WCKD50% بالتتابع مقارنة مع قيم النموذج المرجع والمصنع من L100% والتي كانت 9kN. ان قيم صلابة مارشال(MS) ب (kN/mm) اعطت نفس السياق حيث كانت للنماذج المصنعة من من WCKD100% هي 3.22 و L50%+WCKD50% هي 3.5 و C50%+WCKD50%هي 3.38 مقارنة مع قيم النموذج المرجع والمصنع من L100% والتي كانت 2.43kN/mm أن النتائج المفيدة التي أظهرها هذا البحث من خلال استخدام WCKD كفلر من شأنها الحفاظ على البيئة وتشجيع المنتجين لمادة المزيج القيري الساخن HMA لاستخدام هذه المواد الرخيصة والمتوفرة في أعمالهم.