Investigating the Feasibility of Using Cement Kiln Dust in Cold Bituminous Emulsion Asphalt

Sajjad Al-Merzah[1], Shakir Al-Busaltan[2] ,and Hassan Al Nageim[3]

[1]MSC student, Dept. of Civil Eng., University of Kerbala, Iraq, sajjad_merzah@yahoo.com,

[2] Lecturer, Dept. of Civil Eng., University of Kerbala, shakerfa2003@yahoo.com,

[3] prof., Department of Civil Engineering, LJMU, UK, h.k.alnageim@ljmu.ac.uk

ABSTRACT

Cold mix asphalt (CMA) has been increasingly predictable as an important asphalt mix technology alternative worldwide, where CMA has several advantages including economic, environmental and saving energy aspects over Hot-Mix Asphalt (HMA). Nevertheless, CMA has poor performance mainly about low early strength. This paper reports the experimental test results of a research project aimed to investigate and develop a new cold bituminous emulsion mixtures (CBEMs) containing Cement Kiln Dust (CKD); CKD is an industrial by-products from cement industry. The developed CBEM's are compared with those results of conventional cold mix (CCM) as control, and performance cold mix containing ordinary Portland cement (OPC). However, the experiments were investigated the improvement in mechanical properties of CBEMs due to incorporating OPC, and detect the possibility of replacing the OPC with CKD. The mixtures mechanical properties testing were; Marshall test, indirect tensile strength and wheel track test. Durability in term of water sensitivity and ageing were examined too.

The results have indicated that there is a feasibility to develop CBEM's by supplementary replacement of OPC by CKD. Where up to 25% percentage of replacement can conserve the results of Marshall, indirect tensile strength, wheel track and durability achieved by 100% OPC as a filler in the CBEM. Therefore, this paper introduces new CBEMs having outstanding mechanical characteristics, cost effective, and environmental friendly.

KEYWORDS: By-product materials; Cement Kiln Dust; Cold bitumen emulsion mixtures; Hot Mix Asphalt; OPC.

1. INTRODUCTION

CBEMs have been suggested as an environmental friendly technology according to low CO_2 emissions, energy conservation efficiency [1-4]. Therefore, it may be an alternative to traditional HMA because that required heat during preparation processes, with associated CO_2 emissions. But these mixtures have a comparatively low initial strength at early time, and needed long curing time [5, 6]. Along with inferiority of CBEMs' performance and due to recent economic and environmental impacts, many agencies and researchers have been beginning to study CBEMs characterizations to develop this technology [1, 7-12]. This mixture is produced by mixing aggregates with hydrocarbon binder, with or without additives. The aggregates can be coated with no drying or heating [13]. The Asphalt Institute made different manuals relating to bitumen emulsion (i.e.,MS-19) [14], CMA (i.e.,MS-14) [15].

OPC is extensively used in CBEMs to overcome mainly the low early strength; its role has been investigated in several studies [12, 16-20]. Through studies, OPC was incorporated with bitumen emulsions to control the braking behavior, and to increase mixture strength at the early time and stiffness by binding an excessive water released by the emulsion breaking [19, 21, 22]. The addition of the cement can reduce mixture water sensitivity, and really influenced the development of mechanical properties over time [23], which by reacting cement with the water from the emulsion and by interacting with the emulsifier to effect on the emulsion breaking [22, 24]. It decreases the negative influence of the free water and improves the adhesion of the binder to the aggregate [25] and hydration of the cement, increasing the rate of coalescence and increasing the binder viscosity [5]. Figure (1) shows that the cement splat between emulsified asphalt particles gradually and formed block cement particles hydration to stick the mixture. As illustrated by Head who specified that the addition of cement had a very significant influence on mix stability; addition of 1% cement created an increase in stability of 250-300% over that of untreated sample[8]. Brown and Needham stated that addition OPC improved stiffness modulus, permanent deformation resistance OPC improved stiffness modulus, permanent deformation resistance and fatigue strength [5].

From these studies it observe that the existence of OPC in mixtures gave good results, which encouraged researchers to use waste and/or by-product materials that have hydraulic or pozzolanic characteristics [26, 27]. These materials can facilitate absorption of the trapped water via the hydration process, and powder physical and chemical properties. Incorporating such materials in CBEM is usually helped two benefits: environmental sustainability and economic advantages. Thus, some waste or by-product materials have the probability of working as a supplementary cementing material (SCM) which can be substituted for OPC.

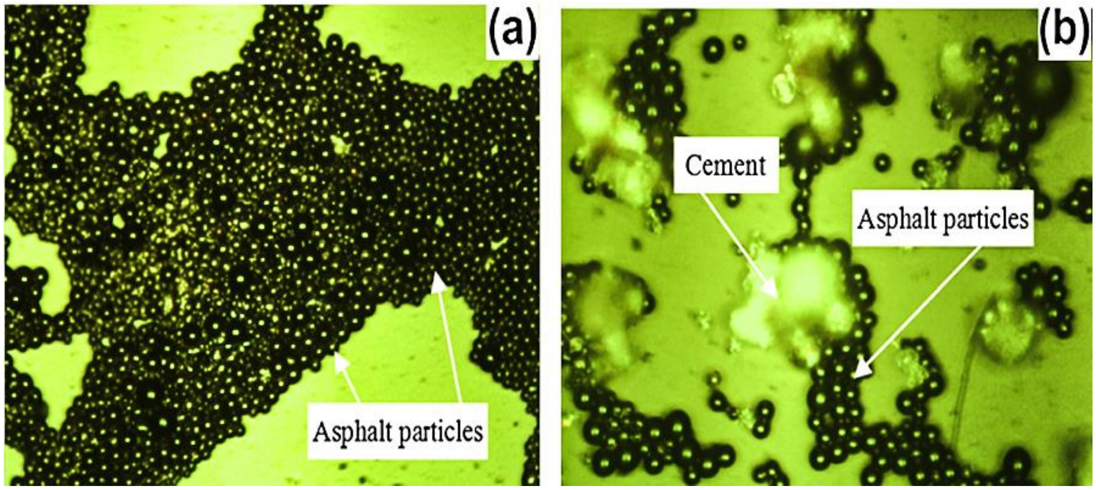


Figure 1 Optical images of fresh emulsified asphalt (×200), (a) without cement and (b) with cement [23].

Cement Kiln Dust (CKD) is a fine powdery by-products material of Portland cement production. It is collection by control air pollution of dust. The collection may be from cyclones or baghouses during operation. In Iraq the amount of CKD generated is highly variable among plants and over time at individual plants. The quantity of generated CKD can be estimated on an average of about (8 – 33) % of the production output, depending on the condition of each plant. Most plants are adopted the CKD land-disposal alternative [28], where most plants are treated the CKD as land-disposal alternative. Normally CKD can recognized as an irregular piles and accumulations spread near or around the plants site. All these landfill and piles are unlined and uncovered. Dust particles may be suspended in the air by either wind erosion or a mechanical disturbance which causes environmental impacts [28], therefore exploitations the CKD for road construction can reduce environmental harmful.

2. MATERIALS

Locally materials were used in this research work as much as its available to ensure economic side and investigate the feasibility of the new mix for local usage. The materials utilized in this study were aggregates, conventional mineral filler (CMF), bitumen emulsion, Portland cement, cement kiln dust and water.

2.1 Aggregates

Aggregates (course and fine) used in this research work were provided from local Karbala quarries. The gradation was for binder course layer according to Iraqi specifications; General Specification for Roads and Bridges (GSRB) section R9 [29], as can be shown in Table (1). The gradation provided for HMA is adopted as no local standard gradation for CBEM yet. Figure (2) illustrates the adopted gradation and its limits, which can be classified as dense grade.

Table 1 Asphalt mixture gradation for binder course

Sieve size	% passing	Used
1	100	100
¾	90-100	95
½	76-90	83
⅜	56-80	68
No. 4	35-65	50
No. 8	23-49	36
No. 50	5-19	12
No. 200	3-9	6

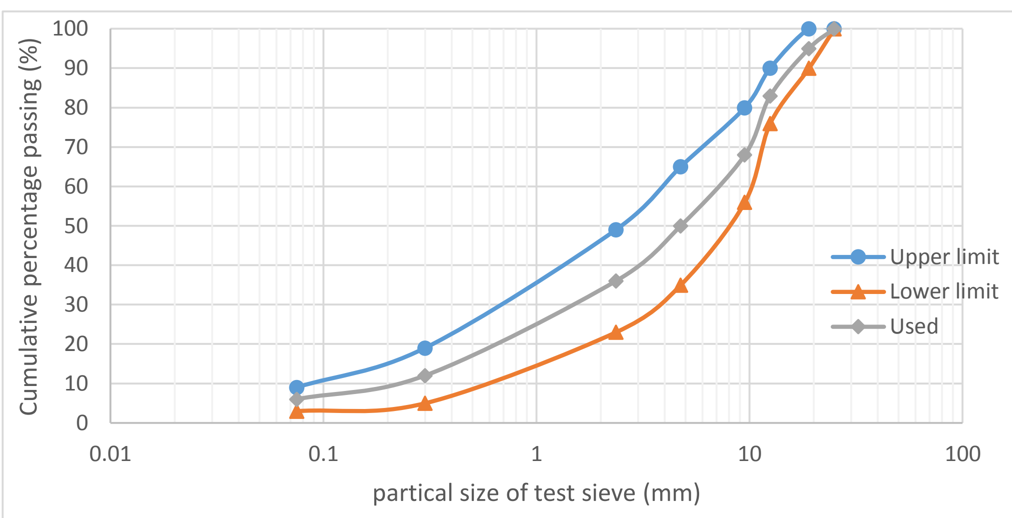


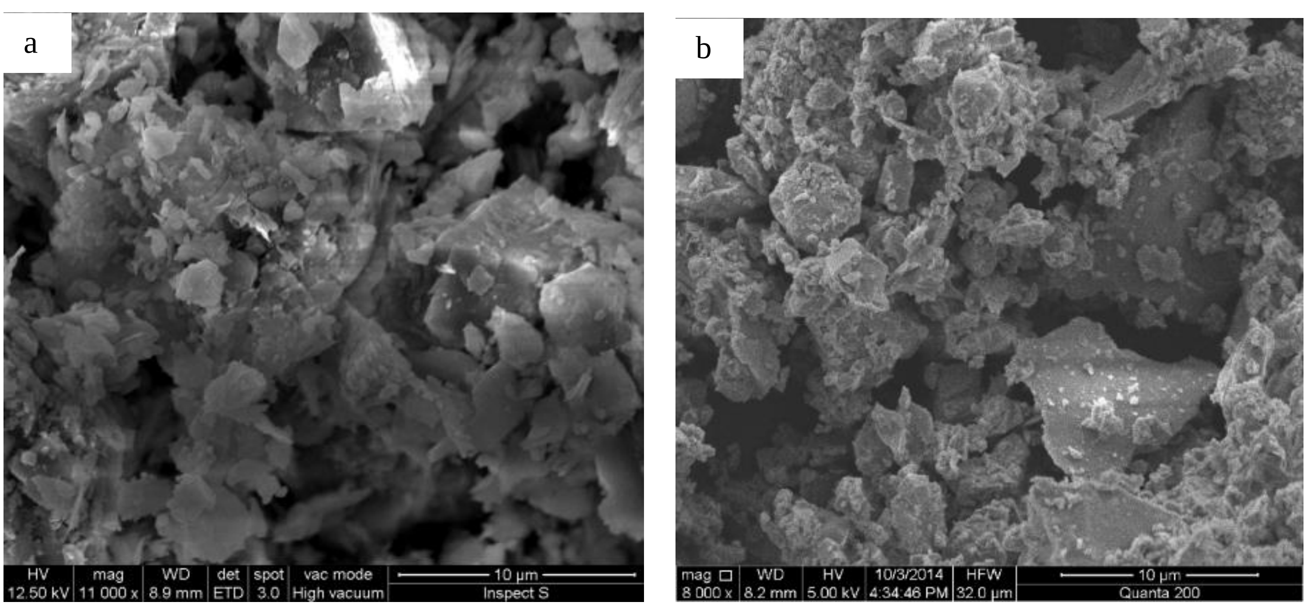
Figure 2 Particle size distribution of the selected gradation

2.2 Fillers

Three types of fillers were used in this study, namely, CMF, OPC, CKD. There properties illustrate in Table (2). Scanning Electron Microscopy (SEM) was used to image the fillers morphology for better understanding the physical properties of fillers in characterizing the CBEMs, SEM results as shown in Figure (3). CMF was obtained from the by-bass collector of crushing process of aggregate, it was provided from local Karbala quarries. Where, OPC and CKD were supplied from Karbala Cement Plant.

Table 2 Properties of the used fillers

Physical Properties			
Property	*Filler type*		
	CON	*OPC*	*CKD*
Specific surface area (m^2/kg)	225	410	485
Density (gm/cm^3)	2.61	2.987	3.012
Chemical compositions (XRF),%			
SiO2	21.60	24.910	17.011
Al2O3	3.78	2.324	3.653
Fe2O3	1.92	1.125	3.684
CaO	31.40	64.148	57.451
MgO	2.90	1.326	1.424
K2O	0.73	0.760	1.036
Na2O	0.19	1.714	0.143



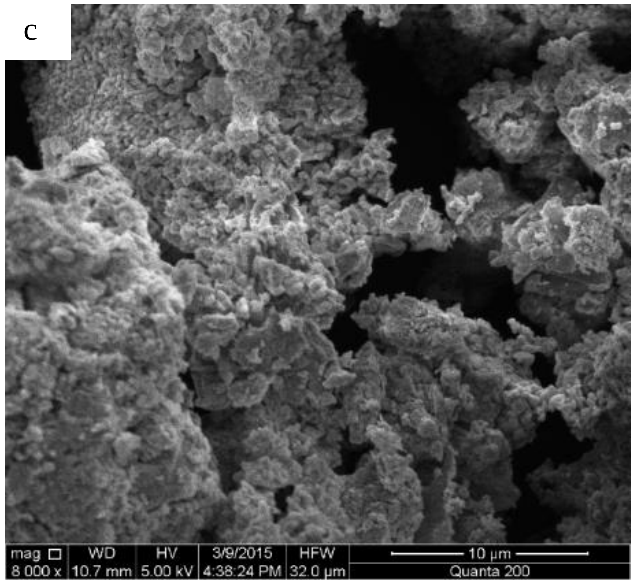


Figure 3 SEM of fillers, (a) CMF, (b) OPC, (c) CKD

2.3 Bitumen Emulsion

Bitumen emulsion (BE) was supplied from Conmix company (under the trade name Moya Shield BE). Its properties can be shown in Table (4)

Table 3 Properties of bitumen emulsion

Property	Specification	Limits	Results
Emulsion type	D2397[30]	Rapid, medium and slow-setting	Medium- setting (CMS)
Color appearance			Dark brown liquid
Residue by Evaporation, %	D6934[31]	Min. 57	54.37
Specific gravity, gm/cm^3	D70[32]		1.05
Penetration, mm	D5[33]	100-250	230
Ductility, cm	D113[34]	Min. 40	42
Viscosity, rotational paddle viscometer 50 ℃ , mPa.s	D7226[35]	110-990	220
Freezing	D6929[36]	Homogenous, broken	Homogenous
Solubility in Trichloroethylene,%	D2042[37]	Min. 97.5	97.7
Emulsified asphalt/job aggregate coating practice	D244[38]	Good, fair, poor	Fair
Miscibility	D6999[39]		Non-miscible
Evaluating Aggregate Coating	D6998[40]		uniformly and thoroughly coated

3. Experimental Program, Test condition and Methods

3.1 Sample preparation and Conditioning

Currently, there is no universally accepted CBEM design procedure that can be followed like HMA design, therefore the design method was based on the method implemented by Asphalt Cold Manual MS-14[15]. Where, -Marshall method for emulsified asphalt aggregate cold mixture design- with some amendments which are associated with Iraqi specification; GSRB section R9[29] for designing the new cold asphalt concrete binder course bituminous emulsion mixtures.

Specimens of CBEMs were prepared using different fillers as CMF,OPC and CKD in this study, all fillers was passed sieve 75 μm. the methodology based on:

- Checking the mechanical and durability performance of CBEM comprising CMF
- Then, checking the improvement in the mechanical and durability performance of CBEM due to replacing CMF by OPC ,
- After that, attempt to check the feasibility to develop new CBEM by using by-product materials, where the OPC was replaced by CKD with different percentages ranging from 0 to 100%.

The improvements in mechanical properties were determined using the Marshall tests, indirect tensile strength, wheel track test and creep stiffness as respected indicators of the mechanical properties. In addition, water sensitivity and ageing tests of the mixes was examined to identify the durability of such mixes.

Initially, coating test was checked, coating ability of the bitumen emulsion to the aggregates is highly sensitive to the pre-wetting water content, particularly when the aggregate gradation comprises a high proportion of fine materials. Thanaya [41] reported that inadequate pre-wetting water content results in balling of the binder with the fines material and thus provides unsatisfactory coating. Different pre-wetting water contents were investigated to determine the lowest percentage to certify suitable coating by visual as said by MS-14 [15]. Furthermore, Marshall stability tests was used to determine the optimum pre-wetting water content in this research work. According to the selected materials characteristics, pre-wetting water content was observed to be 3% for CMF, 3.5% for OPC and 2.5% for CKD, the optimum bitumen emulsion content was 11.2% for all mixture types, therefore optimum total liquid content was 14.2% for

CMF, 14.7% for OPC and 13.7% for CKD. CBEMs were prepared in quantity to produce three 1,170 gm specimens for each specific mix. The mixing and compacting were achieved at lab temperature (20 – 25°C).

The materials were mixed in a mixer mechanical, where aggregate, filler and pre-wetting water content added and mixed for 1 min. then, bitumen emulsion was purred gradually throughout additional 1 min of mixing; mostly spatula used to separate the mix from bowl of the mixer and hand mixing done for more mix homogeneity. Later on, the samples were divided over the molds, then they were directly compacted with 75 blows on each side by using of a standard Marshall Hammer.

3.2 Test Conditions and methods

CBEMs strength characteristics are very sensitive to curing time and temperature. Therefore, sample conditioning occur in two stages: stage one where the specimens was left in their molds at ambient temperature (25 ℃) for 24 hrs.; this is to prevent specimen from disintegration during extruding from mold. stage two is different from test to another, it is described in each test procedure. However the test method used in this study are as follow:

- Marshall Test

The strength and the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically. Table (4) describes the setup of Marshall test. Marshall test procedure based according to ASTM D6927 [42]. Stage two of curing protocol is placing the specimens in an oven with 40 ºC @ 24 hrs, then application the test procedure as illustrates in table below. It have to said that the MS-14 recommended to test of Marshall stability for CMA at 25℃, where 60 ℃ was adopted in this research work to accommodate the local high temperature environment.

Table 4 Marshall test conditions according to ASTM D6927

Item	range	Used
Number of required specimens	3	3
Rate of load application, mm/min	50 ± 5	50
Measuring device accuracy	Min. 50 N	0.01 N
Test temperature, ºC	60 ± 1	60
Specimen diameters, mm	101.6-101.7	101.6
Specimen thickness, mm	63.5 ± 2.5	63.5
Compaction	Marshall 75x 2	75x2
Specimen conditioning before test in water bath, or an oven	30-40 min. 120−130 min.	30 min.
Iraqi roads design requirement for Marshall test of binder coarse		
Marshall Stability kN, min Marshall Flow, mm	7 2-4	

- <u>Indirect Tensile Strength (ITS)</u>

ITS used to evaluate the relative quality of bituminous mixtures for estimating the potential for cracking. The procedure of test followed ASTM D6931[43]. The test conditions are shown in Table 5. Curing protocol for stage two were 40 ºC @ 1 days (to represent 7-14 days of mix age) days 40 ºC @ 14 days (to represent full curing mix age), in addition to stage one, which was previously described.

Table 5 Test conditions of ITS

Item	range	Used
Number of required specimens	3	3
Rate of load application mm/min	50 ± 5	50
Measuring device accuracy	Min. 50 N	0.01 N
Test temperature ºC	25 ± 2	23
Specimen diameters mm	101.6, 150	101.6
Specimen height for selected diameter mm	50.8-65.5	63.5
Compaction	Marshall 75x 2	75x2
Specimen conditioning before test	2 hr.	2 hr.

Equation formula

$$ITS = \frac{2P}{\pi\, t\, D} \quad \textit{Equation 1}$$

Where:

ITS = indirect tensile strength , KPa

P = maximum load, N

t = specimen hieght immediatly brefore test , mm

$D = specimen\ diameter$, mm

- Wheel Track Test (WTT)

WTT is testing a compacted bituminous mixture in a reciprocating rolling wheel device. This test provides information about the rate of permanent deformation due to a moving concentrated load. A laboratory compactor is used to prepare slab or cylindrical specimens. The procedure of this test is described in the specification AASHTO T324 [44]. The testing conditions are summarized in Table (6). This procedure is covered for HMA, for CMA the different is in curing protocol. For this purpose full curing protocol used as a stage two, full curing time can be obtain by 14 day @40ºC as recommended by Thanaya [41].

Table 6 Test conditions for Wheel Track Testing for HMA

Item	range	value
No. of required specimens	2	2
Diameter of rubber wheel	203.2 mm	203.2 mm
Wide rubber wheel	50 mm	50 mm
No. wheel pass per min.	50 ∓5	50
Speed of wheel	Max. 0.305 m/s	0.305 m/s
Load on the wheel	705∓4.5 N	705.5 N
No. of cycles	10,000	10,000
Specimen thickness	38 - 100 mm	63.5
Test temperature ºC	25-70 ºC	40 ºC
Specimens type	Rectangular or Cylindrical	Cylindrical
Specimens diameter	150 mm	150

- Durability Tastings

The durability of asphalt mixtures can be described as the loss of strength due to the impact of the exposure conditions. Performance of asphalt mixtures during their service life related to the effect of environmental conditions. In this research work, the evaluation of durability was determined as a ratio of ITS of conditioned specimens to those of unconditioned specimens, expressed in percent (%). However, water damage and ageing deterioration were adopted as durability indicators.

Water damage test for HMA is described by ASTM, D4867/D4867M [45]. The test conditions of water sensitivity are given in Table (7). Water sensitivity can be investigated for CBEM by the same procedure as in HMA, except curing protocol to ensure full strength of the specimens. The following curing protocol cab be directed, additionally to stage one.

- For un condition protocol, 24 hrs. in an oven at 40 °C.
- For condition protocol. Additional to what follow for un condition protocol, the specimens place in water bath for 24 hrs. at 60 °C.

Table 7 water damage testing conditions

Item	range
Number of required specimens	3
Rate of load application, mm/min	50
Specimen diameters, mm	100
Specimen height, mm	62.5
Compaction	Marshall 75x2
Test temperature, ºC	25 ± 1

Calculate the tensile strength ratio

$$TSR = \frac{S_{tm}}{S_{td}} \quad \text{Equation 2}$$

$TSR = tensile\ strength\ ratio, \%$

$S_{tm} = average\ tensile\ strength\ of\ the\ moisture - conditioned\ subset, kPa$

$S_{td} = average\ tensile\ strength\ of\ the\ dry\ subset, kPa$

Ageing test of bituminous mixtures with detail to durability are more commonly evaluated with HMA compared to CMA [1]. One of the main concern of CBEMs is their low early life strength. According to SHRP A383 [46], there are two types of ageing, namely short-term ageing to simulate mixture ageing during the mixture manufacture stage, and long-term ageing for simulating the ageing of the mixture on the road during service. It is obviously agreed that short-term ageing may not be applicable for CBEMs, as no heating exists during the manufacturing process [47]. However, to simulate long-term ageing, the method recommended by the SHRP A383 programmer can be adopted. The testing conditions are summarized in Table (8). This procedure was covered for HMA. For CMA curing time again adopted as follow, in addition to stage one:

- Unconditioned specimen protocol 14 days @40ºC [48].
- Conditioned specimen protocol 14 days @40ºC +(5) days @85ºC

Table 8 Test conditions for ageing

item	values
No. of required specimens	3
Test temperature, ºC	25
Specimen diameter	100

Specimen thickness	30-75 mm
Compaction	Marshall 75x2
Specimen temp. conditioning	2 hr. before testing
Calculate the tensile strength ratio $TSR = \frac{tensile\ strength\ aftrer\ ageing}{tensile\ strength\ after\ ageing}$ where $TSR = tensile\ strength\ ratio,$ %; Tensile strength after ageing, kPa Tensile strength before ageing, kPa	*Equation 3*

4. Results and Discussion

4.1 Marshall Test Results

All CBEMs specimens for Marshall test were tested at ages of 2 days for curing as described previously. The results as shown in Figures (4, 5) for Marshall stability and flow, respectively. From these figures, it can observe no efficient strength of conventional CBEM that comprising CMF. When CMF replaced by OPC, the performance of CBEM enhanced significantly during early time, high value of stability and low flow as a results of high binding between particles of mixture. where using the OPC cured the mixture faster, OPC may be acts as a secondary binder in CBEMs that may be overcome to low strength at early time by hydration, the hydration process needs water to start and continue, so trapped water between aggregates and bitumen films is the basis for that. However, OPC particles are irregular and angular shapes and evenly distributed, whereas particles shape of CMF is close to sheets as shown Figure (3- a, b).

When supplementary replacement substituted OPC by CKD, the strength of CBEMs is began to decrease, the reason may be according to hydraulic characteristics which is reflected by chemical phases of each filler in the new blend; i.e. the mix of OPC and CKD (see the chemical composition of the fillers in Table 2). Also it might be due to physical characteristics of the CKD which although have high surface area in contrast to OPC (see Table 2), at the same time CKD have relatively less angular particles shape in contrast to OPC that leads to lessen internal friction between particles.

Nevertheless, CBEMs contained (0.25CKD+0.75OPC) disclosed good performance on stability and flow, strength decreases slightly with increasing CKD content up to 40 % where unacceptable stability and flow were recorded with reference to Iraqi specifications. Therefore, the next tests of blending CKD with OPC are considered only this percentage, since other blending percentages are failed in Marshall test according to GSBR limits.

It have to said that CBEM comprising 100 % CKD showed very inferior mechanical characteristics either lower than CBEM comprising CMF. This is might be a result of the physical characteristics of the both fillers; where CMF have more angular particle shape which facilitate more interlock within the mastic that connect the aggregate particles.

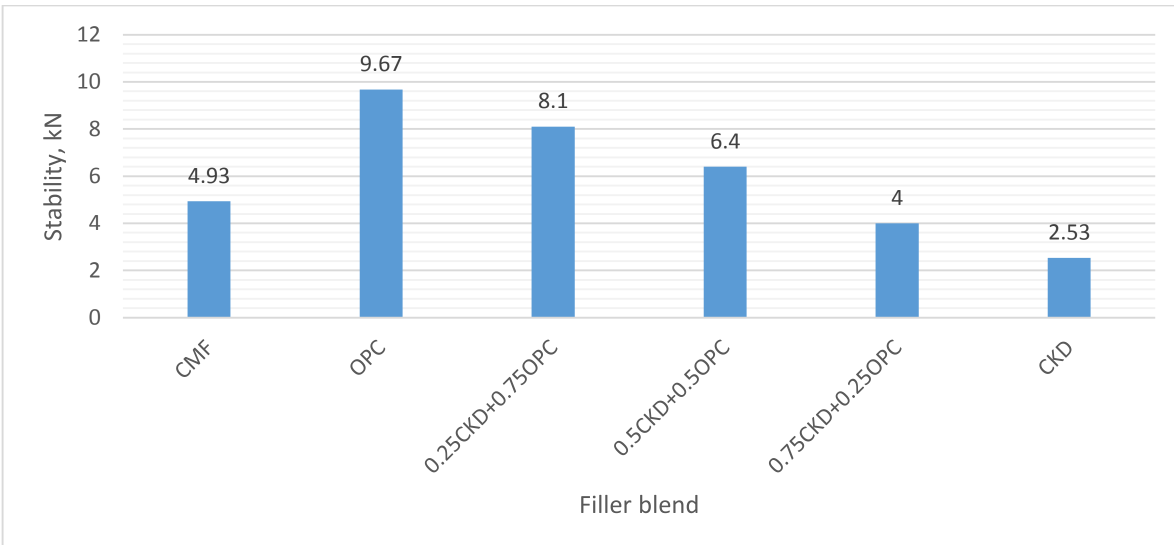


Figure 4 Marshall stability

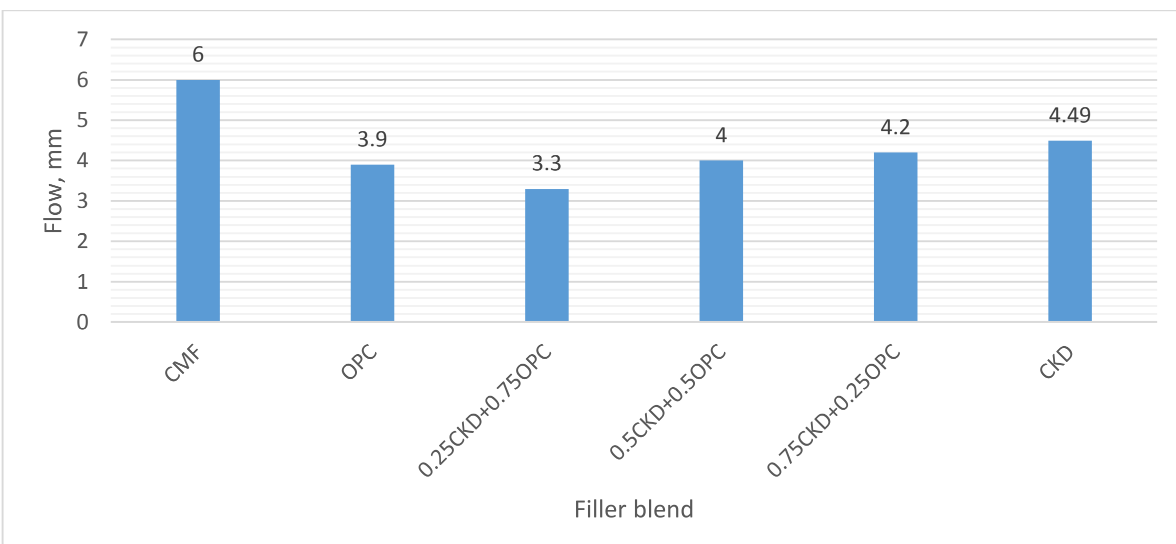


Figure 5 Marshall flow

4.2 Indirect Tensile Strength (ITS)

ITS tests' specimens were prepared in the same procedure described for the Marshall test. The only main differences are in the curing protocols as mentioned earlier. Figure (6) illustrates the results for specimens having CMF as control mixture, OPC and 0.25CKD+0.75OPC.

Comparatively, no efficient ITS of CBEM comprising CMF during early time (2 days). This is a result of exist water that still trapped between the binder and aggregate surface. While after 2 weeks the result improved dramatically up to 67% improvement, this clear evidence to effect water content to impair the mixture at early time. When OPC was replaced totally, it showed double action, whereas as anti-stripping the binder from aggregates due to Ca++. Furthermore, it supplies extra binding because of hydration products. It can be noticed also that there is some extra improvement due to curing reached about 13%; which is might be due to trapped water removal and evaluation of the hydraulic product as well at early time.

Moreover, CBEM with 0.25CKD+0.75OPC showed no significant drop in ITS. This is may be because of pozzolanic properties of the CKD plus the hydraulic proprieties of the OPC. Additionally, still the full curing of the developed mix disclosed a bit improvement due to curing protocol, where 15% improvement recorded. However, the same explanation for the CBEM comprising OPC can adopted here.

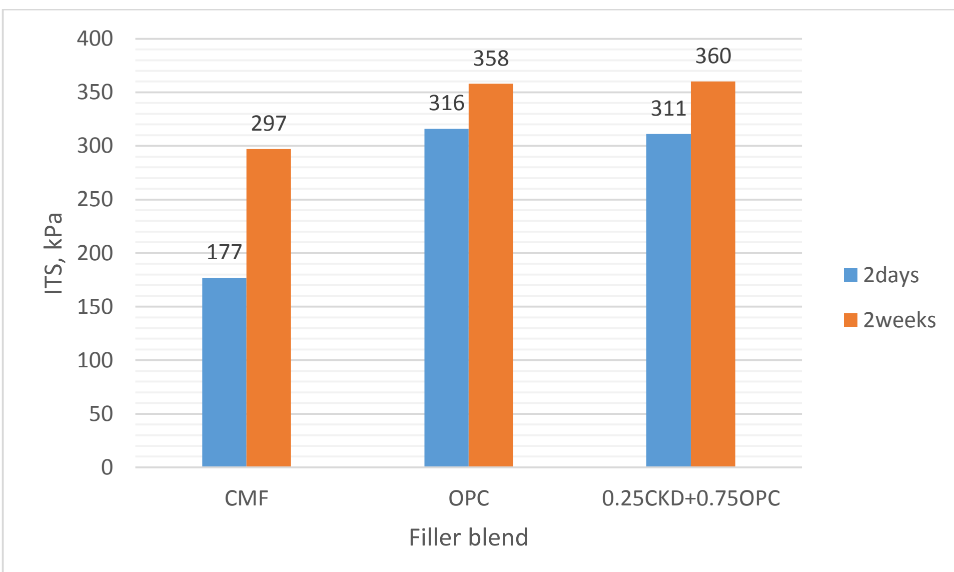


Figure 6 ITS test results

4.3 Wheel Track Test (WTT)

Laboratory wheel-tracking tests were applied to evaluate the rutting resistance of CBEMs. Mixtures were prepared as the same procedure followed in pervious sections, CMF, OPC and 0.25CKD+0.75OPC fillers are introduced to the CBEMs. Figure (7) illustrates the results of total rutting associated with progress of cyclic load. While Figure (8) demonstrates the creep stiffness due to such test.

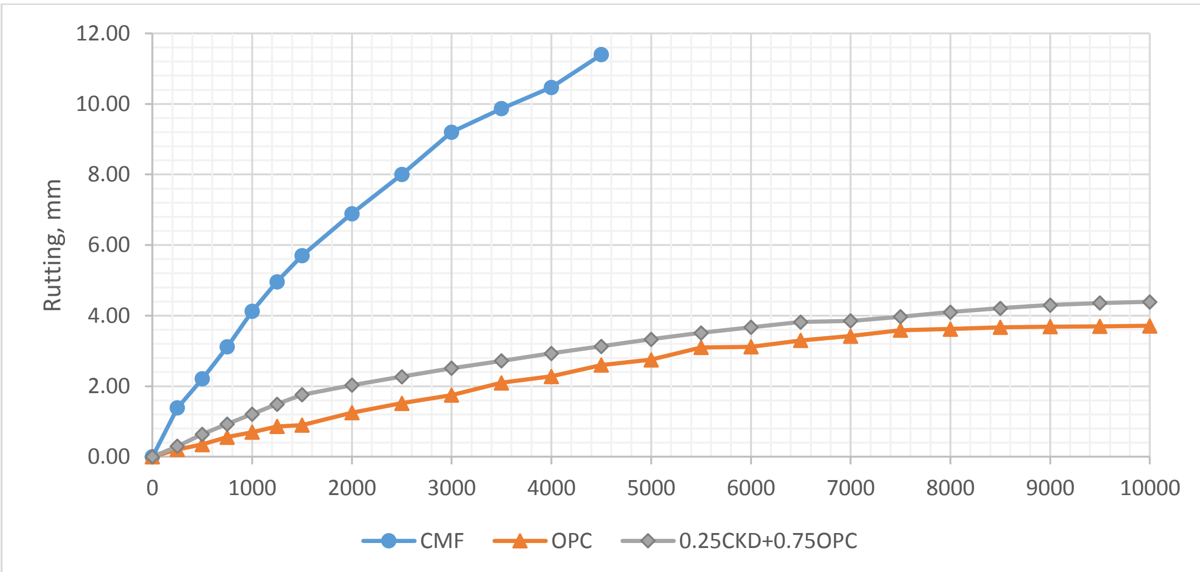


Figure 7 Wheel track test

The test results showed that the CBEM comprising CMF was failed after about 4000 cycles; this is might be because of the weakness of the binder and mastic that grip the coarser aggregate. Less cohesion of mastic materials of mixture when CMF is used is a result of non-active filler. However, significant improvement achieved when OPC and OPC with CKD were introduced. the addition OPC to CBEMs mixture acts as anti-stripping and also built an extra binding against that help to resist the permanent deformation due to cyclic load. Obviously, these improvements in rutting resistance can be approved by the values of creep stiffness, where 206% and 160% are the values of CBEMs comprising OPC and 0.25CKD+0.75OPC, respectively, in contrast to that one comprise CMF as shown in Figure (8). It is accent the creep stiffness value of CCM at end its failure at 4500 cycles, it is clear from Figure (7), while other mixtures the total creep stiffness measured at end of test of the WWT, completed 10000 cycles.

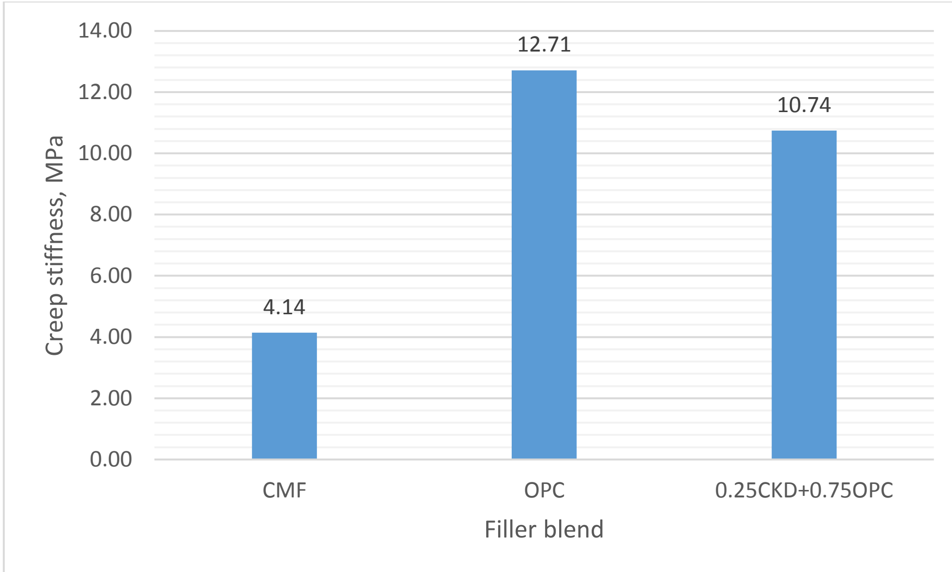


Figure 8 creep stiffness

4.4 Durability Testing

Durability tests include water sensitivity and ageing tests were adopted in this research work. Figure (9) illustrate the results of water sensitivity. However, because no anti-stripping agent can be expected in CBEM comprising CMF, such mixture disclose its high sensitivity attach of water. Inversely, OPC and CKD acts as anti-stripping to the binder, where chemical reaction with water free Ca++, which prevent the stripping. Moreover, the conditioning helps to upgrade the mechanical properties of the developed CBEM; whereas indirect tensile ratio (ITR) recorded values of 109% and 118.8%, for CBEMs comprising OPC and 0.25CKD+0.75OPC, respectively. Actually, the materials became more cohesive, and more resistance for water damage test. It have to said that only satisfied the specification requirement; i.e., ITR at less 70%.

Figure (10) demonstrates the results of ageing test. However, the results indicate the superiority of CBEMs that composing OPC over the other two mixes. This is might be a result of the angular shape of OPC particle that lower the viscosity of the binder and facilitate thicker binder film, consequently higher resistance to ageing.

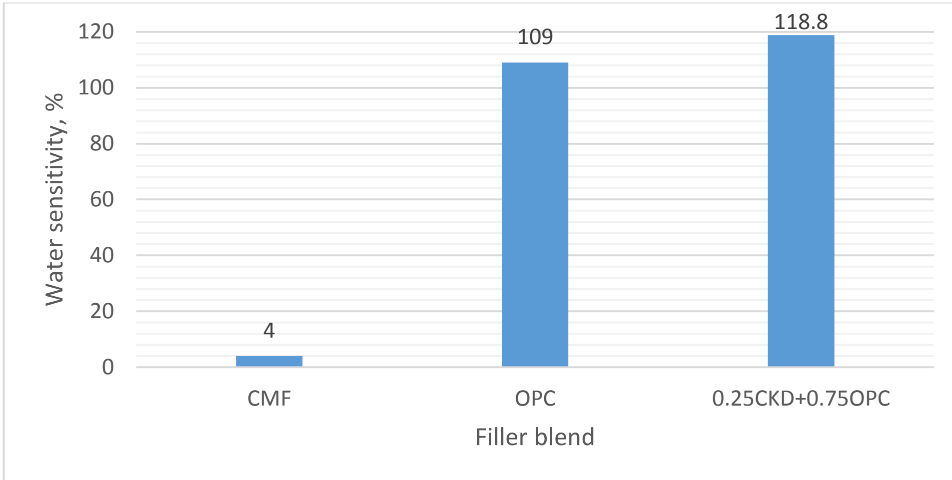


Figure 9 Water sensitivity test results

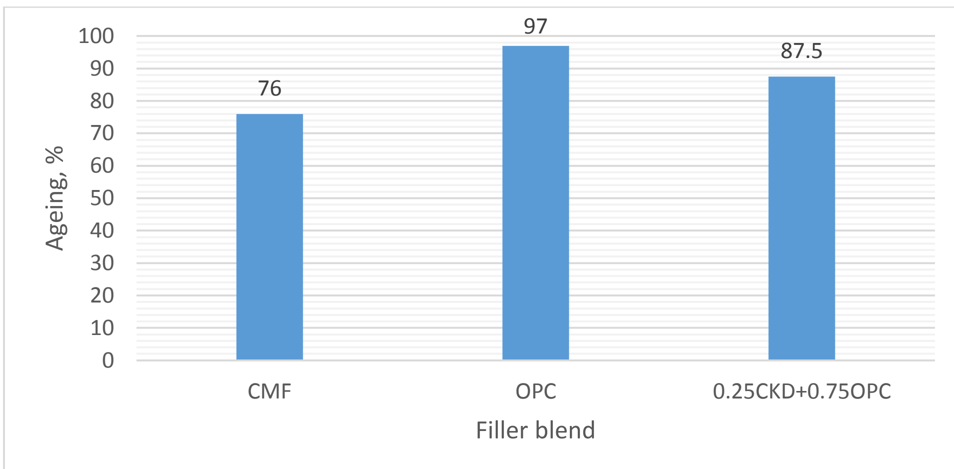


Figure 10 Ageing test results

5. Conclusions

From the above results, it can be concluded that:

1. There is a feasibility to produce CBEMs compliance to the requirements of specification by replace the CMF by OPC
2. There is a feasibility to replace 25% of the OPC by CKD in developed CBEM without significant drop in mechanical properties of CBEMs; the develop mix still within the requirement of the specification.

3. Significant enhancement can be achieved in cracking resistance of conventional CBEM comprising CMF after full curing, which may extend for long period. While outstanding results can achieve by using either OPC or OPC with CKD as a filler.
4. Convectional CBEM exhibits low resistance to permanent deformation, while replacing the CMF by either OPC or OPC and CKD overcome the inferiority of CBEM to rutting.
5. Conational CBEM shows high sensitivity to water damage, while adding OPC or OPC with CKD overcome this inferiority.
6. Almost all CBEMs with all tested filler showed acceptable ageing resistance.

Acknowledgments

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