Characterize Cold Bituminous Emulsion Mixtures Incorporated Ordinary Portland Cement Filler for Local Surface Layer

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Abstract

Cold Bituminous Emulsion Mixtures have many environmental, logistical, and economic advantages over conventional Hot Mix Asphalt. Nevertheless, their inferior performance and high water sensitivity at early life attract little attentions. Moreover, it is impossible to apply CBEM as a structural surface layer if left without treatment or enhancement. The main aim of this study is to enhance the properties of CBEM for the hope of using it as a structural layer. Thus, a trial has been made to improve CBEM mechanical and durability properties by replacing the Ordinary Portland Cement by the Conventional Mineral Filler with 3 percentages; namely, 0, 50%, and 100%. CBEM mixtures mechanical properties were evaluated in term of Marshall Stability and Flow, Indirect Tensile Strength, and Wheel Track Test. While Moisture damage was evaluated in terms of Retained Marshall Stability. Test results showed that the addition of 100%OPC filler can improve CBEM mechanical and durability properties efficiently. In terms of mechanical properties results, CBEM comprised 100%OPC, can be used as a structural Surface layer based on local Iraqi specifications limits, where mixture enhanced about 1.9, 1.78, 9,4.85, and 2.6 times in term of MS, MF, rutting deformation resistance, resistance to tensile cracking, and moisture damage resistance, respectively as compared to untreated CBEM. Also, CBEM-100%OPC mix seemed comparable (and sometime superior) to HMA, e.g., resistance to rutting of CBEM is about 6.2 times higher than that of HMA. It's worth to say that OPC upgrades CBEM to a significant level that enables it to use as a structural layer in terms of the mechanical and the durability properties.

Keywords: Cold Bituminous Emulsion Mixtures, Mechanical properties OPC, Structural surface Layer, CBEM moisture damage

الخلاصة:

تمتلك الخلطات الاسفلتية ذات المستحلب البتيوميني البارد CBEM عده مزايا بيئية ، اقتصادية ، ولوجستية بالمقارنه مع الخلطات الاسفلتية الحاره HMA. وبالرغم من ذلك ، هكذا نوع من الخلطات الاسفلتيه لا تجذب الباحثين والمنظمات بسبب ضعف ادائها وحساسيتها للماء . علاوة على ذلك، فأنه من المستحيل استخدامها لتبليط الطبقات السطحية بدون معالجتها او تحسينها. تهدف هذه الدراسة الى تعزيز الخلطات الاسفلتية الباردة على امل استخدامها كطبقة سطحيه في الطرق. تم استخدام السمنت البورتلاندي الاعتياديOPC لتحسين الخواص الميكانيكية والحجمية وخواص الديمومة ، واستبداله بالماده المالئه التقليدية CMF وبثلاث نسب (٠و٥٠و ١٠٠%). تم تقييم الخصائص الميكانيكية للخلطات باستخدام فحص مارشال ، وفحص الشد غير المباشرITS، وفحص مسار العجلهWTT. في حين تم استخدام فحص الثبات المتبقي لمارشالRMS في تقييم مقاومه الخلطة لضرر الماء. بينت النتائج ان اضافة ١٠٠% من الاسمنت كماده مالئه يمكن ان تحسن الخواص الميكانيكية وخواص الديمومة للخلطات المستحلبة الباردة بكافئة عالية. حيث تبين من خلال الخصائص الميكانيكية والديمومة ان هكذا نوع من الخلطاتCBEM-100%OPC يمكن استخدامها كطبقة سطحيه للطرق بالاعتماد على المواصفات العراقية للطرق والجسور ، حيث ان الخلطه ذات المحتوى الاسمنتى ١٠٠% قد تحسنت بمقدار ١,٩ ، ١,٧٨، ٩,٤، و٢,٦ مره من حيث ثبات مارشال MS، الانسيابMF، فحص الشد غير المباشرITS، فحص مسار العجلةWTT، وفحص تأثير الماء RMS مقارنة بالخلطة الغير معالجة على التوالي. وكذلك اظهرت النتائج ان الخلطة الجديدة مقاربه (وفي بعض الاحيان تفوق) خواص الخلطة الحاره الاعتيادية ومثال على ذلك مقاومة الخلطة للتخدد قد تحسن بمقدار ٦,٢ مره. ومن الجدير بالقول ان ماده الاسمنت قد حسنت خواص الخلطة الاسفلتية الباردة الميكانيكة وخواص الديمومة الى حد ما يسمح باستخدامها كطبقة سطحية للطرق.

الكلمات المفتاحية: الخلطات الاسفلتية ذات المستحلب البتيومين الباردة ،الخواص الميكانيكية، الطبقة السطحية للطرق، تأثير ضرر الماء على الخلطة.

1. Introduction

It has been well known that traditional CBEM has inferior properties as compared to HMA. High air voids content, inferior early life mechanical properties, and long time required to reach full strength are the major defects of CBEM, which were the main reasons for restricting its application to restraint works and roads repairing. On the other side, CBEM has several economic, environmental, and safety advantages over HMA. Some researchers approved the ability of CBEM to work as a structural layer if some modifications or enhancements occurred. Numerous researchers reported that cementitious fillers have the significant improvement on overall CBEM properties in contrast to other types of treatments, such as fibre addition, or increase compaction.

Active fillers such as OPC and lime improved CBEMs performance, as reported by many researchers (Head, 1974 ; Needham, 1996; Thanaya, 2003; Ebels and Jenkins, 2007; Poncino *et.al.,* 1993; Al-Busaltan, 2012; AL-HDABI, 2014; Lin *et.al.,* 2017; Niazi and Jalili, 2009; Dulaimi *et.al.,* 2017; Al Nageim *et.al.,* 2012). In fact, active filler works chemically as a second binder in the mix beside the primary binder (bitumen) in gripping the aggregate particles. Of course in addition to its origin physical purpose, which is as a tiny filling material in aggregate skeleton. Active fillers have the ability to react within the mixture in the existence of water that exist in emulsion composition or from premixing water source to form the hydration products. Such fillers enhance mixture strength, also, at early life since the trapped water is absorbed in the hydration process. As a result, they are considered as catalyser agents for bitumen emulsion breaking process (Ebels and Jenkins, 2007).

The incorporation of OPC as a filler in asphalt emulsion mixture dates back to 1970 (Head, 1974), since that it had had believed significantly as a good mix properties (Needham, 1996). Head concluded that Marshall Stability could be increased about 250-300% if 1% of OPC had substituted the normal filler. Poncino *et.al.*,1993) stated that incorporation of 2% of OPC filler in cold mix asphalt (CMA) with dense graded gradation increases the resilient modulus by 125%, and 66% when limestone filler was used. Furthermore, a study reported that the addition of cement to CBEMS increases fatigue life, results in high toughness, enhances strain energy, and delays micro cracking propagation (Li *et.al.,* 1998).

Moreover, other studies stated that OPC filler with such mixture improves the stiffness modulus, reduces susceptibility to moisture damage, improves temperature susceptibility, increases the ability of mixture to resist creep and permanent deformations (rutting) and makes them comparable to HMA (Oruc *et.al.,* 2007; Schmidt *et.al.,* 1973; Head, 1974 ; Thanaya *et.al.,* 2009 ; Fang *et.al.,* 2016).

Another study concluded that CBEMs comprising cement can enhance the overall mixture properties. The study reported that cement filler increases stiffness properties higher than those of HMA at long time curing. It also founded that full cured CBEMs comprised 2.75-5.5% active fillers offer a higher resistance to the permanent deformation than traditional HMA do (Al Nageim *et.al.,* 2012).

Recently, (Yan *et.al.*,2017) investigated the early-age strength and long-term performance of asphalt emulsion cold recycled mixes with various cement contents. They concluded the following points:

- Cement filler promoted a higher cohesive strength in terms of Hveem cohesion test, and higher ravelling resistance in term of ravelling test at a higher amount of cement content.
- Cement improved mix early strength and increased resistance to moisture damage
- It improves high temperature stability and low-temperature cracking resistance. Higher value could be obtained with higher cement content.

On the other hand, the effect of addition of lime as a filler compared to that of OPC relatively low, since it has been observed by (Brown and Needham , 2000) that stiffness modulus of hydrated lime treated CMA do not have the same useful improvement.

This study will use OPC filler with 3 percentages (0, 50%, and 100%) instead of CMF which uses the combination of design procedure recommended by asphalt institute MS-14 and the local GSRB specifications. The study is intended to clarify such combinations are compatible to each other for the surface layer and for the heavily trafficked loads conditions.

2. Research Aim and Scope

This study aims to demonstrate the possibility to use CBEM mixtures as a surface layer for heavy traffic load according to the Iraqi GSRB specifications utilizing OPC filler with different percentages instead of CMF. However, most of the outside recent studies nominated improving CBEM for either base or binder layers, while very little local studies deal with such subject generally. The following objectives and scopes have been drawn to reach prospective aim:

- Almost the materials used in this study are local
- The local valid specifications variables are used as much as possible. Such variables like mix particle size, gradation, mechanical and durability limits were used for this purpose.
- Conventional HMA mixture with OPC filler is designed for comparison and for clarifying how much CBEM mixture has enhanced in term of the mention tests protocols.
- Conventional Cold mixture (CCM) is designed, without any modifiers, as reference mix.
- Incorporating the OPC filler with 3 percentages namely, 0, 50, and 100% from CMF filler.

3. Materials, Design Procedure, and Test Methods

3.1 Materials

Aggregates (course and fine) used in this research work were supplied from local Kerbala quarries. The materials properties requirements were compliance to the Standard Specification for Roads and Bridges (SORB, 2003). Tables (1) and (2) present the physical properties of coarse and fine aggregates used in this research work, respectively. The aggregates were sieved, separated and graded to compliance to the gradation required for surface layer type IIIA according to the mentioned Iraqi specification (SORB, 2003), as it is shown in Table (6) and Figure (1). Simultaneously, asphalt binder was supplied from Al-Neisseria refinery with properties shown in Table (4). OPC was supplied from Karbala cement plant, Table (3) presents its chemical and physical properties. Asphalt emulsion was supplied from Henkel Company under the commercial name Polybit with properties listened in Table (5).

Table 1: Physical Properties of Coarse Aggregates

Property	ASTM designation	Crushed Course Aggregate	SORB Specification, (binder course)
Bulk specific gravity, gm/cm^3	C127 (ASTM, 2015b)	2.6	-
Apparent specific gravity, gm/cm^3	C127	2.64	-
Water absorption, %	C127	1.36	-
Percent wear by Los Angeles abrasion , %	C131 (ASTM, 2014)	9.1	35% Max
Soundness loss by sodium sulphate ,%	C88 (ASTM, 2013c)	4.1	12% Max
Clay lumps, %	C142 (ASTM, 2010b)	0.05%	-

Table 2: Physical Properties of Fine Aggregates

Property	ASTM & AASHTO Designation	Test Results	SORB Specification for surface course
Bulk specific gravity	C128	2.66	-
Apparent specific gravity	C128	2.67	-
Water absorption,%	C128	0.5	-
Clay lumps , %	C142	2.4%	-
Passing sieve NO.200,%	C117	2.86%	-
Plasticity index, %	D 4318	NA	4% max
sand equivalent,	T 176	49%	45% min

Table 3 Properties of OPC and CMF Used

Physical		
Property	**Filler Type**	
	CMF	**OPC**
surface Area (m^2/kg)	223	415
Density (gm/cm^3)	2.650	2.981
Chemical		
SiO_2	81.89	25.410
Al_2O_3	3.78	2.324
Fe_2O_3	1.92	1.125
CaO	7.37	65.148
MgO	3.45	1.326
K2O	0.73	0.760
Na2O	0.19	1.714

Table 4 Properties of asphalt binder

Test	ASTM designation	Test results	SORB requirements
Penetration,100 gm. ,25 ° C,5sec (1/10 mm)	D5	44	40-50
Specific Gravity, 25 °C (gm/cm3)	D70	1.03	-
Ductility, 25 ° C , 5 cm/min (cm)	D113	>100	>100
Flash point, (° C)	D92	335	>232
Softening point (°C)	D36	41	-
Solubility in trichloroethylene, (%)	D2042	99.2	>99
After Thin Film Oven test			
Penetration of Residue (%)	D 1754	66	>55
Ductility of Residue, (cm)		97	>25

Table 5 Properties of Asphalt Emulsion

Property	Specification, ASTM	Limits	Results
Emulsion type	D2397(ASTM, 2013a)	Rapid, medium and slow-setting	Medium-setting (CMS)
Colour appearance			Dark brown liquid
Residue by Evaporation, %	D6934(ASTM, 2008)	Min. 57	55
Specific gravity, gm/cm3	D70(ASTM, 2009a)		1.02
Penetration, mm	D5(ASTM, 2015a)	100-250	215
Ductility, cm	D113(ASTM, 2007)	Min. 40	45
Viscosity, rotational paddle viscometer 50 ℃ , mPa.s	D7226(ASTM, 2013b)	110-990	350
Freezing	D6929(ASTM, 2010a)	Homogenous, broken	Homogenous
Solubility in Trichloroethylene ,%	D2042(ASTM, 2015c)	Min. 97.5	97
Emulsified asphalt/job aggregate coating practice	D244(ASTM, 2009b)	Good, fair, poor	good
Miscibility	D6999(ASTM, 2012a)		Non miscible
aggregate coating	D6998(ASTM, 2011)		uniformly - thoroughly coated

3.2 Mix Design Procedure

3.2.1 Design of HMA

The design method of Marshall was adopted to prepare the traditional HMA specimens, with five different asphalt content groups (3 replicates each trail). The materials that used were as mentioned previously, asphalt grade type 40-50 and aggregate gradation which was based on Iraqi standard specification (GSRB) for surface layer (type IIIA), as described in Table (6) or Figure (1). Course and fine aggregates were used as presented in table (1) and table (2). OPC filler type was only used to produce HMA specimens. Compaction effort was applied using Marshall Hummer with 75 blows each face. Specimens left to cool down before extraction from mold, then they were ready for testing according each testing procedures. The optimum asphalt content was 4.65%, with properties will be presented for comparison with CBEM treated and untreated mixes

Table 6 Dense Aggregate Gradation for Surface Layer Type IIIA, SORB, Section-R9. (SORB, 2003)

Sieve size	mm	%passing by weight	Used (Average)
1	25	100	100
0.75	19	100	100
½	12.7	90-100	95
⅜	9.525	76-90	83
No. 4	4.75	44-74	59
No. 8	2.38	28-58	43
No. 50	0.3	5-21	13
No. 200	0.075	4-10	7

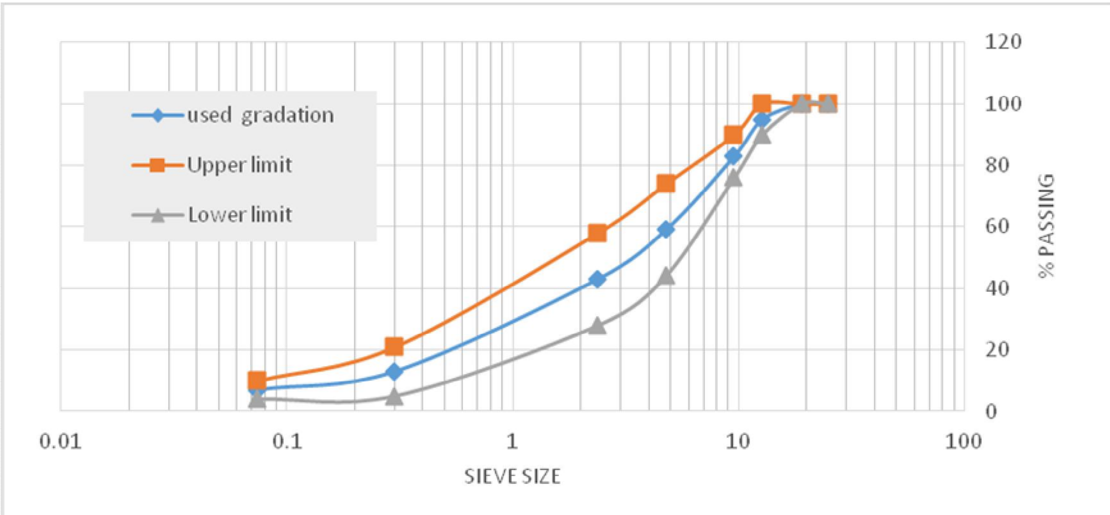

Figure 1 Particle Size Distribution Of Type IIIA Dense Graded Wearing Course Used. (SORB, 2003)

3.2.2 Design of CBEMs

Since there is no universally accepted procedure for designing the CBEM, the design procedure listened in asphalt institute MS-14 with some modification adopted from Iraqi local specification GSRB. The following procedure describes the adopted procedure:

- Selection of aggregate gradation: the dense aggregate gradation listened in GSRB, in section R9, for the surface layer type IIIA has adopted, since such gradation has proved its efficiency to withstand the intended loads. Table (6) clarifies the adopted gradation.
- Determination of initial residual emulsion content: the following empirical formula can be used to fine IRBC (see equation (1))

$$P = (0.05A + 0.1B + 0.5C) * 0.7$$ .... **Equation 1**

Where:

P = amount of asphalt emulsion based on weight of graded mineral aggregate, %,

A = mineral aggregate retained on sieve (No.8), %,
B = mineral aggregate passing sieve (No.8) and retained on (No.200), %,
C = mineral aggregate passing (No.200), %.

Initial Emulsion Content (IEC) value was determined by dividing P by the percentage of the residual bitumen content in the emulsion, which was determined as 55%

$$IEC = \frac{P}{X} \quad \textbf{.. Equation 2}$$

Where:
IEC = Initial emulsion content by mass of dry aggregate, %.
X = residual bitumen content of the emulsion.

Based on the adopted gradation, P value was 6.95% based on equation (1), and the IEC was 12.63% based on equation (2).

- Coating test: coating test or binder compatibility test is necessary to estimate the quantity of the required added water corresponding to the best aggregate coating. Five mix trials were made; each with a different water content, and with 0.5 % increment. Asphalt institute recommended to use 3% water content initially. The selected optimum water was 3.5% for OPC incorporated mixtures, 3% for mixtures with 50% OPC filler, and 2.5% for CMF incorporated mixtures. All these percentages were selected based on visual estimation based on the fact that mixture with lowers moisture state should not be too stiff due to low water content or too sloppy due to the higher amount of the added water.
- optimum bitumen emulsion content (OBEC): Marshall specimens were prepared using the value of IEC that previously determined in step1 (12.5%) as middle value, with two percentage points on each side to determine OBEC.
- Total liquid content at compaction (TLC): TLC is the summation of optimum added water for coating and optimum emulsion content resulted the total liquid content. It is necessary to mention that the resulted value seems to be higher than the value of optimum total liquid content at compaction. Therefore mixture should be exposed for drying by either leaving mixture for a short time period or applying air van to ensure getting better mechanical properties.
- Mixing Procedure for CBEM components: it has been observed that mixture was suffering from segregation as fine materials are still uncoated at the bottom of container. Therefore , a mixing procedure as recommended by Thanaya (2003) was adopted. This procedure is used to mix course and fine aggregate with filler in dry condition, then the same composition is remixed after the addition of water. Finally, asphalt emulsion is added and then mixed again using automatic electric mixer.
- Compaction: In this research, compaction method adopted in this research using Marshall hummer by applying 75 blows each face to simulate heavy traffic load.
- Curing Protocols for CBEM: In general, CBEM requires long time to reach required design strength. In order to accelerate mixture strength, researchers have adopted several protocols for CBEM curing. There are two common protocols used by most of researchers illustrated as follows:
- To simulate mixture strength after 7-14 day in place curing, CBEM specimens were left in mold for 24hr at lab temperature, followed by 24hr in an oven at 40°C, as

recommended by Jenkins (2000). Such protocols was adopted for Marshall test and ITS test.

- To simulate full strength of mixture, specimens were left for 24hr in mold at lab temperature, then conditioned in an oven for 14 days at 40°C. As recommended by Thanaya (2003). Such protocol was adopted for wheel track test specimens.
- CBEM volumetric properties: The recommended equation listened in Asphalt Institute in MS-14 was adopted in case of mixture volumetric analysis (air void, void in mineral aggregate, void in total mix, and void filled with bitumen).

Table 7 GSRB Limitation for Surface Layer, Section R9 (GSRB, 2003).

property	GSRB Requirements
stability, Kg	>800
Flow, 1/10mm	2-4
Air Void, %	3-5
Retained strength, %	>70
VMA, %	>14

3.3 Tests Methods

3.3.1 Marshall Test

The same procedure has been followed for both HMA and CBEM in Marshall test, except in conditioning protocols, where CBEM specimens have conditioned as mentioned previously to simulate mix strength after 7-14 day. While HMA specimens were left to cool down at lab temperature for 24hr. After curing, both CBEM and HMA specimens were conditioned in water bath for 30 min at 60C. Finally, compacted HMA specimens were ready for testing. The specimens subjected to loading until failure, and the results were recorded using computer device with the help of load cell 5 ton capacity and LVDT sensors.

3.3.2 ITS Test

ITS test was used to measure the ability of asphaltic mixtures to resist tensile cracks failure. In simple way, Marshall specimen is subjected to compression loading by two strips across the specimen's diameter until reaching failure according to ASTM D6931(ASTM, 2012b), as can be seen in the setup clarified in Plate (1), where equation (4) is used to determine ITS value.

$$ITS = \frac{2P}{\pi . D . t} \quad \text{.. Equation 4}$$

Where:

ITS = indirect tensile Strength , kPa.

P = maximum Load , N.

t = specimen hieght immediately brefore test , mm.

D = specimen diameter , mm.

Plate 1 Indirect Tensile Strength Test Device

3.3.3 Wheel Track Test

Wheel track test (WTT) is a common well known simulative test which describes mixture resistance to rutting or permanent deformation. The WTT gives an indication for mixture stiffness and rate of permanent deformation. It can be performed for both CMA and HMA mixtures with difference between them only in curing protocol. The test has been performed according to (BS EN 12697-22: 2008) (EN, 2003) specifications.

The preparation of HMA and CBEM specimens includes preparation of rectangular slab specimen with dimension 5x16x30 cm. the mixtures were prepared with the optimum asphalt content that determined from Marshall test. trial mixes were made with different compaction effort applied to determine the specified target air void specified in BS standard (BSI: EN, 2003), as they can be seen in Plate (2) for both HMA and CBEM specimens.

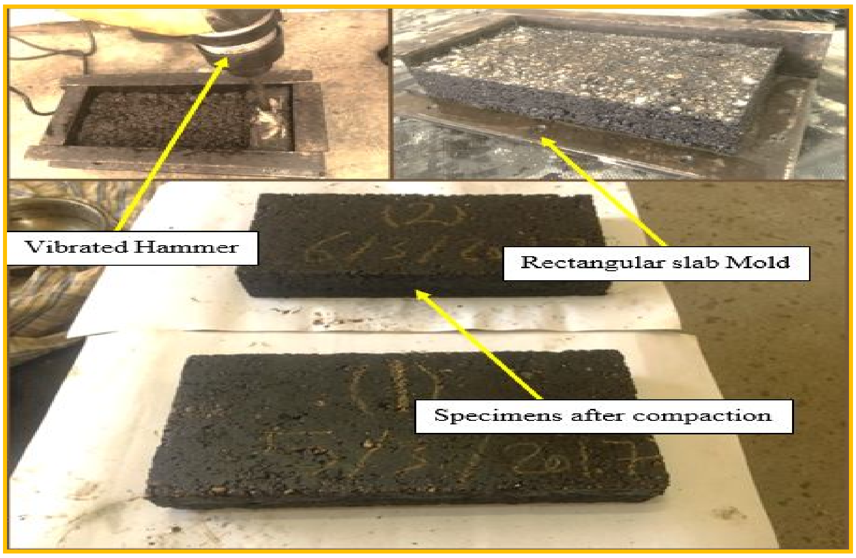

Plate 2 Preparation of Rectangular Slab Specimens for Wheel Track Test

After the preparation of 4 trial mixes for HMA to determine compaction time required to reach 7% air voids content, a 3 minutes compaction time was selected based on figure (2). While no air voids reduction has been observed in term of CBEM even after 6 min vibrator compaction as cleared in the same figure. So, the same time selected for compaction CBEM specimens (3 minutes)

The full curing condition was selected of CBEM specimens as recommended by Thanaya, which stated placing molded specimens in lab temperature for 24, followed by 14 day curing in oven at 40C .

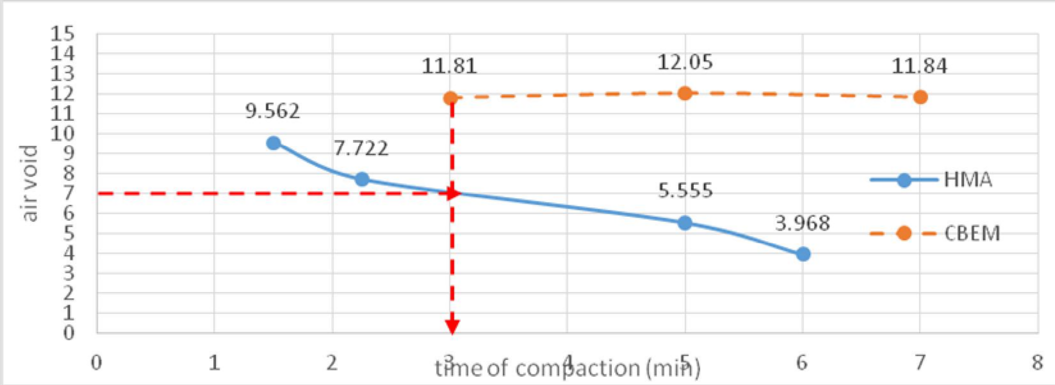

Figure 2 Compaction Time vs. Air Voids Content for HMA

3.3.4 Retained Marshall Stability Test (RMS)

The RMS used to evaluate Marshall stability loss when specimens are subjected to water action according to MS-14 (Asphalt Institute, 1989) requirements. The water sensitivity in term of loss of Marshall stability is determined by dividing the average of socked specimens group by the average standard Marshall specimens group as it is shown in equation (11). However, the (Asphalt Institute , 1989) MS-14 specified that ratio of the conditioned to unconditioned specimens should not be less than 50% for CMA specimens. Table (7) clears curing protocols for conditioned and unconditioned specimens.

Table (7) Conditioning Protocols For Water Sensitivity Tests

unconditioned specimens	conditioned specimens
24hr in mold @ lab temperature	24hr in mold @ lab temperature
24hr in oven @ 40 °C	24hr in oven @ 40 °C
………………	24hr in water bath @ 60 °C

The RMS value can be obtained using the following formula:

$$RMS\% = \frac{average\ of\ conditoned\ specimens}{average\ of\ unconditoned\ specimens} \times 100\%$$ ……………Equation 11

4. Test results

Based on Marshall mechanical and volumetric properties of CBEM, the selected OEC for CBEM-100%OPC was founded to be 12%, 11.75% for CBEM50%OPC, and 12.2% for CBEM-CMF.

After selecting optimum emulsion content, the following results has been observed:

- In term of the volumetric properties, as it was mentioned previously, there were no clear improvements has noticed while dosing different OPC in mix, as it can be observed in Figures (3, 4, and 5).
- CBEM-CMF mixture has weak stability as compared with HMA, which is approximately about 2.5 times higher than CBEM-CMF. While the mix incorporated

50%OPC has been improved about 1.6 times of untreated mix, but still lower than HMA. Consequently, the addition of 100%OPC improved mix stability about 1.9 times of untreated one, and this level is also still lower than HMA stability. Both CBEM-OPC treated mixes have acceptable stability values according to the SORB specification, as it can be seen in figures (5 and 6).

- Flow results shown in figures (5and 7), indicated that the untreated CBEM has high flow value, which is unacceptable based on SORB limits. While flow property has been improved about 1.42 times and 1.78 times for CBEM-50%OPC and CBEM-100%OPC mixes, respectively, as compared to the case of untreated CBEM.
- Stability and flow results of 100%OPC treated mix have acceptable limits according to the SORB specification. Hence, 100%OPC replacement value has been selected for other tests.

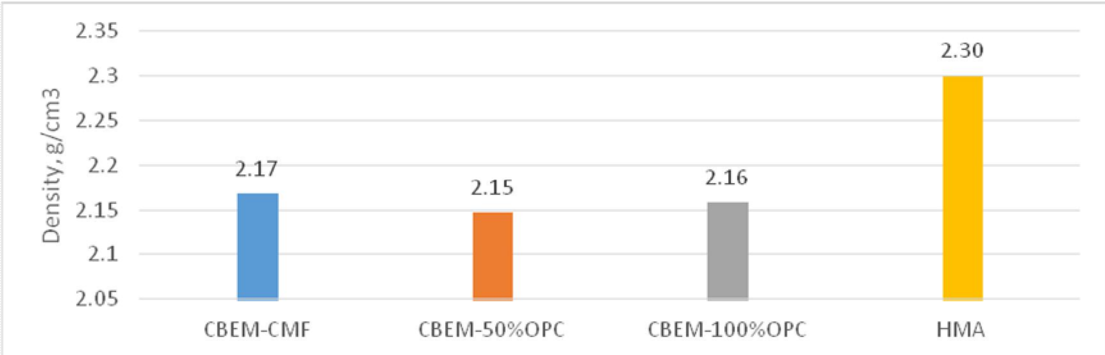

Figure 3 Density Results Values for Different CBEM Incorporated OPC Mixtures at Optimum Asphalt Emulsion Content, Compared With HMA

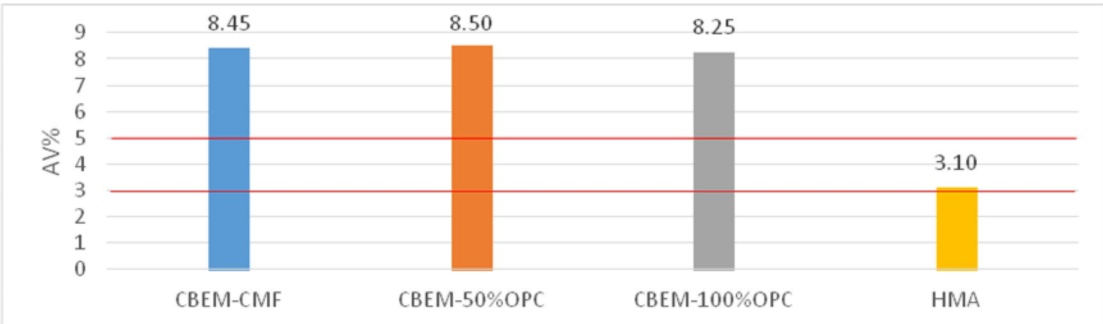

Figure 4 AV% Results for Different CBEM Incorporated OPC Mixtures at Optimum Asphalt Emulsion Content, Compared With HMA

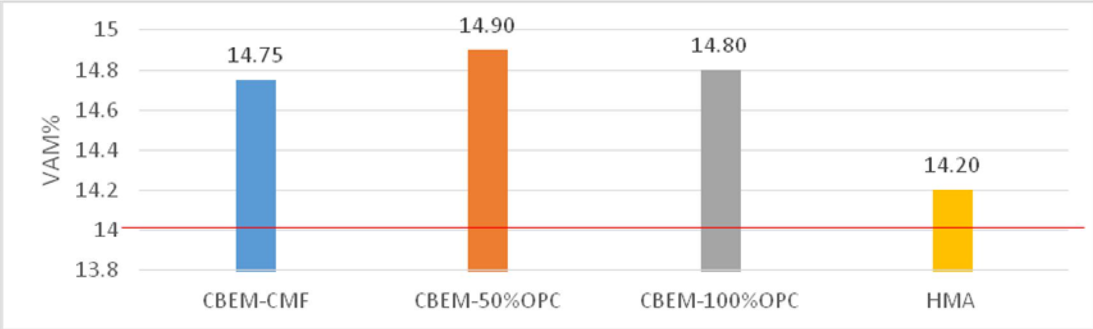

Figure 5 VMA% Results for Different CBEM Incorporated OPC Mixtures at OAEC%, Compared With HMA

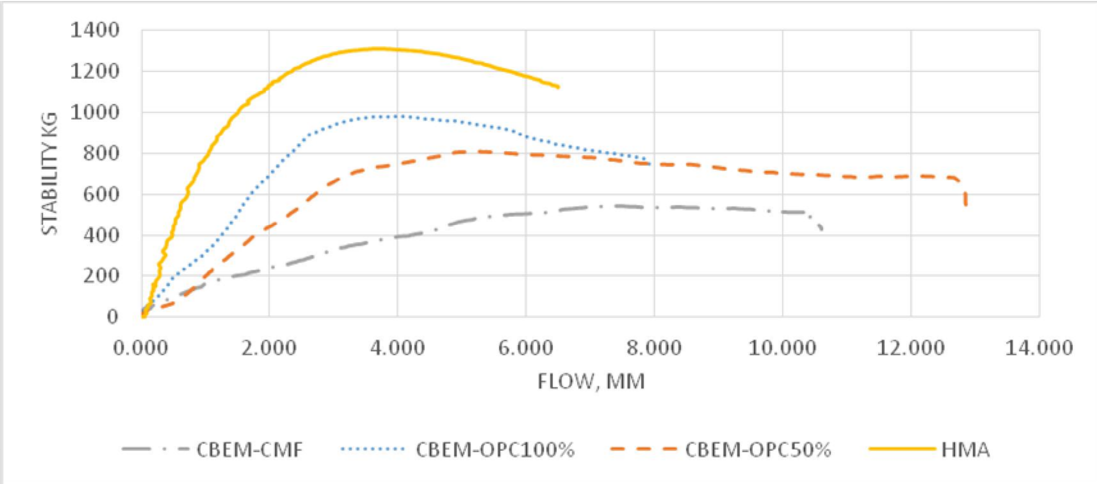

Figure 6 Stability- Flow Curves for Various Mixtures Types at OAEC%.

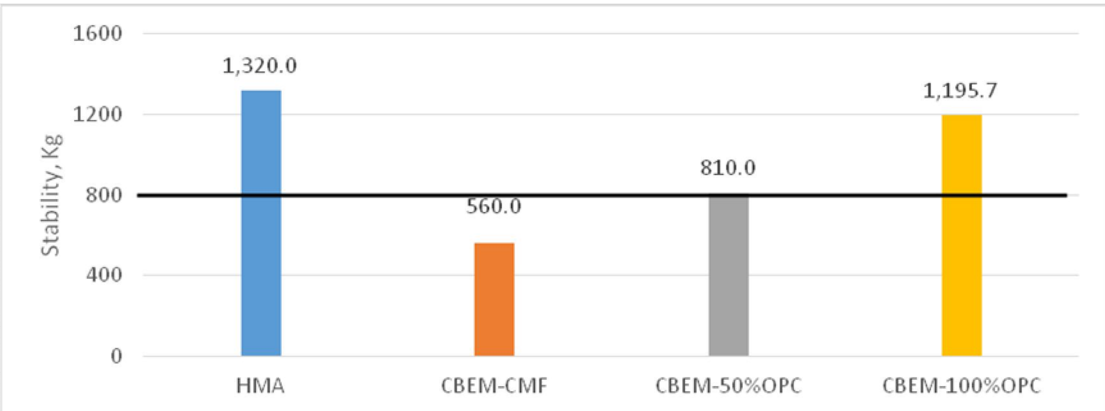

Figure 7 Marshall Values for Different CBEM Incorporated OPC Mixtures at OAEC%, Compared With HMA

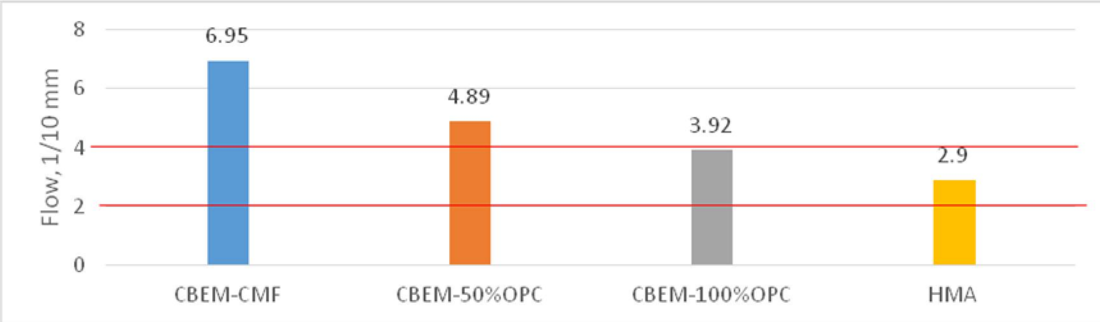

Figure 8 Marshall Flow Values for Different CBEM Incorporated OPC Mixtures at OAEC%, Compared With HMA

4.3 WTT results

Test results of wheel track shown in figure (9), have indicated that the untreated CBEM mix has the highest rutting value among other mixes. The addition OF 100%OPC improves mix resistance to rutting about 9 times of untreated CBEM, and 6.2 times of HMA. It has to be mentioned that all mixes types have acceptable results according to BS test standards (less than 15mm rutting under 1000 cycle test). Also, it can be observed that existence of OPC filler reflected a stiffer, more brittle mixture, as it can be noticed clearly that rutting after the test is 0.979mm.

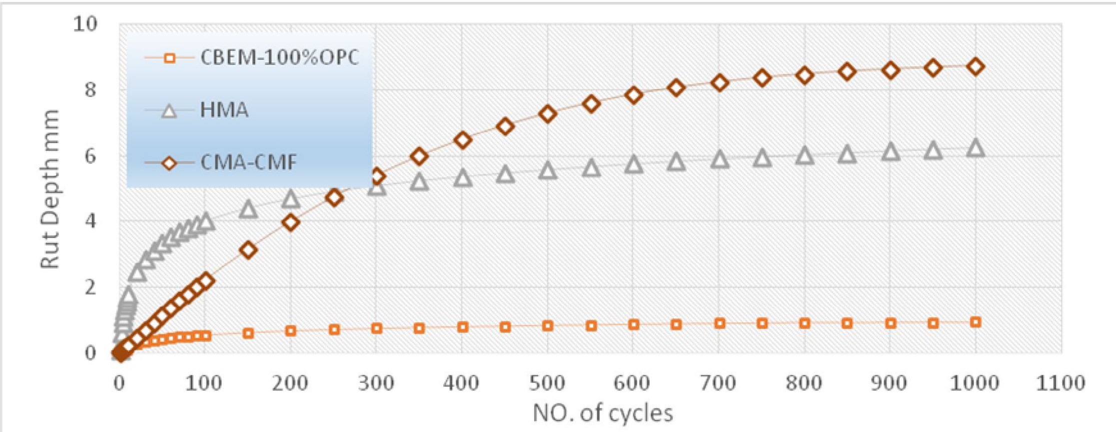

Figure 9 Rutting vs. No of Cycle Curves for CBEM Comprised Different OPC Content Compared with HMA.

4.4 ITS results

ITS results as can be seen in figure (10), clarifies that CBEM-CMF mix has low ITS value as compared to other mixes. While significant improvement has observed when OPC is incorporated. Mix has been improved about 3.11 and 4.85 times of CBEM-50% OPC and CBEM 100% OPC mixtures as compared to the untreated one, respectively. Mix with 100% OPC replacement has comparable ITS property as compared to HMA. The existence of OPC has enhanced mix bonding accelerate curing rate and gain higher tensile cracking resistance.

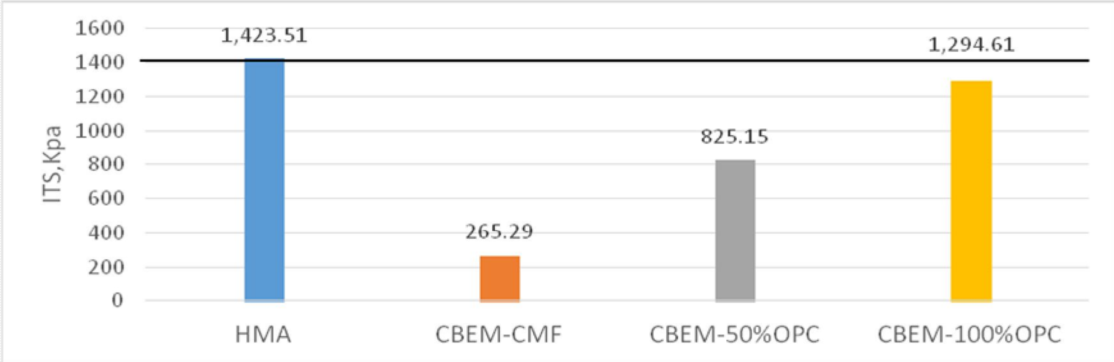

Figure 10 ITS% for CBEM Comprised Different OPC Content Compared with HMA.

4.5 RMS test results

Test results as plotted in figure (11), have shown that the untreated CBEM has weak resistance to moisture damage as compared to HMA, and this result unacceptable according to the GSRB specification. Also, the addition of OPC filler has enhanced mix resistance by about 2 and 2.6 times of the untreated CBEM-50%OPC and CBEM-100%OPC mixes, respectively. CBEM-100%OPC treated mix is improved about 1.3 time higher than HMA, while approximately the same value has been observed for CBEM-50% OPC as compared with HMA. It is believed that some OPC particles have enhanced with the required water to complete hydration process during specimens conditioning, which resulted in higher bonding property and higher stability.

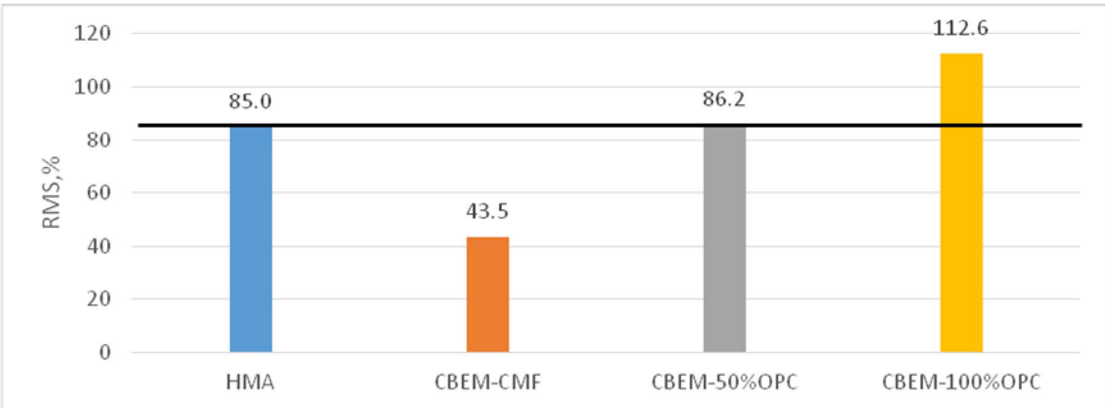

Figure 11 RMS% Results for Different CBEM Mixtures Compared with HMA.

4. Conclusions

From the testing program and analysis of the obtained results, the following points can be concluded:

A. Test results has indicated that the untreated CBEM is absolutely unacceptable to work as structural surface layer according to the GSRB specifications, since poor mechanical, volumetric, and durability properties have been observed as compared to those of HMA.

B. Replacing CMF with 50% OPC has increased CBEM mechanical properties efficiently, but it still doesn't meet the GRSB criteria. Also, no clear improvement has been noticed in terms of the overall volumetric properties.

C. Replacing CMF with 100% OPC has increased mix stiffness, improved the mixture resistance to moisture damage, increased stability and reduced flow, enhanced mixture resistance to tensile cracking. In terms of the mechanical properties, the new developed CBEM (with100%OPC) has acceptable mechanical properties to work as structural surface layer for heavily trafficked condition based on the GRRB requirements. They are comparable (and sometime superior) to HMA.
D. Although CBEM-100%OPC mixture having high air voids as compared to HMA, it was more durable than HMA. In other words, CBEM-100%OPC mixture was still suffering high air voids content, which resulted in reducing other volumetric properties.
E. In term of vibratory compaction, no air voids reduction has been observed when compaction effort for CBEM was doubled, which still has high air voids content.

References

AL-BUSALTAN S. ,2012. *Development of New Cold Bituminous Mixtures for Road and Highway Pavements.* PhD Thesis, School of Built and Environment, Liverpool John Moores University.

AL-HDABI A. , 2014. *High strength cold rolled asphalt surface course mixtures.* Liverpool John Moores University.

AL NAGEIM, H., AL-BUSALTAN, S. F., ATHERTON, W. & SHARPLES G. ,2012. A comparative study for improving the mechanical properties of cold bituminous emulsion mixtures with cement and waste materials. *Construction and building materials,* 36**,** 743-748.

ASPHALT INSTITUTE ,1989. *Asphalt Cold Mix Manual, manual series No.14 (MS-14),* Maryland,USA.

ASTM , 2007. Standard Test Method for Ductility of Bituminous Materials. D113, American Aociety for Testing Material, West Conshohocken, PA, United States.

ASTM , 2008. Standard Test Method for Residue by Evaporation of Emulsified Asphalt. D6934, American Aociety for Testing Material, West Conshohocken, PA, United States.

ASTM , 2009a., Standard Test Method for Density of Semi-Solid Bituminous Materials (Pycnometer Method). D70, American Aociety for Testing Material, West Conshohocken, PA, United States.

ASTM , 2009b. , Standard Test Methods and Practices for Emulsified Asphalts. D244, American Aociety for Testing Material, West Conshohocken, PA, United States.

ASTM 2010a. Standard Practice for Freezing of Emulsified Asphalts. D6929, American Aociety for Testing Material, West Conshohocken, PA, United States.

ASTM , 2010b., Standard Test Method for Clay Lumps and Friable Particles in Aggregates. C142, American Aociety for Testing Material, West Conshohocken, PA, United States.

ASTM , 2012a. , Standard Practice for Miscibility of Emulsified Asphalts. D6999, American Aociety for Testing Material, West Conshohocken, PA, United States.

ASTM , 2012b. , Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures. D6931, American Aociety for Testing Material, West Conshohocken, PA 19428-2959, United States.

ASTM , 2013a. , Standard Specification for Cationic Emulsified Asphalt. D2397, American Aociety for Testing Material, West Conshohocken, PA, United States.
ASTM , 2013b. , Standard Test Method for Determining the Viscosity of Emulsified Asphalts Using a Rotational Paddle Viscometer. D7226, American Aociety for Testing Material, West Conshohocken, PA, United States.
ASTM , 2015a. , Standard Test Method for Penetration of Bituminous Materials. D5, American Aociety for Testing Material, West Conshohocken, PA, United States.
ASTM , 2015c. , Standard Test Method for Solubility of Asphalt Materials in Trichloroethylene. D2042, American Aociety for Testing Material, West Conshohocken, PA, United States.
BROWN S. & NEEDHAM, D. , 2000. , A study of cement modified bitumen emulsion mixtures. *Asphalt Paving Technology,* 69**,** 92-121.
BSI: EN , 2003. , 12697-32. Bituminous mixtures. Test methods for hot mix asphalt. Part 32: Laboratory compaction of bituminous mixtures by vibratory compactor. *Brussels: European Committee for Standardization*.
DULAIMI, A., AL NAGEIM, H., RUDDOCK, F. & SETON, L. , 2017. , High performance cold asphalt concrete mixture for binder course using alkali-activated binary blended cementitious filler. *Construction and Building Materials,* 141**,** 160-170.
EBELS, L.-J. & JENKINS, K., 2007 , Mix design of bitumen stabilised materials: Best practice and considerations for classification. Proceedings of the 9th Conference on Asphalt Pavements for Southern Africa (CAPSA’07),. 5.
EN, B. 2003. 12697-22. Bituminous mixtures. Test methods for hot mix asphalt. Part 22: Wheel tracking. *Brussels: European Committee for Standardization*.
FANG X., GARCIA A., WINNEFELD, F., PARTL, M. N. & LURA, P. , 2016. Impact of rapid-hardening cements on mechanical properties of cement bitumen emulsion asphalt. *Materials and Structures,* 49**,** 487-498.
HEAD R. , 1974 , An informal report of cold mix research using emulsified asphalt as a binder. Association of Asphalt Paving Technologists Proc.
JENKINS K. J. , 2000. *Mix design considerations for cold and half-warm bituminous mixes with emphasis of foamed bitumen.* Stellenbosch: Stellenbosch University.
LI G., ZHAO Y., PANG S.-S. & HUANG W. , 1998. Experimental study of cement-asphalt emulsion composite. *Cement and Concrete Research,* 28**,** 635-641.
LIN J., HONG J. & XIAO Y. , 2017. Dynamic characteristics of 100% cold recycled asphalt mixture using asphalt emulsion and cement. *Journal of Cleaner Production,* 156**,** 337-344.
NEEDHAM D. , 1996. Developments in bitumen emulsion mixtures for roads.
NIAZI, Y. & JALILI, M. 2009. Effect of Portland cement and lime additives on properties of cold in-place recycled mixtures with asphalt emulsion. *Construction and Building Materials,* 23**,** 1338-1343.
ORUC S., CELIK F. & AKPINAR M. V. , 2007. Effect of cement on emulsified asphalt mixtures. *Journal of Materials Engineering and Performance,* 16**,** 578-583.
PONCINO H., ANDRESI R. & MARTINEZ F. A , 1993 , laboratory and field study of factors affecting the behaviour of emulsified asphalt mixes. First World Congress on Emulsions, Paris. 4-40.

SCHMIDT, R., SANTUCCI, L. & COYNE, L. , 1973, Performance characteristics of cement-modified aspahlt emulsion mixes. Association of Asphalt Paving Technologists Proc.

SORB , 2003. GENERAL SPECIFICATION FOR ROADS AND BRIDGES. State Orgnization of Roads and Bridges, Ministry of Housing and Construction, Iraq.

THANAYA I., 2003. *Improving the performance of cold bituminous emulsion mixtures (CBEMs): incorporating waste.* University of Leeds.

THANAYA I., ZOOROB S. & FORTH J. A , 2009 , laboratory study on cold-mix, cold-lay emulsion mixtures. Proceedings of the Institution of Civil Engineers: Transport. Institution of Civil Engineers, 47-55.

YAN J., LENG Z., LI F., ZHU H. & BAO S. , 2017. Early-age strength and long-term performance of asphalt emulsion cold recycled mixes with various cement contents. *Construction and Building Materials,* 137**,** 153-159 .