Rutting Resistance of Cold Bituminous Emulsion Mixtures (CBEMs) with Acrylic (AR) Polymer

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Abstract

Rutting is one a distress that commonly occurs in flexible pavement, mainly due to exceedingly heavy axle loads, high ambient temperature, and insufficient paving materials quality. Dealing with the last reason of rutting, the paper aims at investigating rutting resistance of Cold Bituminous Emulsified Mixture (CBEMs) with Acrylic (AR) polymer. CBEMs were prepared with Ordinary Portland Cement (OPC) and conventional mineral filler (CMF) as a filler for its recognition benefit when introduce to CBEM. Acrylic (AR) polymer emulsified was added to a cationic medium setting emulsified bitumen, with various dosages ranged from 0% to 5% of residual bitumen, to obtain a modified asphalt emulsion that was mixed with a local aggregate in order to prepare CBEMs. Also, it is intended to make a comparison between CBEMs, for the same circumstances of local aggregates and different types of filler, with the Hot Mix Asphalt (HMA).

Marshall test is conducted to investigate the stability and flow of different mixes in the scope of the research. Further, Wheel track device connected to a computer system is used to measure rutting depth that indicates the expected rutting resistance. The results demonstrated a significant effect for AR polymer adding, where the rutting resistance for CBEMs comprising OPC is improved for almost all dosages, but the 1.25% recorded as the best one. It is worth to mention that the new polymer modified CBEM offers rutting resistance better than that of HMA, which sustain the possibility of replacing the common environment harmful paving technology by sustaining one.

Keyword :- Acrylic (AR),Cold Bitumen Emulsion Mixtures(CCBEMs) Polymar , Rutting Resistance , Wheel Track Test (WTT).

الخلاصة

التخدد هو احد انواع الاضرار الشائعة الحدوث في الرصف المرنة وينتج بصورة رئيسية من تجاوز الاحمال المحورية العالية جدا، درجة الحرارة العالية للجو وعدم جودة نوعية مواد الرصف. وهذا البحث يهدف الى تقييم مقاومة التخدد لخلطات المستحلب البتيوميني الباردة مع اضافة الاكريليك بوليمر. حيث تم تحضير خلطات المستحلب البتيوميني الباردة مع الاسمنت البورتلاندي الاعتيادي و الفلر المعدني العادي ؛ لتميز فوائد نوعية المادة المالئة في تحسين خلطات المستحلب البتيوميني الباردة.كما تم اضافة مستحلب الاكريليك بوليمر الى مستحلب كاتايوني اسفلتي متوسط الاسقرار لتحسين المستحلب الاسفلتي مع نسب مختلفة (٠ −٥%) كنسبة من البتيومن المتبقي ، ثم الخلط مع الركام المحلي لتحضير خلطات المستحلب البتيوميني الباردة. وذلك للمقارنة بين خلطات المستحلب البتيوميني الباردة تحت نفس الظروف للركام المحلي وانواع الفلر المختلفة مع الخلطة الحارة.

تم التقييم بأستخدام فحص مارشال بمعياري الثبات والزحف للخلطات المختلفة ضمن نطاق البحث. وايضا استخدم جهاز مسار العجلة المربوط مع نظام الحاسوب لقياس عمق التخدد الذي يشير الى مقاومة التخدد المتوقعة. وقد بينت النتائج التأثير المهم لهذه لاضافة (البوليمر) في حين مقاومة التخدد لخلطات المستحلب البتيوميني الباردة المتضمنة الاسمنت البورتلاندي الاعتيادي كانت الافضل وضمن كل النسب ، لكن نسبة (% ١.٢٥ بوليمر) سجلت النسبة الافضل. ومن الجدير بالذكر أن البوليمر الجديد المعدل لخلطات المستحلب البتيوميني الباردة يوفر أفضل مقاومة التخدد مما يحافظ على إمكانية استبدال تقنيات الرصف الشائعة الضارة للبيئة بتقنية اخرى مستدامة.

الكلمات المفتاحية :- الاكريليك ، الخلطات الباردة للبتيومن المستحلب ، البوليمر، مقاومة التخدد، اختبار عجلة المسار.

1- Introduction

Transfer to more sustainable paving technology these days become global need. Of course, the current best practice in HMA technology reaches to mature stages in terms of mechanical performance characteristics. Nevertheless, such technology associates high-energy consumption and in its turn high CO_2 emissions; further to other shortcomings like: safety, cost, and hauling distance (Redelius *et.al.*, 2016). Therefore, several tries have been worked to overcome on these shortcomings with alternative technologies, such as Warm Mix Asphalt (WMA) and Cold Mix Asphalt (CMA)(Nassar *et.al.*, 2016;Tutu and Tuffour, 2016; Rubio *et.al.*, 2012; Al-Busaltan *et.al.*, 2012). CMA is a compound of low viscosity bitumen, and mineral aggregate prepared at ambient temperature. The bitumen viscosity is decreased by either fluxing hard grade asphalt with oil to obtain cut back asphalt, or by emulsifying bitumen to produce bitumen emulsion, or by foaming process to produce foamed bitumen. However, CMA and more specific Cold Bitumen Emulsion Mixture (CBEM) have be proven as a sustainable paving technology, in term of CO_2 emissions and low energy for preparations, further to its cost effectiveness (Al-Busaltan *et.al.*, 2012). CBEMs are produced from blending the aggregate particles, pre wetting water and bitumen emulsion with or without additives at ambient temperature. Unfortunately, such mix has low mechanical performance in early stage life, thus numerous of researchers attempt to overcome this defect. Whereas, different techniques were used; such as filler types (Al-Busaltan *et.al.*, 2012;Thanaya, 2007; Al Nageim *et.al.*, 2012), reinforcement, compaction efforts(Thanaya, 2007, Ibrahim, 1998), and introduce of polymers(Chávez-Valencia *et.al.*, 2007; Warid *et.al.*, 2015). Also, this mixture

The use of polymer modified asphalt (PMA) is not a new concept. Polymer modifier was utilized in hot mix asphalt to enhance both the rutting and thermal cracking problems of HMA by changing the properties of the asphalt binder (Albritton et al., 1999). In pavement, PMBs demonstrate more resistance to rutting distress and low temperature cracking, and reduced fatigue damage, stripping and susceptibility of temperature, which used with success in the high stress locations; such as intersections of busy streets, airports, vehicle weigh stations, and race tracks (King *et.al.*, 1999). Normally, polymer modified asphalt are extra viscous from untreated asphalt and tend to demonstrate better adhesive binding to aggregate particles (Deb, 2012). As comparison with untreated bitumen emulsion or hot applied polymer modified asphalt, Polymer Modified Bitumen Emulsion (PMBE) has numerous benefits. Whereas, emulsifying of polymer modified asphalt make on a dried the film of asphalt binder consequence it is extra uniform and has a better distribution of polymer which can enhance the binder properties, especially ability of the binder to advance consistent cohesion strength and enhance the stone retention (Forbes *et.al.*, 2001).

At this time, modification technology by polymer modifier is utilized with emulsified binder such as bitumen emulsion for enhance its performance, durability characteristic, and physical properties. Furthermore, PMEA shows enhancements in decreased costs of life cycle and distress on flexible pavement when compared to unmodified asphalt emulsions. Additionally, PMEA has many advantages compared with unmodified emulsion asphalt which can summarize as follows (Johnston and Gayle, 2009; Donald, 1986):

- Enhance the resistance to thermal cracking damage and rutting deformation.

- Enhance the resistance to the occurrence of bleeding.
- Enhance the fatigue resistance characteristics.
- Enhance the resistance to retention of the aggregate particles.
- Faster time to open the road after constructions or repair.
- Increase the pavement lifespan with same cost of equivalent, as a result of reduction in fatigue and thermal cracking, decreasing in high temperature susceptibility (e.g., rutting and shoving).

2-Materials

In this research, local materials were utilized as far as its available to ensure economic aspect and investigate the possibility of using the new mix of local applications. These materials included:

2.1 Virgin Aggregate

Virgin aggregates were supplied from local Karbala quarries. The selected gradation was for surface (wearing) layer gradation type IIIA according to; General Specification for Roads and Bridges, section R9 (GSRB, 2003), as demonstrates in Figure 1.This gradation was special for HMA, and adopted here because no local standard gradation for CBEM until now. The adopted gradation and its limits, which can be classified as dense grade, such approach was used recently by different local studies (Joni and Hashim, 2017; Al-Mishhadani and Al-Baid, 2014).

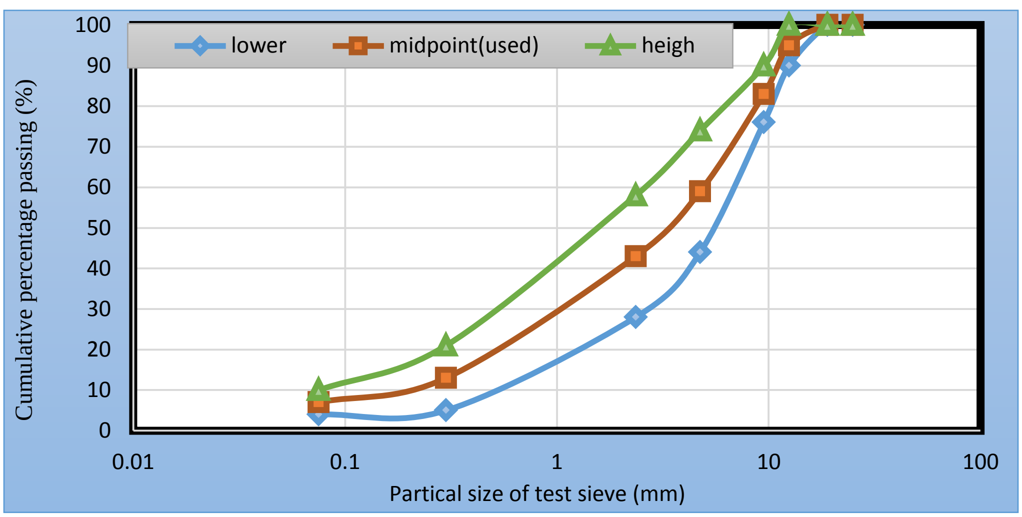

Figure 1 Particle Size Distribution of the Used Gradation

2.2 Filler

Conventional Mineral Filler (CMF) and Ordinary Portland Cement (OPC) were utilized as fillers in this work, where their properties are explicated in Table 1. CMF was supplied from aggregate crushing plant, which is a by-product of crushing process. While, OPC was supplied from Karbala cement Plant. The morphological properties of the two fillers are shown it Plate 1.

Table 1 Physical and Chemical Properties of OPC and CMF

Physical Testing		
Property	**Type of Utilized Filler**	
	CMF	**OPC**
Specific Surface Area of Filler (m^2/kg)	225	410
Density of Filler (gm./cm^3)	2.61	2.98
Chemical Testing (XRF)		
SiO2	81.15	24.910
Al2O3	3.78	2.324
Fe2O3	١.٩٢	١.١٢٥
CaO	6.37	64.148
MgO	٢.٩٠	١.٣٢٦
K2O	0.73	0.760
Na2O	٠.١٩	١.٧١٤

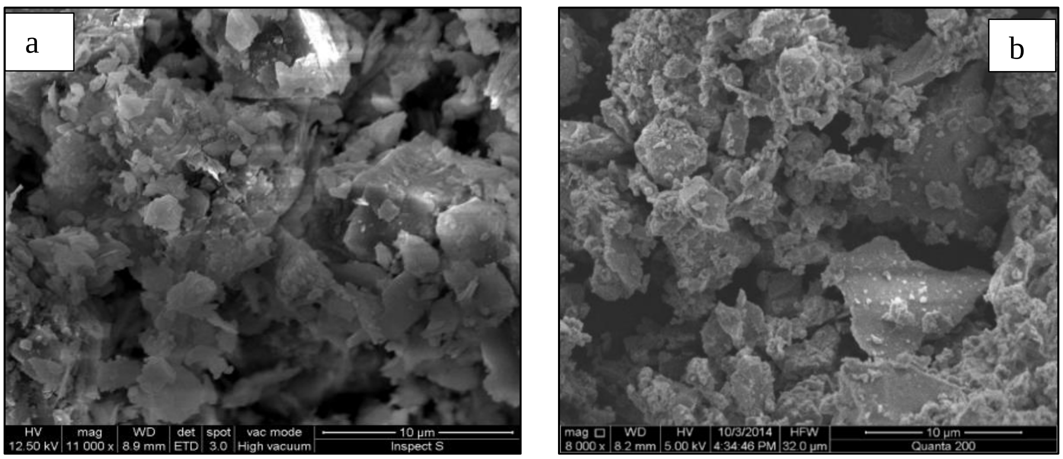

Plate 1 SEM of Fillers the Used: (a) CMF, (b) OPC (Ahmed, 2017)

2.3 Bitumen Emulsion

Bitumen emulsion was medium setting emulsion, which is manufactured by Henkel Company (beneath the commerce name “POLYCOAT”) with characteristics are detailed in Table 2.

Table 2 Characteristic of Bitumen Emulsion

Property	Specification	Limits	Results
Emulsion type	ASTM D2397	Rapid, medium and slow-setting	Medium- setting (CMS)
Color appearance			Dark brown liquid
Residue by Evaporation, %	ASTM D6934	Min. 57	٥8
Specific gravity, gm/cm^3	ASTM D70		1.05
Penetration, mm	ASTM D5	100-250	230
Ductility, cm	ASTM D113	Min. 40	42
Viscosity, rotational paddle viscometer 50 ℃ , mPa.s	ASTM D7226	110-990	220
Freezing	ASTM D6929	Homogenous, broken	Homogenous

Solubility in Trichloroethylene,%	ASTM D2042	Min. 97.5	97.7
Emulsified asphalt/job aggregate coating practice	ASTM D244	Good, fair, poor	Fair
Miscibility	ASTM D6999		Non-miscible
Evaluating Aggregate Coating	ASTM D6998		uniformly and thoroughly coated

2.4 Acrylic Polymer (AR)

Acrylic polymer supplied from local market and manufactured by Conmix Company with properties show in Table 3. This type of polymers was selected and for the first time to investigate it significant in improving CBEM, such polymer was used successfully to improve concrete mixture(Aggarwal *et.al.*, 2007;Wang and Shi, 2014). Plate 2 demonstrates the used acrylic polymer emulsified.

Table 3 Properties of utilized acrylic polymer

Property	Test Method	Standard limits	Results of Test
Component	-	Single	Single
Form	-	Liquid	Liquid
Colour	-	Milky white	Milky white
Specific gravity	ASTM D1475	1.02 kg/Lr +/-0.05	1.06 kg/Lr
Viscosity 25C°	-	100 ± 50 cps	125 cps
Percent of the solid	-	49.0 ±1.0%	49

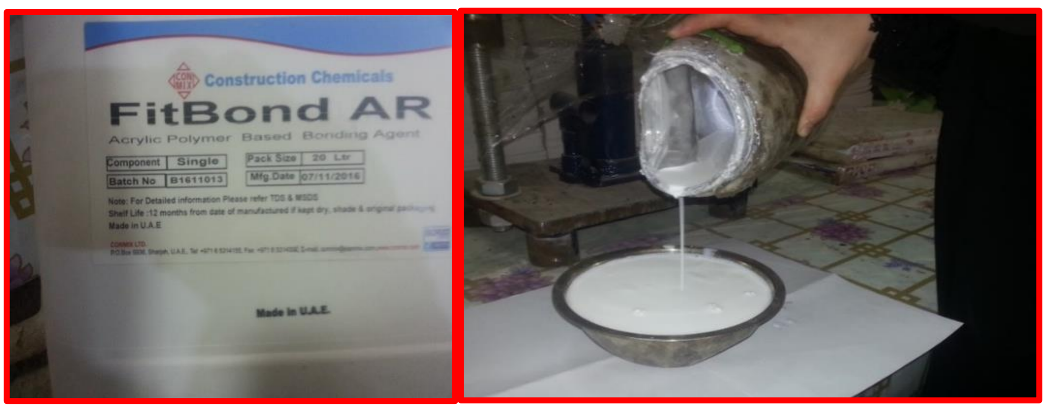

Plate 2 Acrylic Polymer

3- Experimental Program, Test Conditions and Methods

3.1 Experimental Program

The experimental program was designed to accommodate the main aim of the study, which is developed further enhancement of rutting resistance for CBEM comprising OPC by introducing of Acrylic polymer. However, the specimens were prepared under the following objective:

- Preparing HMA with two type fillers (OPC and CMF) for compression purpose to detect the effect filler types on HMA rutting resistance in one side, and HMA and CBEM in other side.

- Preparing CBEM with two type fillers (OPC and CMF) for compression purpose to detect the effect filler types on CBEM rutting resistance.
- Evaluating the variation in rutting resistance of CBEM due to the addition of Acrylic polymer to emulsion bitumen with existence of OPC as a filler, to detect the effect of introducing of Acrylic polymer. Four percentages were used which ranged from 1.25 to 5% with incremental of 1.25% of bitumen residue.
- Thus the mixtures matrix is as demonstrated in Table 4

Table 4 Abbreviations of The designation Names for Asphalt Mixtures

No.	Mix abbreviation	Mix details
1.	HMA-CMF	Hot Mix Asphalt comprising Conventional Mineral Filler
2.	HMA-OPC	Hot Mix Asphalt comprising Ordinary Portland Cement
3.	CBEM-CMF	Cold Bitumen Emulsion Mixture Comprising Conventional Mineral Filer
4.	CBEM- OPC	Cold Bitumen Emulsion Mixture Comprising Ordinary Portland Cement
5.	CBEM-OPC-1.25%AR	Cold Bitumen Emulsion Mixture comprising Ordinary Portland Cement and 1.25% (of bitumen residue) Acrylic polymer
6.	CBEM-OPC-2.5%AR	Cold Bitumen Emulsion Mixture comprising Ordinary Portland Cement and 2.5% (of bitumen residue) Acrylic polymer
7.	CBEM-OPC-3.75%AR	Cold Bitumen Emulsion Mixture comprising Ordinary Portland Cement and 3.75% (of bitumen residue) Acrylic polymer
8.	CBEM-OPC-5%AR	Cold Bitumen Emulsion Mixture comprising Ordinary Portland Cement and 5% (of bitumen residue) Acrylic polymer

3.2 Specimens preparation and Conditioning

In this study, the CBEM specimens were prepared according to the design method that adopted by Asphalt Cold Manual MS-14 (Asphalt, 1989). Marshall Method for emulsified asphalt-aggregate cold mixture design and some adjustments which associate to Iraqi specification; GSRB section R9 (GSRB, 2003). Marshall specimens were prepared to select optimum bitumen emulsion of CBEMs from Marshall stability and flow, which utilized for design the new CBEMs as surface course.

The specimen's preparation comprising several steps as follows:

- Firstly, coating test was examined the coating ability of bitumen emulsion to the aggregate particles which is extremely sensitive to the pre-wetting water content particularly when the aggregate gradation includes of fine aggregate with high proportion.
- The lowest percentage for pre-mixing water content was selected visually as started in MS-14 (Asphalt, 1989), by examine various pre-mixing water contents. According to characteristics of the adopted materials, pre-wetting water content was noticed to be 3.5% for CBEM-OPC; the optimum bitumen emulsion content was 12 % for OPC, consequently optimum total liquid content was 15. % for OPC. The associated percentages for CBEM-CMF were 3%, 12%, and 15%, respectively.

- Mixing machine was used for mixing aggregate, filler and pre-wetting water for 1 min. after that, emulsion bitumen was added slowly throughout additional 1 min of mixing.
- The specimens were compacted with 75 blows on each side by using Marshall Hammer for Marshall specimens. While vibratory compaction for 3 min was used for wheel track specimens. The preparation and compaction were achieved at lab temperature (20 – 25°C).
- The specimens of Marshall test are left for 24hrs. at 25 ºC before demolding then cured at 40 ºC for additional 24 hrs. before test is conducted. While the specimens of wheel track test are left for 24hrs. at 25 ºC before demolding then cured at 40 ºC for additional 14 days before test is conducted.

3.3 Test Methods and Conditions

The test methods and their conditions that used in this study are presented as follow:

3.3.1 Marshall Test

This test is utilized to evaluate the resistance to plastic flow due to load application in perpendicular direction to the cylindrical axis of cylindrical specimens of asphalt mixture. This test utilized to determine the optimum asphalt content for HMA according to ASTM D6927 (ASTM, 2015). Whereas, MS-14 was adopted for CBEMs with some modifications according to Iraqi specification GSRB,R9 (GSRB, 2003). Table 5 demonstrates the parameters for this test.

Table 5 Marshall test conditions according to ASTM D6927(ASTM, 2015)

Parameter	Standard limits	Used Value for CBEM
required number of specimens	3	3
load application rate, mm/min	50 ± 5	50
accuracy of measuring device,N	Min. 0.01	0.01
temperature of test, ºC	60 ± 1	60
diameters of specimen, mm	101.6-101.7	101.6
thickness of specimen, mm	63.5 ± 2.5	63.5 ± 2.5
Compaction, Marshall hammer	75x 2	75x2
Specimen conditioning pre-test in water bath (or an oven), min	30-40 (120-130)	30
Curing		24 25°C in mold+24@ 40°C

3.3.2 Wheel Track Test (WTT)

This test is used for assess the rutting resistance for bitumen mixture. The testing specimens were prepared with dimensions 300x165x50 mm. The test method is described in the BS specification BS EN 12697-22 (BSI, 2003). The testing conditions are shown in Table 6. This method is specified for HMA, while it can be adopted for CBEMs with little variation in curing system. For this purpose full curing system utilized as second stage, full curing time can be obtain by 14 day @40ºC as recommended by Thanaya (2003). Plates 3 , 4 demonstrate the apparatuses for wheel track device and computer system for wheel track device.

Table 6 Test Conditions for Wheel Track Testing

Parameter	Standard Limits	Used value for CBEM
No. of required specimens	2	1
Diameter of rubber wheel, mm	200±2	200
rubber wheel width, mm	50	50
No. of **wheel pass per min.**	50 ∓5	50
wheel s**peed of wheel, m/s**	Max. 0.305	0.305
wheel l**oad** , N	700∓10	700
Specimen thickness, mm	38 to 100	50
Specimens' a**ir void content** , %	4 or 7	7 % as critical case
Test temperature, **ºC**	60 ± 2	60
Specimens type	Slab/beam or Cylinder	slab
Specimen dimensions, mm	320 X 260 X 50	300x165x50 mm
Compaction time,min	Depended on the required air void 7% as critical case	3

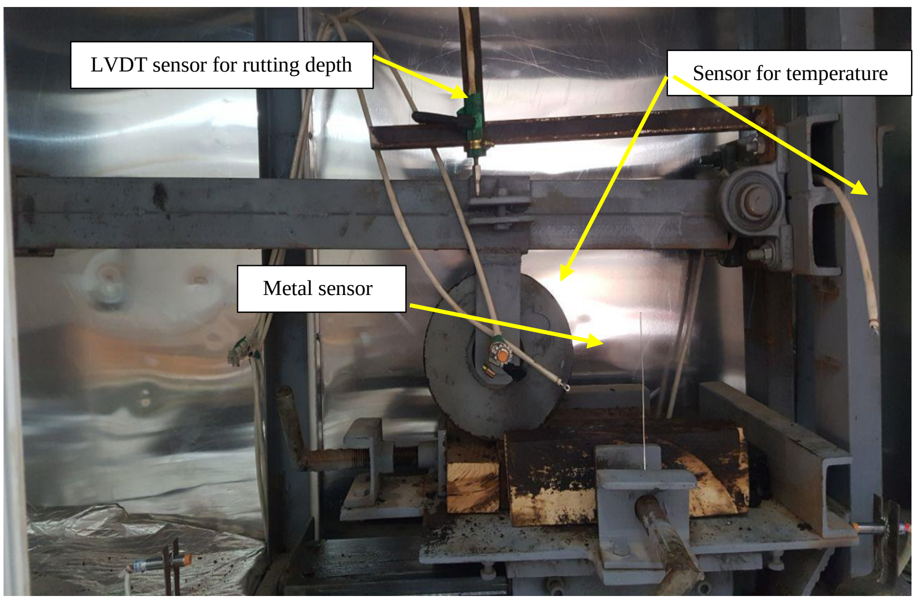

Plate 3 Apparatuses for Wheel Track Device

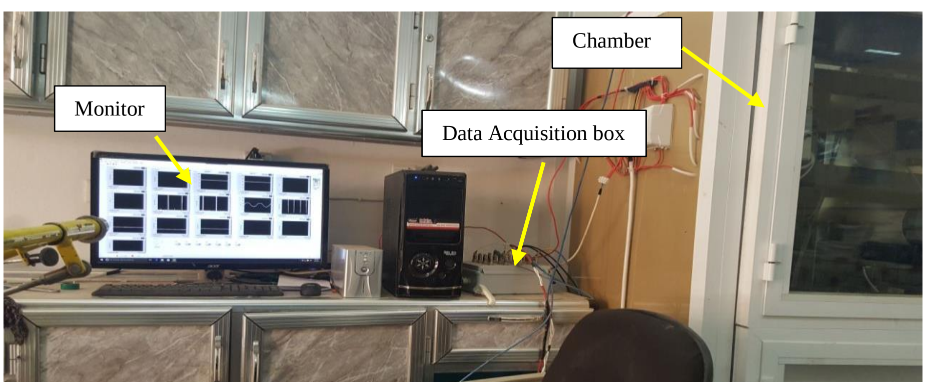

Plate 4 Computer System for Wheel Track Device

Results and Discussion

4.1 Marshall Test Results

In contrast to filler type, the results present the significant effect of OPC over CMF in HMA, which is mainly because the fineness, particle morphology and cementing effect of the OPC, as can be noticed from Table 1 (specific surface area) and Plate 2 (agglomerated morphology). Whereas, these two properties facilitate stiffer mastic that connect the bigger aggregate particles, and reflect on Marshall stability. Using OPC as filler with CBEMs results in increasing stability by around four times of that in case of using conventional mineral filler (CMF), as shown in Figure 2.

On the other side, the results demonstrate that the AR polymer with OPC filler could enhance Marshall stability, and percentage of 1.25% AR results in the best enhancing effect that shows an increase of 15 % and 5% than that of CBEMs with OPC and conventional HMA respectively, as shown in Table 7. This increase in stability could be results of cross-linking characteristics of polymer and enhance both primary and secondary binding characteristics. Whereby, maximum stability values of modified CBEMs – OPC- AR at 1.25% AR polymer has almost more than Marshall stability of conventional HMA.

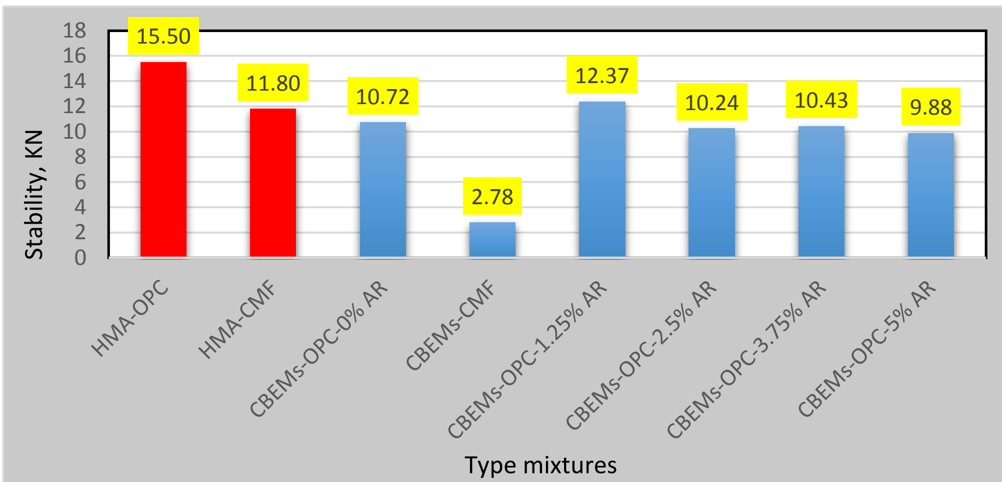

Figure 2 Marshall Stability

Furthermore, the results showed that using OPC as filler with CBEMs results in decreasing flow by around one-half times of that in case of using conventional mineral filler (CMF), as shown in Figure 3.

On the other side, the results demonstrate that the AR polymer with OPC filler could enhance Marshall flow, and percentage of 1.25% AR results in the best enhancing effect that shows a decrease of 25 % than that of CBEMs with OPC while it is decrease of 4% to the flow of conventional HMA, as shown in Table 7. This decrease in flow could be a result of crosslink and polymer elastic characteristics, which reflected on the binder. It made CBEMs more flexible, which can be stretched without noticeable permanent deformation, and return immediately to its normal form after deloading.

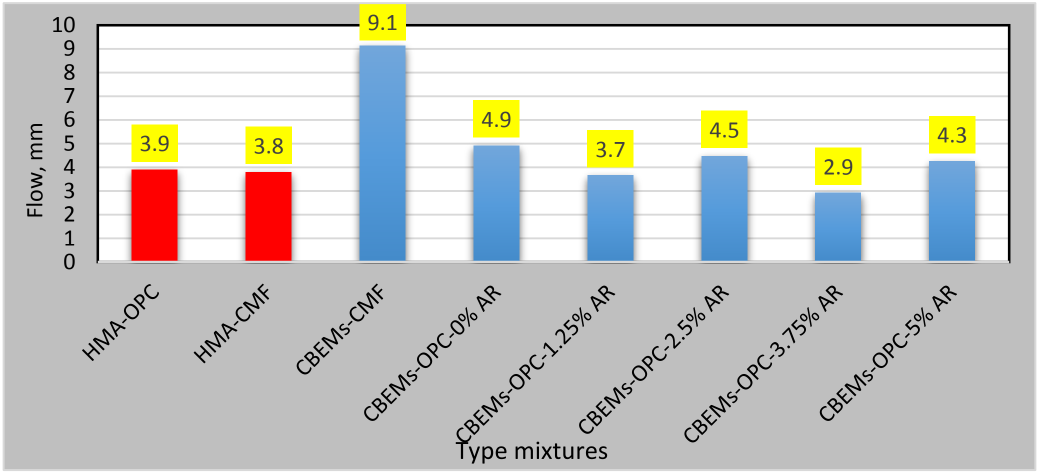

Figure 3 Marshall Flow for asphalt mixtures

Table 7 Percentages Change in Marshall Stability (Δ MS) and Marshall Flow (Δ MF) Relative to Reference Mixture

Reference Mixture	CBEM – OPC -0.00% AR		CBEM – OPC -1.25% AR		CBEM– OPC -2.50 % AR		CBEM – OPC -3.75 % AR		CBEM – OPC -5.00 % AR	
	ΔMS	ΔMF	ΔMS	ΔMF	ΔMS	ΔMF	ΔMS	ΔMF	ΔMS	ΔMF
HMA	-9.15	29.3	4.9	-3.6	-13.2	17.7	-11.6	-23.2	-16.3	12.1
CBEM-CMF	285.0	-46.1	344.3	-59.8	267.9	-51.0	274.4	-68.0	254.6	-53.3
CBEM-OPC	0	0	15.4	-25.4	-4.4	-50.9	-2.8	-68	-7.9	-53.3

The stability – flow curves are plotted for each percentage of AR polymer, and compared with unmodified mix as illustrated in Figure 4. The results show that the CBEM-CMF is looked very weak (high strain with low stability strength), also no clear failure point. Introducing OPC to CBEM improves it behavior significantly. While, CBEMs with OPC and AR polymer have different behavior compared to CBEM-CMF and CBEM-OPC. Grades of CBEM-OPC-AR were higher, and load failure points are clear noticed. High grades line is incorporated with increase in ductility, i.e. CBEM-OPC-1.25% AR has high ductility value compared to other mixtures. In other words, due to AR introducing, the ability of resisting applied load improve in its magnitude, also the ability to recover the strain is improved too. Which both are a good indication of the improvement of the developed mix to resist permanent deformation.

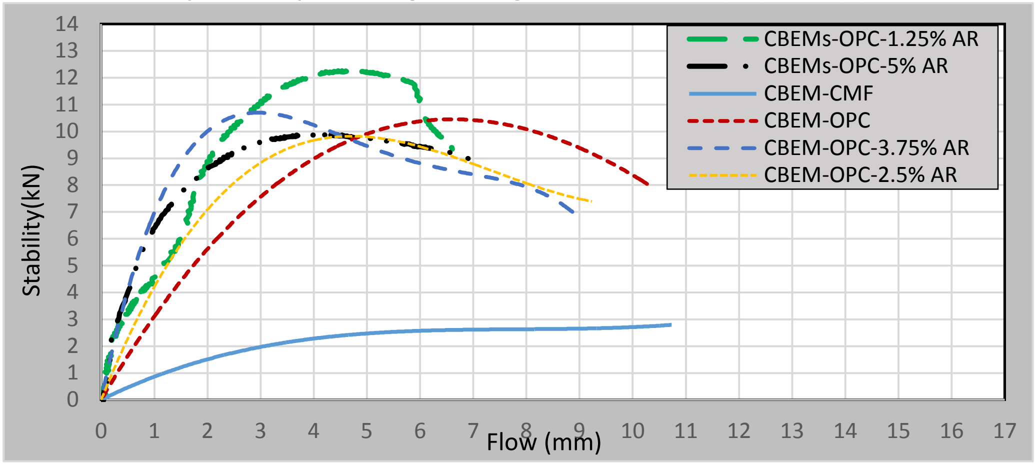

Figure 4 Stability-Flow curves for CBEM comprised OPC and AR content compared with CBEMs-CMF

4.2 Wheel Track Test

Wheel track test results reveal the facts of the inferiority of CBEM-CMF in contrast to HMA, the superiority of OPC filler in contrast to CMF in HMA, and the significant of introducing OPC in CBEMs. All these facts can be interpreted as explained previously for the stability behavior of such mixes.

On the other hand, Almost AR polymer added extra improvements to CBEMs-OPC in terms of resistance to permanent deformation. The results demonstrate in Figure 5 showed that the optimum value of the rutting resistance for CBEM-OPC-1.25% AR is recognized to be higher than from other percentages. The rutting depth reduce about 90% and 93% in contrast to conventional HMA and CBEM-CMF, as shown in Table 8. This is could be because the elastomer polymers as AR polymer have high response of elastic characteristic consequently it can withstand the rutting performance via ability to stretch and recover their normal form after the load is removed. Also, addition of OPC to CBEMs formed a secondary binder. Dynamic stability of CBEMs –OPC-1.25% AR is higher than conventional HMA and CBEM-CMF by about 800 % and 1080%, respectively, as can be seen in Figure 6. Such indication sustains the fact of the ability of AR polymer in improving the rutting resistance of modified CBEM.

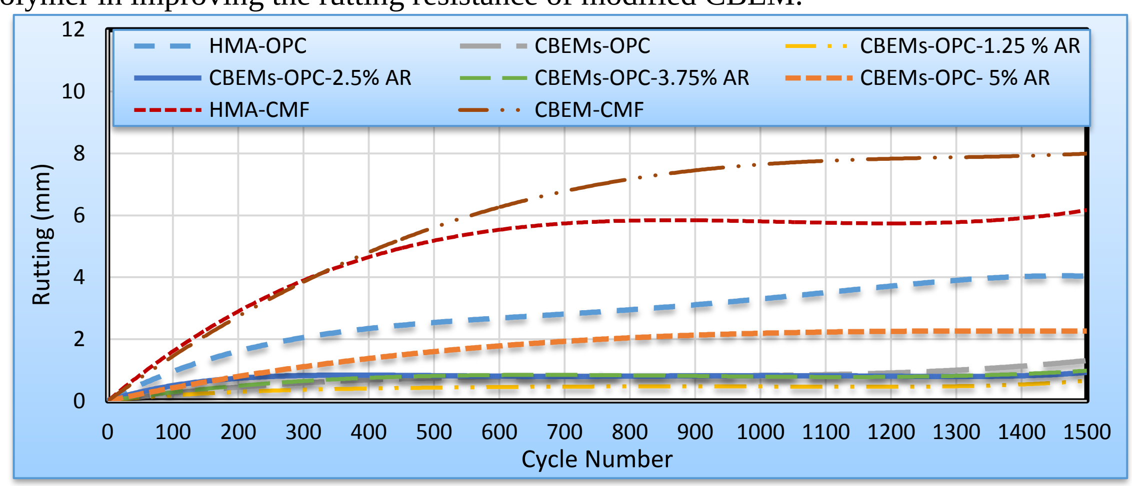

Figure 5 Rutting Depth verse Cycle Number for CBEMs comprising OPC-AR polymer

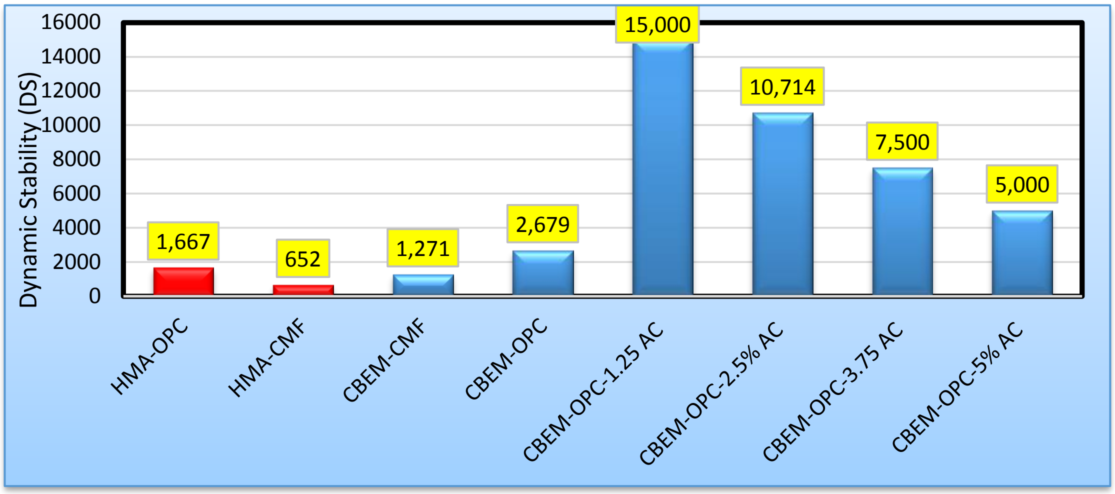

Figure 6 Dynamic Stability for CBEMS Comprising OPC-AR polymer

Table 8 Percentages Change in Rutting Depth (Δ RD) and Dynamic Stability (Δ DS) Relative to Reference Mixture

Reference Mixture	CBEM–OPC -0.00% AR		CBEM – OPC -1.25% AR		CBEM– OPC -2.50 % AR		CBEM– OPC -3.75 % AR		CBEM– OPC -5.00 % AR	
	ΔRD	Δ DS	ΔRD	Δ DS	ΔRD	Δ DS	ΔRD	Δ DS	ΔRD	Δ DS
HMA	-79.0	310.7	-90.3	2200.0	-84.7	1542.8	-83.9	1050.0	-62.9	666.6
CBEM-CMF	-83.8	110.7	-92.5	1080.0	-88.1	742.9	-87.5	490.0	-71.3	293.3
CBEM-OPC	0	0	-53.8	460.0	-26.9	300.0	-23.1	180.0	76.9	86.7

Conclusions

From the above results, it can be concluded that:

1. The addition of OPC to CBEM exhibits a significant effect on Marshall Stability (MS) and Marshall Flow (MF) for CBEMs. However, from the stability flow relation this fact proven clearly
2. The addition of OPC to CBEM exhibits a significant effect on the rutting resistance for CBEMs, in terms of measured rut depth via wheel track device.
3. AR polymer can add further improvement to CBEM-OPC. The experimental lab work reveals that the optimum percentage of AR polymer for modified was 1.25% by weight of residual asphalt. This percentage caused the maximum expected increase in Marshall Stability, and rutting resistance.
4. Maximum dynamic stability for CBEM comprising OPC and AR polymer was included with maximum resistance for rutting. Which give further proven to the gained improvements.

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