Kufa Journal of Engineering
Vol. 6, No. 2, June, P.P.49-62
Received 22 March 2015, accepted 28 April 2015

INFLUENCE OF SELECTED ADDITIVES ON WARM ASPHALT MIXTURES PERFORMANCE

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ABSTRACT

Warm Mix Asphalt (WMA) is a technology that allows significant lowering of the mixing and compaction temperature of conventional Hot Mix Asphalt (HMA). This research presents the results of laboratory tests conducted to evaluate the properties and performance of warm mix asphalt. The WMA has been prepared from two asphalt grades and one aggregate source with two additives (Aspha-min® and Sasobit®). The crumb rubber is also added to WMA which is prepared with Aspha-min® and Sasobit® to evaluate effect of crumb rubber on WMA properties. The results of the study indicated that the two additives to the warm asphalt affected the mixture properties differently. When the mixture properties were compared, it was observed that Aspha-min® reduced the indirect tensile strength and resilient modulus values of the mixes, the two WMA additives increased the rut depths of the mixes, and both the additives reduced the tensile strength ratio of the mixes. WMA contains crumb rubber appears

KEY WORDS: Aspha-min®, indirect tensile strength, indirect tensile resilient modulus, indirect tensile fatigue, rut depth, Sasobit®, crumb rubber and warm mix asphalt (WMA).

تأثير انواع مختارة من المضافات على اداء الخلطات الاسفلتية الدافئة

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الخلاصة

تقنية الخلطات الاسفلتية الدافئة يسمح بتخفيض درجات حرارة المزج والحدل للخلطات الاسفلت الحارة التقليدية . هذا البحث يقدم نتائج التجارب المختبرية المعدة لتقييم خواص واداء للخلطات الاسفلتية الدافئة. الخلطات الاسفلتية الدافئة .تم تحضير الخلطات الاسفلتية الدافئة من صنفين من الاسفلت و مصدر واحد من الركام بالاضافه الى مضافين هما (ASPHA-MIN® و SASOBIT®) . تم اضافه فتات مطاط للخطات الاسفلتية الدافئة التي تحضيرها مسبقا من (ASPHA-MIN® و SASOBIT®) لتقييم تاثير فتات المطاط على خواص الخلطات الاسفلتية الدافئة. نتائج الدراسة اوضحت ان تاثير مختلفا للمضافات على خواص الخلطات الاسفلتية الدافئة. من خلال مقارنة خواص الخلطات يمكن ملاحظة ان المضاف (ASPHA-MIN®) قلل من مقاومة الشد الغير مباشر و معامل الرجوع كما ان المضافين يزيدان من عمق التخدد و كلا المضافين يقللان نسبة مقاومة الشد للخلطات.

1. INTRODUCTION AND BACKGROUND

Asphalt mixtures could be classified into different categories such as hot mix asphalt (HMA), cold mix asphalt and warm mix, which is less common than the others (Akisetty, 2008). The author reported that hot mix asphalt properties are much better than cold mix asphalt. Therefore, HMA is mainly used for a pavement with high volume traffic (Larsen et al., 2004). Moreover, the temperature of the mix depends mainly on the type of mix and grade of binder. In general hot mix asphalt properties are much better than cold mix asphalt so HMA is being used for the higher volume traffic. The type of mix and grade of any binder largely governs the temperature of the mix (Larsen et al. 2004). To overcome some of these problems, a study conducted by Kolo Veidekke suggested the asphalt mix at somewhat lower temperatures than conventional HMA that was called as warm asphalt (Koenders et al., 2000). The warm mix asphalt (WMA) is an asphalt mixture which is mixed at temperatures lower than conventional hot mix asphalt. Typically, the mixing temperatures of warm mix asphalt range from 100 to 140 °C compared to the mixing temperatures of 150 to 180 °C for hot mix asphalt (Australian Asphalt Pavement Association, 2001 and Prowell et al., 2007).

Probably due to their relatively higher prices of fossil fuels and asphalt, Europe (Koenders et. al, 2000), South Africa (Jenkins et al., 2002), and Australia (AAPA, 2001) began early to examine the benefits and performance of WMA. Although WMAs have been used in the USA in 2002, they are being evaluated at a rapidly increasing rate.

There is no need for a major plant modification to the existing HMA plant system in order to obtain WMA. The WMA technologies are original and the manufacturing processes are various from the others (*NCAT*, *FHWA*). Aspha-min® could be defined as a fine powder. This powder releases its hydration bound water and creates foaming to asphalt binder, the lubricating action keeps the mix workable at a temperature range between 130-140 °C (Jones, 2004). Sasobit® contains the organic additives which are mixed with asphalt binder, which melts at about 100 °C and these chemically change the temperature -viscosity behavior of the asphalt binder. So the workability of the mix is acceptable at a low temperature of 90 °C (Jones, 2004).

The rutting resistance of HMA and WMA mixtures (as measured using the Asphalt Pavement Analyzer, APA) was more linked to the aggregate type than to the WMA technology (Xiao et al., 2010). The Sasobit® additive yielded the lowest rut depths, whereas the mixes containing Aspha-min® and Evotherm have APA rutting characteristics similar to the control HMA mixtures. On the other hand, Jones et al., (2010) reported that the use of WMA technologists will not significantly influence rutting and fatigue performance. However, they found no significant difference in the level of moisture sensitivity between the control HMA and the WMA mixtures.

In general, there are two categories of crumb rubber mix asphalt: the wet process and the dry process. The wet process is the most efficient in improving properties of an asphalt mixture (Takallou et al., 1991). Crumb rubber is known to absorb liquids and swell, depends on the temperature and viscosity of the liquids it is absorbing (Gawel et al., 2006). The interaction of the rubber particles with the asphalt can be affected by several factors such as temperature and type of mix, rubber size and texture, and chemical composition of the asphalt (Mathias et al., 2003).

2. AIM OF THE STUDY

In light of the above, various binder properties and warm asphalt additive type affect the performance of the warm mix such as the moisture susceptibility, rutting potential and fatigue life. So a thorough understanding of the properties and performance of the warm mixture technologies is necessary in order to be able to implement WMA safely, especially since WMA is a relatively new topic in Iraq, and no thorough research has been conducted to investigate many aspects of warm asphalt. The current study aims to evaluate the influence of selected two additives (Aspha-min® and Sasobit®) on the warm mix asphalt properties and performance (the indirect tensile strength, rutting, and potential fatigue life and moisture susceptibility).

3. EXPERIMENTAL WORK

3.1. Materials

The experimental part of this study has been conducted using control mixture (without any WMA additives) and two commercially available WMA additives (Aspha-min® and Sasobit®).The materials used in this work, namely asphalt , aggregate , fillers were characterized using conventional tests and results were compared with State Corporation for Roads and Bridges specifications (SCRB, R/9,2003).
Asphalt cements 40/50 and 60/70 brought from Daurah refinery with the physical properties given in Table 1 were used within this research. The aggregate used in this work was crushed quartz obtained from Al-Nibaie quarry .The coarse and fine aggregates used in this work were sieved and recombined in the proper proportions to meet the type IIIA mixes of wearing course gradation as required by SCRB specifications (SCRB, R/9,2003). The gradation for the aggregate is shown in Table 2. Routine tests were performed on the aggregate to evaluate their physical properties. The results together with the specification limits as set by the SCRB are summarized in Table 3. Test results show that the chosen aggregate met the SCRB specifications.

Table 1. Properties of used asphalt cement

Property	ASTM Designation	Test Results		Requirements Penetration –Graded Asphalt Cement	
				(40/50)	(60/70)
1.Penetration at 25 ^{o}C , (0.10mm)	D5	48	66	40-50	60-70
2. Ductility at 25 ^{o}C , (cm)	D113	110	120	>100	>100
3.Specific gravity at 25 ^{o}C	D70	1.03	1.01	------	-----
4.Flash point ,(^{o}C)	D92	275	249	>232	>232
5.Solubility in trichloroethylene, (%wt)	D2042	99.37	99.26	>99	>99
6.Residue from thin –film oven test - Retained penetration , % of original -Ductility at 25 ^{o}C, (cm)	D1754 D5 D113	68 57	61 73	>55 >25	>52 >50

Table 2. Selected mix gradation for the type IIIA mixes of wearing course

Sieve	19 mm	12.5 mm	9.5 mm	No.4	No.8	No.50	No.200
% Passing	100	95	83	59	43	13	7

The filler is a non- plastic material that passing sieve No.200 (0.075 mm). In this work, the asphalt mixes were prepared using limestone dust as mineral filler at a content of 7 percent; this content represents the mid-range set by the SCRB specifications for the type III A mixes of wearing course. The limestone dust was obtained from lime factory in Karbala governorate, south east of Baghdad. The chemical composition and physical properties of the fillers are presented in Table 4 below.

Table 3. Physical properties of aggregates

Property	ASTM Designation	Test results	SCRB specifications
Coarse aggregate			
Bulk specific gravity	C 127	2.614	….
Apparent specific gravity	C 127	2.686	….
Percent wear by Los Angeles abrasion , %	C131	22.7	30 Max.
Soundness loss by sodium sulfate solution,%	C88	3.4	12 Max.
Flat and elongated particles ,%	C 4791	5	10 Max.
Degree of crushing, %	D5821	96	90 Min.
Fine aggregate			
Bulk specific gravity	C127	2.664	….
Apparent specific gravity	C127	2.696	….
Sand equivalent, %	D2419	57	45 Min.
Angularity ,%	C1252	54	….
Clay lumps and friable particles, %	C142	1.85	3 Max.

Table 4. Properties of limestone dust filler

Chemical Composition, %						Physical Properties		
Cao	Sio_2	Mgo	Fe_2o_3	So_3	L.O.I	Specific gravity	Surface area (m^2/kg)	% Passing sieve No.200
68.3	2.23	0.32	---	1.20	27.3	2.41	244	94

Aspha-min® and Sasobit® were utilized as WMA additives in this work. Aspha-min® powder is a sodium–aluminum–silicate crystal, which is hydrothermally crystallized into fine powder. The addition of Aspha-min® (containing 21% water by weight) into the warm mix causes the release of all the crystalline water and forming a very fine water spray and a volumetric expansion of bitumen. This volume expansion will increase the workability and the compatibility of the mixture at lower temperatures (Hurley et al., 2005).

Sasobit® is a Sasol Wax company production and is a fine crystalline, long-chain aliphatic polyethylene hydrocarbon extracted from coal gasification using the Fischer–Tropsch (F–T)

process. Sasobit® forms a homogenous solution with the base bitumen when mixed at a rate of 1.5% by weight of the bitumen, and reduces the bitumen viscosity. It is completely soluble in asphalt at temperature higher than 98 and it has ability to reduce the viscosity of asphalt .This can reduce the workability temperature by 15 – 55 ^{o}C (Hurley et al., 2005).
Crumb rubber (CR) was brought from tires factory in Al-Najaf governorate, which is a black, large size pieces casting to a small size in the laboratory with specific gravity (1.16). Crumb rubber that has been subjected to treatment by heat, pressure or by addition of softening agents after grinding to alter physical and chemical properties of the recycled material. In this study single particle size of crumb rubber retained on mesh the No.50 (0.300 mm). The process of mixing crumb rubber with asphalt used in this study is the wet process, in which crumb rubber is added to the asphalt before introducing it in the warm mix asphalt. CR will be directly blended with asphalt in blending machine for 60 minutes at 150 ^{o}C temperature. After mixing, the asphalt with CR was allowed to cool to room temperature for 24 hours before being reheated for testing. The warm asphalt mix was prepared with the concentrations of 15 and 20% by the weight of asphalt cement for 66 and 48 penetration grade respectively.

3.2. Asphalt mixtures code

Six asphalt mixture types of different combinations of asphalt type and additive type are coded as shown in Table 5.

Table 5. The code for the six asphalt mixture types

Asphalt mixture code	Description
HMA48	Control mix 48 penetration grade asphalt
HMA66	Control mix 66 penetration grade asphalt
WMA48AS	Warm mix asphalt 48 penetration grade asphalt , Aspha-min® additive
WMA66AS	Warm mix asphalt 66 penetration grade asphalt , Aspha-min® additive
WMA48SS	Warm mix asphalt 48 penetration grade asphalt , Sasobit aditive
WMA66SS	Warm mix asphalt 66 penetration grade asphalt , Sasobit addive
CWMA48 AS	Warm mix asphalt 48 penetration grade asphalt , Aspha-min® additive and crumb rubber
CWMA66 AS	Warm mix asphalt 66 penetration grade asphalt , Aspha-min® additive and crumb rubber
CWMA48 SS	Warm mix asphalt 48 penetration grade asphalt , Sasobit aditive and crumb rubber
CWMA66 SS	Warm mix asphalt 66 penetration grade asphalt , Sasobit additive and crumb rubber

3.3. Sample preparation

Following the aggregate gradation, they have been stored in different buckets. Aggregates were heated at the temperature of 125 ^{o}C for 6 hours in the oven prior to mixing process. The asphalt grade 40/50 or 60/70 was selected as the binder for this study. The binder was kept in the oven for 2 hours at 150 ^{o}C prior to mixing process. To produce WMA mixtures by the dry process, WMA additive was added to the heated aggregate and manually stirred in bucket mixer and then asphalt was added All examined asphalt concrete mixtures were prepared in accordance to (ASTM Designation: D 1559-89) (ASTM, 2004) with the standard 75-blow Marshall design method for designing hot asphalt concrete mixtures, designated as using automatic compaction.

There is no standard specifications available for WMA mixing and compaction temperature in Iraq, the values were obtained from making trial mixes to get required properties such as 125-135 °C mixing temperature and 120-125 °C compaction temperature. The manufacturer of Aspha-min recommends 30 °C reduction in mixing and compaction temperature and Sasobit allows working temperatures to be decreased by 18–54 °C (Hurley and Prowell, 2005a; Hurley and Prowell, 2005b; Gandhi et. al, 2009; Kristjansdottir et al., 2007 and Xiao et al., 2010).

4. MARSHALL AND VOLUMETRIC PROPERTIES

The Marshall test was performed during the mix design according to the (ASTM Designation: D 1559-89) (ASTM, 2004). This test is performed at a deformation rate of 51 mm/min (2 inch/min) and a temperature of 60 ºC. The properties obtained from this test are the Marshall stability and flow. The Marshall stability of an asphalt mixture is the maximum load the material can carry when tested in the Marshall apparatus. The Marshall flow is the deformation of the specimen when the load starts to decrease. Stability is reported in (KN) and flow is reported in (mm) of deformation. Three specimens were tested and an average is reported and used in the analysis.

Marshall Properties at optimum asphalt content by weight of total mix and SCRB (SCRB, 2003) specifications for asphalt mixes used as a surface course are presented in Table 6.

Table 6. Marshall and volumetric properties of different asphalt mixture types

Mix type	Asphalt paving properties					
	Optimum Asphalt Content (%)	Marshall Stability (KN)	Marshall flow(mm)	Voids in total mix (%)	Voids in mineral aggregate (%)	Voids filled with asphalt (%)
HMA48	4.9	13.6	2.8	4.2	16.2	74.07
HMA66	4.7	10.3	3.1	4.1	15.9	74.21
WMA48AS	5.3	11.9	3.0	4.3	16.0	73.13
WMA66AS	5.2	9.8	3.2	4.0	14.9	73.15
WMA48SS	5.6	11.3	3.1	3.9	14.9	73.83
WMA66SS	5.5	9.2	3.4	3.8	15.2	75.0
CWMA48 AS	5.1	12.0	2.9	3.7	15.4	75.97
CWMA66 AS	5.0	10.4	3.1	3.6	15.6	76.92
CWMA48 SS	5.3	11.6	3.2	3.7	15.0	75.33
CWMA66 SS	5.2	9.7	3.3	4.1	15.7	73.88
SCRB specifications	(4-6)%	Min. 8 KN	(2-4) mm	3-5 %	Min. 14	(65-85)%

As reported in Table 6 that all properties of asphalt paving mixture are within SCRB specification (SCRB, 2003) requirements for surface course asphalt mixtures.

5. MECHANICAL BEHAVIOR TESTS

The mechanical behaviors of the polymer-modified and unmodified mixtures were evaluated based on the indirect tensile strength, indirect tensile resilient modulus, flexural beam fatigue and Hamburg Wheel-Tracking tests.

5.1. Indirect tensile strength test

The indirect tensile strength tests were conducted using the standard method designated by ASTM D 4123 (ASTM, 2004). The experimental procedure used to determine the tensile, or splitting, strength of a cylindrical specimen is based on loading it diametrically in compression to create a tension zone along the specimen's loaded diameter. The expression for the maximum tensile strength generated can be stated as:

$$\sigma_t = \frac{2P_{\max}}{\pi.H.D} \quad \textbf{(1)}$$

Where σ_t is the indirect tensile strength(kPa) , P_{max} is the maximum applied load(kN) , and H, D are the height and the diameter of the specimen(m) , respectively.

5.2. Indirect tensile resilient modulus test

The indirect tensile resilient modulus test is conducted at temperatures of 25ºC according to the modified ASTM D4123 (Mohammad and Paul, 1993). It is a repeated load indirect tension test for determining the resilient modulus of the asphalt mixtures. The recoverable horizontal deformation, ΔH was used to calculate the indirect tensile resilient modulus, MR in Equations 2.

$$M_R = \frac{P.(0.27+\mu)}{t.\Delta H} \quad \textbf{(2)}$$

Where:
M_R = Resilient Modulus, MPa
P = Applied vertical load, N
t = Sample thickness, mm
μ =Poisson's ratio (assumed 0.35 for asphalt concrete mixtures) , and
ΔH = Horizontal deformation, mm.

5.3. Flexural beam fatigue tests

The purpose of the flexural beam fatigue tests is to measure the fatigue behavior of the mixture. Pavements that are experiencing fatigue failure will suffer cracking caused by repeated traffic loading. These cracks occur in the wheel paths, initiating as longitudinal cracks and progressing to an alligator crack pattern. The results from a beam fatigue test can be used to provide an estimation of the number of wheel loads that can be carried by a pavement before fatigue cracking appears. In this study, the fatigue properties of the modified and unmodified asphalt mixtures were measured and compared.
Flexural fatigue testing was performed in accordance with AASHTO T 321-07(AASHTO,2007). Six specimens were tested for each mix: three each at 300 micro-strains at a temperature of 20 ± 0.5°C. The specimens were compacted in a kneading beam compactor, and then trimmed to the dimensions of 380 ± 6 mm in length, 63 ± 2 mm in width, and50 ± 2 mm in height. The target void content was 7 ± 1 percent. Data acquisition software was used to record load cycles, applied loads, strain levels and beam deflection. The software

calculates the beam stiffness in each a loading iteration. At the beginning of each test, the initial beam stiffness was calculated by the data acquisition software after 50 conditioning cycles. AASHTO T 321-07 (AASHTO,2007) was used to define beam failure as a 50% reduction in beam stiffness in terms of number of cycles until failure. Fatigue life relationship (power model) result in log strain applied (ε_t) versus N_f relationship plotted. This results in a relationship for fatigue tests of the form (Monismith et al., 1971).

$$N_f = K_1 \varepsilon_t^{-k2} \quad \textbf{(3)}$$

K_1= Fatigue constant value of N_f when ε_t=1
K_2= Inverse slope of the straight line the logarithmic fatigue relationship.
N_f= Number of repetition to fracture.

5.4. Hamburg wheel-tracking test

The Hamburg wheel tracking test was conducted using the latest version of APA in accordance with the testing procedures specified in AASHTO T324. Samples were submerged in the water bath controlled at 50±0.5 °C for a minimum of 30 min. A data acquisition system records rutting out to 20,000 wheel passes at 25 Hz and plots rut depth versus number of passes for each sample automatically. The target air-void content was 7 ± 0.5%.The WMA rut depth was slightly greater than the HMA rut depth; however, both were less than the commonly used criterion of 10mm at 20,000 passes.

5.5. Moisture sensitivity

To evaluate the moisture sensitivity of WMA mixtures, the modified Lottman test following AASHTO T283 (AASHTO, 2007) was performed. Six specimens (three for dry condition and three for wet condition) for each WMA mixtures, and the control HMA mixture were prepared. For dry conditioning, three specimens in a sealed pack were placed in the water bath at 25 °C for 2 hours and , for wet conditioning three specimens saturated between 70 % and 80% were placed in a freezer at -18 °C for 16 hours and in water bath at 60 °C for 24 hours followed by conditioning in water bath at 25°C for 2 hours. The moisture damage in asphalt mixtures is determined as a loss of strength due to the presence of moisture in terms of a tensile strength ratio (TSR) that is defined as a ratio of the indirect tensile strength of a wet specimen over that of a dry specimen.

6. DISCUSSION OF RESULTS

After implementing the above experimental works, five results have been obtained from the conduction of these experimental works. Firstly, Fig. 1 indicates the average results of the indirect tensile strength (ITS) test for the surface course mixtures with different types of mix. In general, the two control HMA demonstrates higher values for ITS than WMA mixtures. WMA66AS mixtures have lower strengths than the other mixture types wearing course mixes. However, this figure reveals all WMA mixtures give low tensile strength which shows lower resistance under tension stresses.

Fig. 2 represents the relationship between the indirect tensile resilient modulus (MR) of the surface course mixtures at 20 °C test temperature with different type of mixtures. The results

show minor differences among other mixtures. The HMA48 is the highest in the indirect tensile resilient modulus among other types. Whereas, the second level of difference which less in the tensile than the HMA48 comes with the WMA48SS and WMA48AS mixtures. The third level is WMA66SS and WMA66AS. On the hand , the addition of crumb rubber causes the relative increase in indirect tensile strength and resilient modulus of WMA .
The results of the flexural beam fatigue test for various mix types are presented in Fig. 3. While evaluating the fatigue resistance of asphalt concrete mixes, the numbers of cycles to failure are used as performance indicators. A high number of cycles to failure are the desired properties to resist fatigue cracking. From this figure, it is clearly shown there is no significant influence of additive types on fatigue life of WMA. However, fatigue life for two control HMA mixtures is more that of various WMA by about 50 % this conclusion contrasts with Jones et al., (2010). The difference between the current study and the other reported by Jones et al., (2010) could be resulted from the aggregate, asphalt and additive properties that have been used in preparing of WMA. On other hand, it was found that the asphalt grade has effect on fatigue life values of asphalt mixtures.

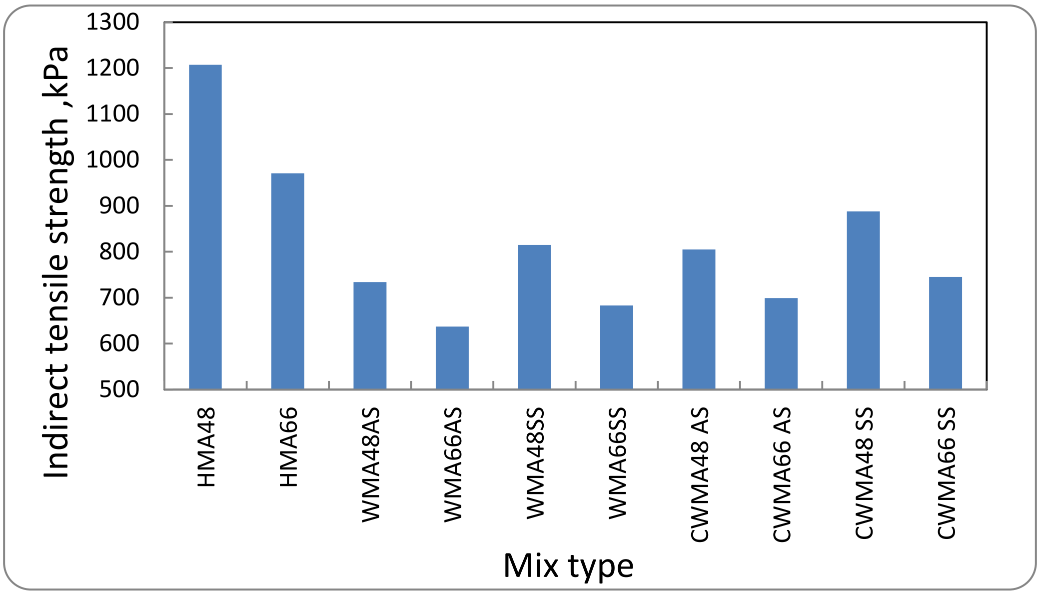

Fig. 1. Effect of mix type on indirect tensile strength values.

Fig. 4 illustrates the influence of the selected additives on rut depth. As it is clear from Fig. 4 the average rut depth of the WMA was higher than that of the HMA by about 75%**.** It can be concluded that the using of WMA in the construction of surface course for the pavement structure increases the rutting in comparison with using HMA. In addition, it can be observed for same asphalt type that there is no significance influence of additive types on rut depth values of WMA.

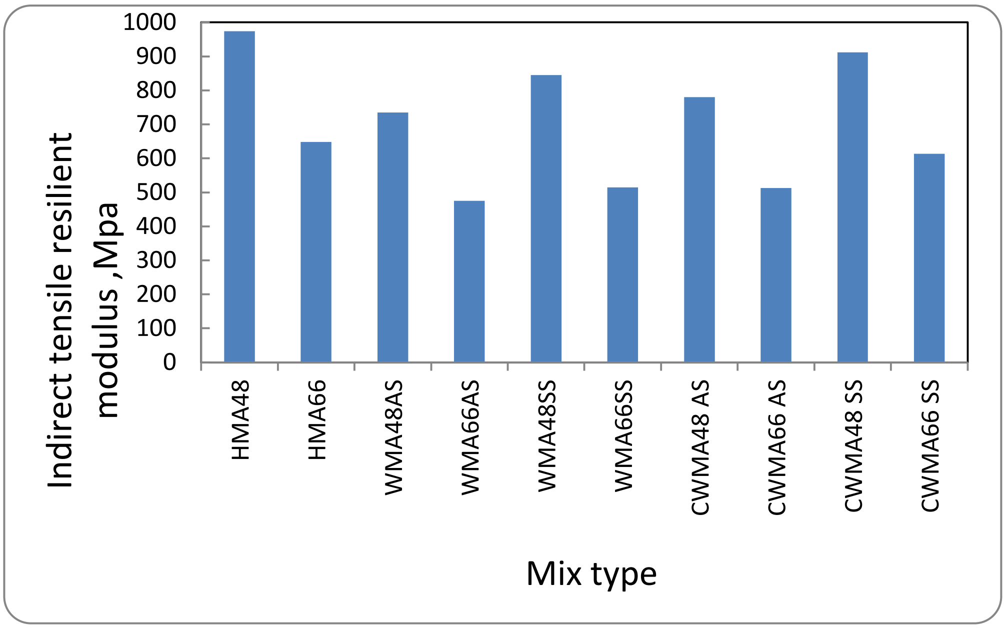

Fig. 2. Effect of mix type on indirect tensile resilient modulus values

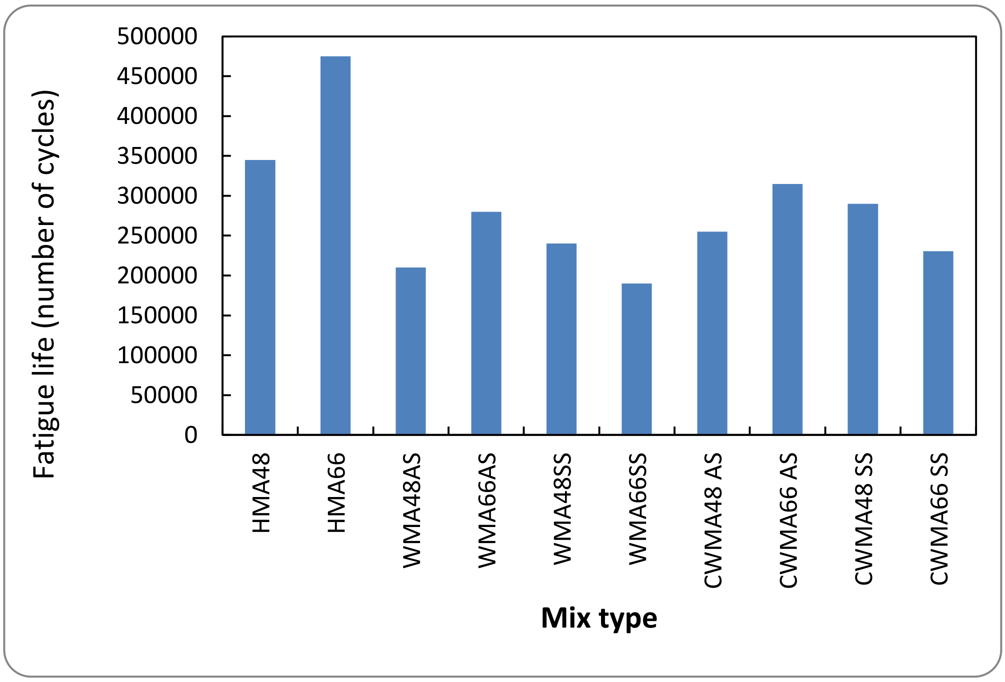

Fig. 3. Effect of mix type on indirect fatigue life values

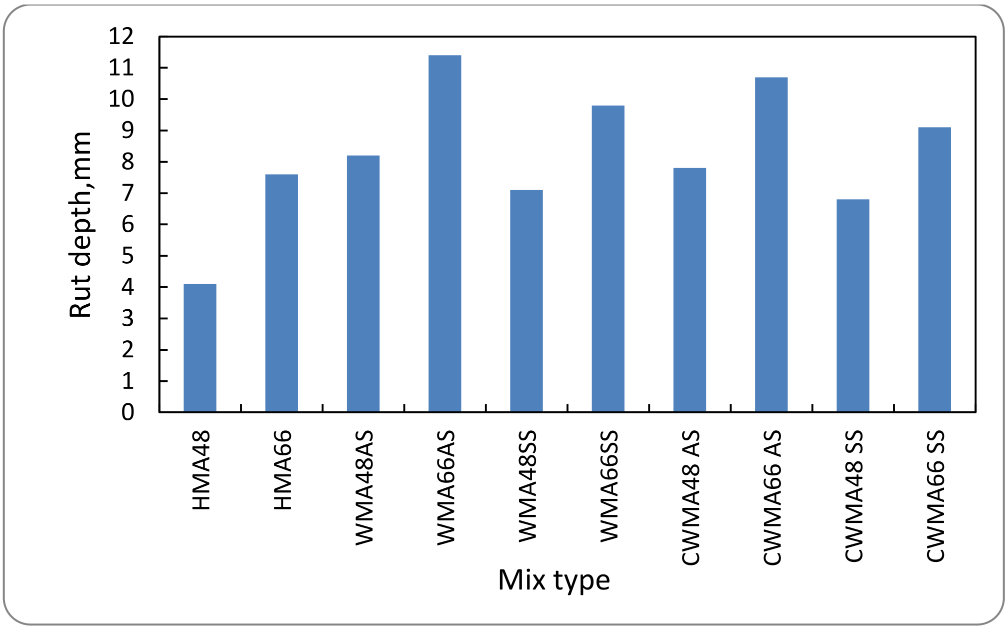

Fig. 4. Effect of mix type on rut depth values

Fig. 5 shows the tensile strength ratio (TSR) values in HMA and WMA, TSR gives an idea of moisture sensitivity of various mixtures.

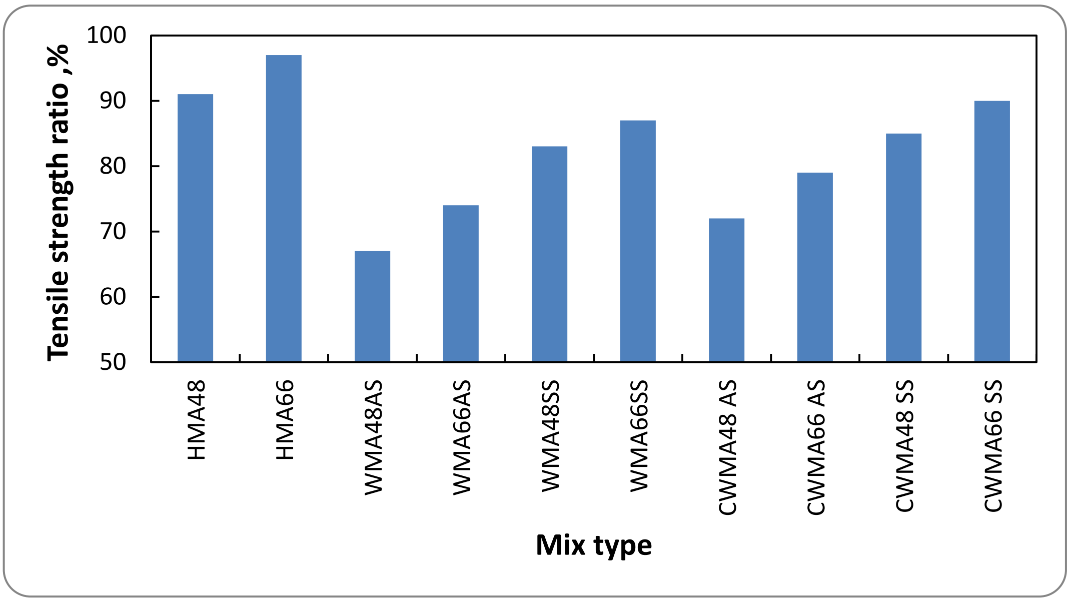

Fig. 5. Effect of mix type on tensile strength ratio

Almost control HMA and warm asphalt mixes got TSR higher than acceptable value of 80% except WMA66AS and WMASS exhibited TSR values of 67% and 74%, respectively. The WMA66SS mixture showed higher TSR among other warm asphalt mixtures. Lower temperatures used for preparing WMA can result in incomplete drying of the aggregates. The resulting trapped water in the coated aggregates may cause moisture damage. Care must be taken to monitor this. This could be attributed that the WMA mixes gives lower TSR values than for the HMA.

7. CONCLUSIONS

According to the above study, the main conclusions can be drawn as:

1. The values of indirect tensile strength (ITS) obtained from various WMA mixtures were lower than those of control mixtures, but in WMA prepared from Sasobit(WMA48SS,WMA66SS, CWMA48 SS and CWMA48 SS) ITS values were higher than those of the others. This means that the WMA appears low resistance to tensile stresses.
2. Laboratory measurements of indirect tensile resilient modulus (M_R) values indicated the various WMA exhibited lower values than those of control HMA.
3. The incorporation of WMA additives in warm asphalt mixes lead to reduction in the fatigue life as compared with the response of HMA.
4. The performance of warm mixture that contained Sasobit is better than that contained Aspha-min but the performance of HMA is relatively better than that of WMA.
5. Alternatively, introducing warm mix asphalt (WMA) is known to provide decreased optimum mixing and compaction temperatures of the rubberized mixes and expected to be comparable to those of conventional mixes. Also, the crumb rubber improved the properties of WMA by increasing the tensile strength , fatigue life and tensile strength ratio and decreasing rut depth as compared with WMA without crumb rubber.

REFERENCES

AAPA (2001) ,*Warm Mix Asphalt–A-State-of-the-Art Review*. Advisory Note 17, Australian Asphalt Pavement Association, Kew, Victoria, Australia, (http://www.aapa.asn.au/content/aapa/download/ AdvisoryNote17.pdf).

AASHTO, (2007), *Standard Specifications for Transportation Materials and Methods of Sampling and Testing.* 5 th edition , American Association of State Highway and Transportation Officials, Washington, D.C., USA.

ASTM Standards, (2004), *Roads and Paving Materials.* Annual Book of the American Society for Testing and Materials Standards, Section 4, Vol. 04-03.

D'Angelo, J., Harm ,E.,Bartoszek, J., Baumgardner ,G. ,Corrigan, M.,Cowsert,J.,Harman , T.,Jamshidi,M.,Jones, W.,Newcomb,D.,Prowell,B.,Sines,R. andYeaton, B. (2008) Warm-Mix Asphalt :European Practice . FHWA Report No.FHWA-PL-08-007 ,American Trade Initiatives , Alexandria ,Virginia.

Gandhi T, Xiao F, Amirkhanian SN (2009), *Estimating indirect tensile strength of mixtures containing anti-Stripping agents using an artificial neural network approach*. Int J Pavement Res Technol; 2(1):1–12.

Gandhi, T. and Amirkhanian, S. (2007), *Laboratory Investigation of Warm Asphalt Binder Properties – A Preliminary Investigation.* MAIREPAV5 Proceedings, Vol. 5, pp. 475-480, Park City, Utah.

Gawel , Irena, Stepkowski, Robert and Czechowski, Franciszek (2006), *Molecular Interactions between Rubber and Asphalt*. Industrial and Engineering Chemistry Research, Vol.45, pp.3044-3049.

Harrison, T., and Christodulaki, (2000) , *Innovative Processes in Asphalt Production and Application -Strengthening Asphalt's Position in Helping to Build a Better World.* Proceedings, First International Conference, World of Asphalt Pavements, Australian Asphalt Pavement

Hurley G, Prowell B. (2005a), *Evaluation of Aspha-Min for use in warm mix asphalt.* NCAT report 05-04. Auburn.

Hurley G, Prowell B. (2005b) ,*Evaluation of Sasobit for use in warm mix asphalt.* NCAT report 05-06. Auburn.

Jenkins, K.J., A.A.A. Molenaar, J.L.A. de Groot, and M.F.C. van de Ven (2002), *Foamed Asphalt Produced Using Warmed Aggregates.* Journal of the Association of Asphalt Paving Technologists. Volume 71, Colorado Springs, Colorado.

Jones , D. , C. Barros, J.T. Harvey , B.W.Tsai, R.Wu. (2010), *Preliminary Results from the California Warm Mix Asphalt Study*. Proceedings (CD), 89th Annual Meeting of the Transportation Research Board, the National Academies, Washington D.C.

Jones, W. (2004) Warm Mix Asphalt Pavements: Technology of the Future?. http://www.asphaltinstitute.org/Upload/_Fall_Mag_Warm_Mix_Asphalt_Pavements.pdf.

Koenders, B.G., D.A. Stoker, C. Bowen, P. de Groot, O. Larsen, D. Hardy, and K.P. Wilms (2000) ,Innovative Processes in Asphalt Production and Application to Obtain Lower Operating Temperatures. 2nd Eurasphalt & Eurobitume Congress, Barcelona, Spain.

Kristjansdottir O, Muench S, Michael L, Burke G. (2007) ,*Assessing potential for warm-mix asphalt technology adoption*. J Transport Res Board, vol (2040): 91–9.

Larsen, O., Moen, Ø., Robertus, C., and Koenders, B.(2004), *WAM Foam Asphalt Production at Lower Operating Temperatures as an Environmental Friendly Alternative to HMA.* In Proceedings of the 3rd Eurasphalt and Eurobitume Conference, Book 1, Foundation Eurasphalt, Breukelen, The Neterhlands, , Pp 641-650.

Maccarone, S., G. Holleran, and A. Ky (1994), *Cold Asphalt Systems as an Alternative to Hot Mix.* Proceedings, 9th International AAPA Conference, Surfers Paradise, Queensland, Australia. (http://asphalt.csir.co.za/FArefs/).

Mathias Leite L .F., Almeida da Silva , P. , Edel G., Goretti da Motta L. , and Herrmann do Nascimento L.A. (2003) ,*Asphalt Rubber in Brazil : Pavement Performance and Laboratory Study*. Proceedings of the Asphalt Rubber 2003 Conference , Brasilia , Brazil, pp.229-245.

Mohammad, L.N. and Paul, H. (1993) ,*Evaluation of the Indirect Tensile Test for Determining the Structural Properties of Asphalt Mix.* Transportation Research Record, No. 1417, TRB, National Academy of Science, Washington, D.C.

Monismith C.L., Epps, J. E., Kasianchuk , D., A.,McLean, D., B. (1971) , *Asphalt mixture behavior in repeated flexure.* Report TE 70-5, University of California, Berkeley.

NCAT (2005), *Evaluates Warm Mix, Asphalt Technology News*. National Center for Asphalt Technology, Auburn University, Vol.17, No.2.

Prowell, B., Hurley, G., and Crews, E. (2007) ,*Field Performance of Warm-Mix Asphalt at National Center for Asphalt Center for Asphalt Technology Test Track.* Transportation Research Record: Journal of the Transportation Research Board, No. 1998, pp. 96-102.

Rajagopal, A. (2004) ,*Comparison and Definition of State DOT's Practices in Selection of Materials for Pavements.* Final Report prepared in cooperation of The Ohio Department of Transportation and the Federal Highway Administration.

State Commission of Roads and Bridges (SCRB/R9), (2003) ,*General Specification for Roads and Bridges.* Republic of Iraq, Ministry of Housing and Construction, Department of Planning and Studies, Baghdad, Revised Edition, Addendum No.3.

Takallou H.B., Takallou M.B. (1991) , *Recycling Tires in Rubber Asphalt Paving Yields Cost, Disposal Benefits.* Elastomeric, Vol.123, pp.19-24.

Xiao , F., S.N. Amirkhanian , B.J.Putman (2010), *Evaluation of Rutting Resistance in Warm Mix Asphalts Containing Moist Aggregate.* Proceedings (CD), 89th Annual Meeting of the Transportation Research Board, The National Academies, Washington D.C.

Xiao F, Zhao W, Gandhi T, Amirkhanian SN. (2010) , *Influence of Anti-stripping Additives on Moisture Susceptibility of Warm Mix Asphalt Mixtures.* J Mater Civil Eng. 2010; 22(10):1047–55.