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EFFECT OF WARM ASPHALT ADDITIVE ON PAVEMENT PERFORMANCE

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Abstract: Warm mix asphalt (WMA) is mixed at temperatures ranging 20 – 50 °C lower than those in which called hot mix asphalt (HMA). The use of synthetic zeolites as a warm mix asphalt additive has exhibited many additional advantages, such as a reduced susceptibility to permanent deformation. However, there are also indications that the use of synthetic zeolites as a warm mix asphalt additive for some percentages increases the moisture sensitivity of pavements except for 5% there is a slightly improve. The results of the study indicated that the selected percentages of synthetic zeolite to the warm asphalt differently effected on the mixture properties. When the mixture properties were compared, it was observed that WMA with 3% of synthetic zeolite reduced the indirect tensile strength value, also the WMA mixture with 5 % of synthetic zeolite decreased the rut depth of the mixtures and slightly increased in the tensile strength ratio (TSR).

Keywords: *Indirect Tensile Strength, Synthetic Zeolite, Rut Depth, Warm Mix Asphalt (WMA), Asphalt Concrete, Superpave and Performance.*

تأثير إضافة الأسفلت الدافئ على أداء الرصف

الخلاصة: تخلط الخلطة الأسفلتية الدافئة (WMA) في درجات حرارة تتراوح بين 20 - 50 درجة مئوية أقل من تلك التي تسمى الخلطة الاسفلتية الساخنة (HMA). إن استخدام الزيوليت الاصطناعي كمضاف إسفلتي دافئ قد أظهر العديد من المزايا الإضافية ، مثل قابلية منخفضة للتشوه الدائم. ومع ذلك ، هناك أيضا مؤشرات على أن استخدام الزيوليت الاصطناعي كمضاف الأسفلت المزيج الدافئ لبعض النسب المئوية يزيد من حساسية الرطوبة للأرصفة باستثناء 5 ٪ حيث كان هناك تحسن طفيف. أشارت نتائج الدراسة إلى أن النسب المئوية المختارة من الزيوليت الاصطناعي إلى الأسفلت الدافئ تتأثر بشكل مختلف بخواص الخليط. عند مقارنة خصائص الخلطات ، لوحظ أن WMA بنسبة 3٪ من الزيوليت الاصطناعي قللت من قيمة قوة الشد غير المباشرة ، كما أدى خليط الـ WMA مع 5٪ من الزيوليت الاصطناعي إلى تقليل من عمق التخدد للخليط وزيادة طفيفة في نسبة مقاومة الشد (TSR).

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1. Introduction

Warm mix asphalt (WMA) is a new technology that allows asphalt to flow at a lower temperature for mixing, placing, and compaction than hot mix asphalt (HMA). This technology reduces energy consumption, carbon dioxide emission, asphalt oxidation and increases the paving season and hauling distance for a better working environment [1]. Several warm mix technologies are available for reducing asphalt mixing and compaction temperatures, thereby saving energy and reducing emission problems. Among the available technologies, the use of organic additives, such as commercial wax and mineral additives, such as synthetic zeolites, show great promise [2, 3]. Improved compaction was noted at temperatures as low as 88°C for both of these technologies (wax and zeolites) [4].

Results showed that lower plant temperatures can lead to a significant reduction, up to 30%, in energy consumption [5]. Moreover, reduction of production temperature leads to a reduction in pollution emission, making the WMA an environmental attractive material. According to previous studies, the reduction of emissions represents significant cost savings estimating that 30–50% of overhaul costs at an asphalt plant [6].

2. Experimental Work

2.1. Materials

In the experimental work, asphalt binder of 40⁄50 penetration grade from Daurah refinery in Baghdad, Iraq, was used its physical properties are shown in Table1.

The aggregate used in this work was crushed quartz supplied from Al-Nibaie quarry. Also the gradation for the aggregate is as shown in Table 2. 12.5 mm used as a nominal aggregate size. The results related with the specification limits set by the State Corporation for Roads and Bridges in Iraq (SCRB) are summarized in Table 3. Test results show that the chosen aggregate met the SCRB specifications.

The filler used in the experimental work is a non- plastic material that passing sieve No.200 (0.075 mm). The first type is the limestone dust which supplied from lime factory in Karbala governorate, south west of Baghdad. The second type is the Portland cement was provided from local market. The physical properties of the fillers are presented in Table 4.

Synthetic Zeolite used in this work was utilized as WMA additive is a hydrothermally crystallized white fine powder of sodium–aluminum–silicate crystal. It contains 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 [7]. This volume expansion will increase the workability and the compatibility of the mixture at lower temperatures [2, 3, and 7]. The additive percentages used in this study range from 3 - 7% by weight of the binder which was chosen based on the previous studies. The chemical composition and physical properties of the Synthetic Zeolite were prepared by the manufacturer as illustrated in Table 5.

2.2. Samples Preparation

The production of the WMA mixtures is by dry process, WMA additive was heated and added to the asphalt then mixed by mechanical mixer for one hour at 179 °C. The aggregate and asphalt were mixed in mixing bowl for several minutes until asphalt sufficiently coated the surface of the aggregates. The mixing temperatures corresponding to the asphalt binder. All examined asphalt concrete mixtures were prepared in accordance to the works in [8] and [10] with the standard 160 number of gyrations for designing hot asphalt concrete mixtures, designated as using superpave gyratory compactor [9, 10].

Table 1. The result of physical properties and standard limitation

Test	Test Conditions	Standard		Test value (measured)	Standard Limit according to SCRB /R9, 2003
Penetration	100 gm, 25°C, 5 sec., (0.1mm)	ASTM D5		47	40-50
Ductility	25°C, 5cm/min	ASTM D113		+120	+100
Softening Point		ASTM D36		53.5	
Specific gravity asphalt	25°C	ASTM D70		1.031	-----
Flash and fire points	…..	ASTM D92	Flash	291°C	> 232 °C
			Fire	305°C	-------
Loss on heating	163 °C, 50gm, 5 hr	ASTM D1754	Penetration	65	>55
			Ductility	55	>25
Rotational Viscosity	Pa.sec	ASTM D4402		0.369 @ 135ºC	
				0.112 @ 165ºC	

Table 2. Gradation of the aggregates.

Sieve size: Standard Sieves	Sieve size: English Sieves	Superpave Specification, 2007		Iraqi Specification (SCRB R9, 2003) surface layer type IIIA		% Passing
		Max	Min	Max	Min	
19mm	3/4"	100	--	100	--	100
12.5mm	1/2"	100	90	100	90	97
9.5mm	3/8"	---	90	90	76	86

4.75mm	No.4	---	---	74	44	60
2.36 mm	No.8	39.1		58	25	36
1.18mm	No.16	31.6	25.6	---	---	25
0.6mm	No.30	23.1	19.1	---	---	19
0.3mm	No.50	15.5		21	5	14
0.15mm	No.100	---	---	---	---	10
0.075mm	No.200	10	2	10	4	6

Table 3. Physical properties of aggregates

Property	ASTM Designation	Test results	SCRB specifications
Bulk specific gravity (Coarse agg.)	C 127	2.580	….
Apparent specific gravity		2.591	….
Bulk specific gravity (Fine agg.)	C 128	2.616	….
Apparent specific gravity		2.642	….
Percent wear by Los Angeles abrasion , %	C 131	21.3	30 Max.
Soundness loss by sodium sulfate solution,%	C 88	3.2%	12 Max.
Flat and elongated particles ,%	C 4791	2.5%	10 Max.
Degree of crushing, %	D 5821	97%	90 Min.
Sand equivalent, %	D 2419	89.6	45 Min

Table 4. Physical properties of Filler.

Property	Test Result
Portland Cement Filler	
Specific gravity	3.2
% Passing Sieve No.200 (0.075 mm)	97
Limestone Dust Filler	
Specific gravity	2.92
% Passing Sieve No.200 (0.075 mm)	94

Table 5. Physical properties and chemical structure of Synthetic zeolite.

Property	Test Result
Color	White
Shape	Powder
Diameter	325 Mesh
SiO_2	41.07 %
AL_2O_3	28.25 %
CaO	0.03 %
MgO	0.81 %
K_2O	0.21 %
Na_2O	0.05 %
Ti_2O	12.99 %
Bulk Density	0.5 gm/cm^3
PH	9.3
Water Content	21 %
Static H_2O Adsorption	25.9 %

2.3. Marshall and Volumetric Properties

The Marshall test was performed during the mix design according to the [10]. This test was performed at a temperature of 60 ºC and with a deformation rate equal to 51 mm/min (2 inch/min). The properties obtained from this test are the Marshall stability and Marshall Flow. The Marshall stability is define as the peak resistance load obtained during a constant rate of deformation loading sequence. The Marshall flow is the total sample deformation. Marshall Stability and Marshall Flow are reported in (kN) and in (mm) of deformation, respectively. Three specimens were tested and an average is reported and used in the analysis. Table 6. Shows the results of volumetric properties and the specification limits according to [12].

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

Type of filler	Dosage of Zeolite (%)	Marshall Stability (kN)	Marshall Flow (mm)	Voids in total mix (%)	Voids in mineral aggregate (%)	Voids fill with binder (%)	Bulk density (gm/cm^3)
Portland Cement	0	14.29	3.1	4.0	15.87	74.80	2.338
	3	13.50	3.9	4.1	15.64	74.42	2.330
	4	14.00	3.7	3.6	15.48	74.16	2.336
	5	15.70	3.1	3.2	15.47	74.14	2.338
	6	13.30	3.5	2.7	15.46	74.13	2.339
	7	11.83	3.6	2.4	15.38	73.99	2.342
Limestone	0	12.00	3.4	4.0	15.75	74.60	2.329
	3	11.10	4.0	4.2	15.38	73.99	2.325
	4	12.20	3.9	3.8	15.26	73.79	2.330

Dust	5	13.40	3.2	3.3	15.20	73.68	2.333
	6	11.90	3.6	2.8	15.18	73.65	2.335
	7	10.60	3.8	2.5	15.17	73.63	2.336
SCRB specifications		**Min. 8 kN**	**(2 –4) mm**	**(3 – 5) %**	**Min. 14**	**(65-85) %**	---

2.4. Indirect Tensile Strength Test

The Indirect Tensile Strength tests were performed according to the [11]. The experimental procedure was used to determine the tensile, or splitting strength of a cylindrical specimen, this test is based on diametrical loading configuration in compression to create a tension zone along the loaded specimen's diameter. The expression of the maximum tensile strength generated can be stated as:

$$\sigma t = \frac{2\,P_{max}}{\pi HD} \qquad (1)$$

Where:
σt is the indirect tensile strength (kPa),
Pmax is the maximum applied load (kN),
H and D: are the height and the diameter of the specimen (m), respectively.

2.5. Moisture Damage of Asphalt Mixtures

The moisture sensitivity of WMA mixtures was evaluated according to [13]. Six specimens were prepared (three for dry condition and three for wet condition) for each percent of WMA mixture and the control HMA mixture. For dry condition, the specimens in a sealed pack were placed in the water bath at 25 ^{o}C for 2 hours and, for wet condition, the specimens saturated between 55 % and 80% were placed in a freezer at -18 ^{o}C for 16 hours and in water bath at 60 ^{o}C for 24 hours followed by conditioning in water bath at 25 ^{o}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), which is defined as a ratio of the indirect tensile strength of a wet specimen over that of a dry specimen.

2.6. Wheel-Tracking Testing

The Pavement Wheel Tracker is a device for testing the wearability of asphalt mixes by simulating roadway conditions, the test is performed according to the [14]. The loaded wheel applies about 700 N (158 pounds) of load at contact points and passes repetitively over the sample for up to 10,000 cycles. In this study, compacted asphaltic slabs for rutting testing were prepared at air voids equal to (4%) using Roller Compactor Device according to the [14].and Superpave system [15].

The dimensions of the compacted slabs used in this work were of (400 mm x 300 mm x 50±6 mm) as proposed by [14]. The rut depth induced on the material with respect to the number of wheel passes raises. The testing temperature is around 50 or 60 °C. The WMA rut depth was slightly lower than the HMA rut depth; however, both were less than the commonly used criterion of 20mm at 20,000 passes [14-16].

3. Discussion of Results

After implementing the above experimental works, four results have been obtained from the conduction of these experimental works. Firstly, Fig. 1 indicates the average results of the indirect tensile strength (ITS) for the asphalt mixtures with different percentages of synthetic zeolite. In general, the WMA with 5% of synthetic zeolite demonstrates higher values of ITS than other mixtures. WMA with 3% of synthetic zeolite mixtures have lower strengths than the other mixture types wearing course mixes. However, some of WMA mixtures demonstrated low tensile strength which shows lower resistance under tension stresses, as shown in Fig. 1.

Fig. 2 illustrates the tensile strength ratio (TSR) values in HMA and WMA for two types of filler, TSR gives an idea of moisture sensitivity of various mixtures. Almost control HMA and warm asphalt mixes got TSR higher than the acceptable value of 80%. The WMA with 5% of zeolite mixture showed higher TSR than other warm asphalt mixtures. The Indirect Tensile Ratio for warm mixtures with Portland cement as a filler was higher than the mixtures with filler of limestone type. Accordingly, (ITS) for warm mix asphalt mixture, is found to be increased with decreasing air void content in a similar behavior that occurs with the conventional hot asphalt pavement. 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 may be attributed that the WMA mixes gave lower TSR values than for the HMA.

Fig. 3 illustrates the influence of the additives on the rut depth. As it is clear from Fig. 3 the average rut depth of the WMA with 5 percentage of zeolite was less than that of the HMA by about 45% for the mixtures that used cement as a filler. While for the mixtures that used limestone dust, it can be denoted that the rut depth of the WMA was lower than that of the HMA by about 48%. Zeolite addition to mix asphalt improved the resistance of wheel-tracking with regard to reference mix asphalt, despite decreasing the compaction temperature by 30 ^{o}C. It can be concluded that the using of WMA with limestone dust in the construction of surface course for the pavement structure is better than that used cement in comparison with using HMA.

Fig. 4. Shows that the Marshall Stability for different mixtures. All mixtures with filler of cement type were higher than that of the mixtures with filler limestone dust type. The increase in Marshall Stability for mixtures with Portland cement as filler type can be attributed to the cement would reacted with water released from Zeolite at first hours from mixing of mixture and developed hydration products which would reducing porosity and increasing the bond of cement. HMA and WMA got higher

Marshall Stability than the minimum acceptable value (8 KN) according to the State Corporation for Roads and Bridges in Iraq (SCRB) specifications.

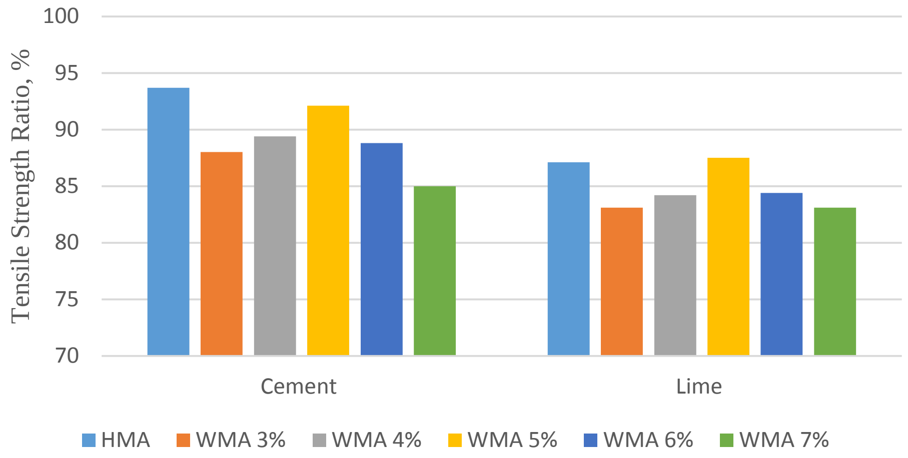

Figure 1. Indirect tensile strength for different asphalt mixtures.

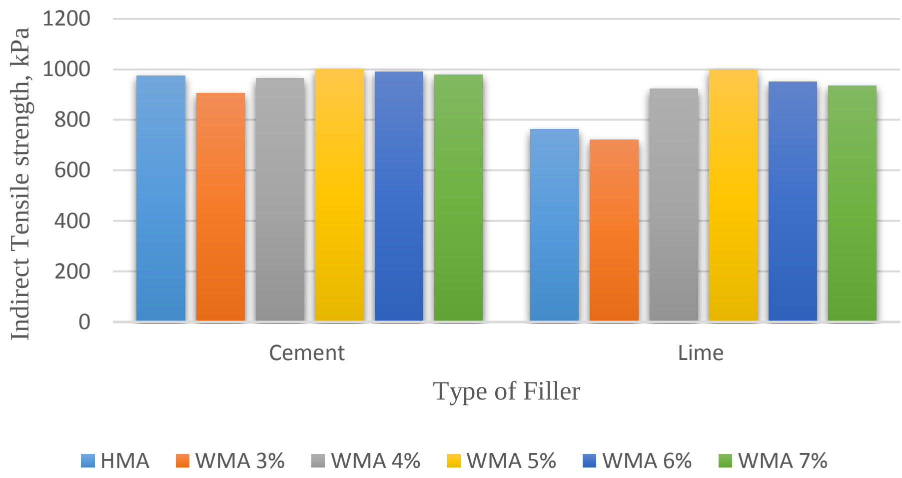

Figure 2. Tensile strength ratio for different asphalt mixtures.

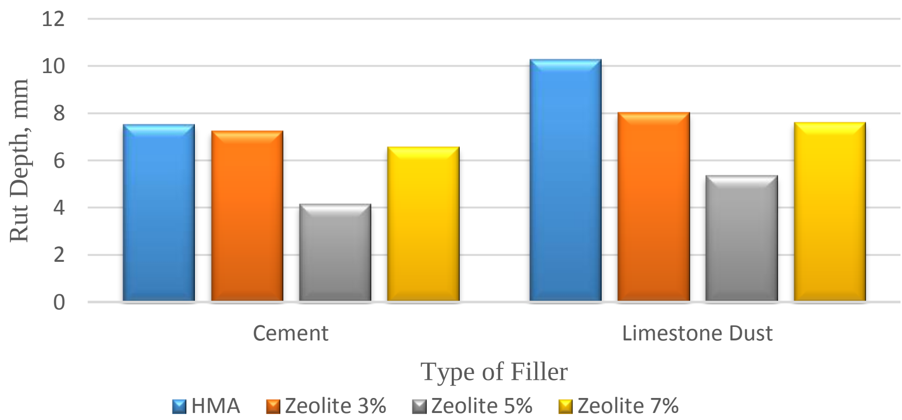

Figure 3. Effect of mix type on rut depth values

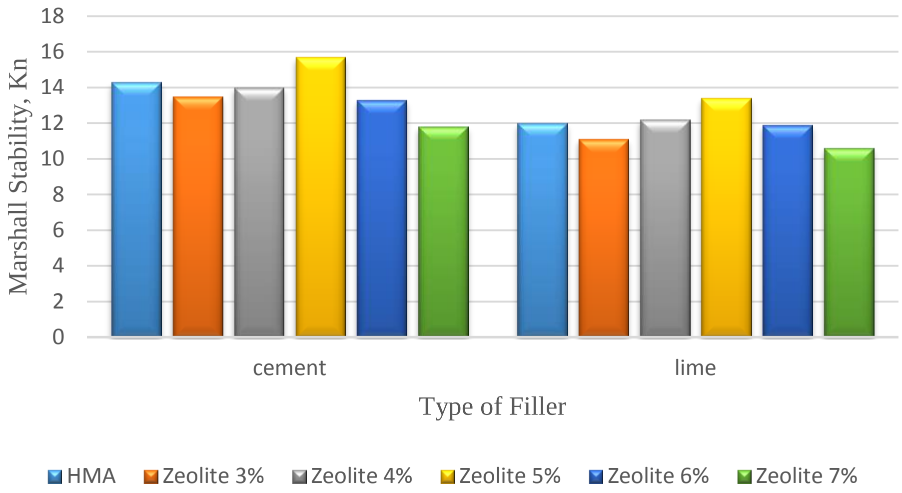

Figure 4. Effect of mix type on Marshall Stability value.

4. Conclusions

According to the results of study, the main conclusions can be drawn as:
It appears that the permanent deformation behavior of WMA apparently depends on the production temperature. For high levels of temperature reduction WMA performance is consistently reduced. The general tendency observed has been interpreted as a consequence of lower oxidative hardening of binder originated from reduction of production temperatures. Therefore, it is recommended that the permanent deformation resistance must be evaluated prior to the construction.

Marshall Stability test results indicate that stability is gradually increased with increasing of zeolite percentage and after (5.0 %) of synthetic zeolite it was decreasing. Maximum Marshall Stability obtained is 15.7 kN and 13.4 kN for mixtures with cement and limestone dust filler, respectively. The warm asphalt mixtures are suitable to Iraqi environmental conditions because of the reduction in mixing and compaction temperatures. Generally, it is believed that the warm asphalt mixtures with cement as a filler type having indirect tensile strength (ITS) higher than those containing filler of limestone dust type.

5. Recommendations

Further works are required to investigate the importance of other factors in pavement design. Such as fatigue characteristics to predict the fatigue life of WMA.

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