Evaluation Warm Asphalt Performance Integrated Laboratory and Field Study

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ABSTRACT: The Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo in cooperation with the City of Hamilton and McAsphalt Industries is currently investigating the use of Evotherm® warm mix technologies for both environmental reasons but also to examine the warm mix technologies. There are several reasons to consider reducing the temperature at which a hot mix is placed in the field. The performance of warm mix relative to a conventional hot mix was investigated through the laboratory and field study. This paper provides a summary of work to date on the two years project being carried out by CPATT. The dynamic and resilient modulus testing results at three different temperatures were obtained and compared both with results from the previously conducted trial as well as the results from conventional HMA Asphalt at CPATT laboratory. The permeability testing and pavement evaluation with Portable Falling Weight Deflection (PFWD) with time for warm mix surface and conventional asphalt surface have been conducted at the site by CPATT. The coefficients of permeability rate were compared with porous asphalt and other highway materials. The deflection and modulus of warm asphalt pavement and conventional asphalt mix pavement were analyzed. It is observed that warm asphalt pavement performance is statistically the same as conventional asphalt pavement.

KEY WORDS: Warm Asphalt, Dynamic Modulus, Deflection,

1 INTRODUCTION

There are several reasons to consider reducing the temperature at which a hot mix is placed in the field. Lowering the mix temperatures could result in several construction and performance benefits including reduced aging of the asphalt binder, reduced fumes or odours, reduced tenderness of the mix during compaction and reduced draindown with coarse mixes (APEC 2000). The Centre for Pavement and Transportation Technology (CPATT) at the University of

Waterloo in cooperation with the City of Hamilton, McAsphalt Industries is currently investigating the use of Evotherm® warm mix technologies. The performance of the warm mix relative to a conventional hot mix was investigated through laboratory and field study. This paper provides a summary of work to date on the two years project being carried out by CPATT.

2 SCOPE AND OBJECTIVES OF STUDY

Although there are various positive aspects of utilizing Warm Mix Technologies, it is important to carry out performance testing on the mixes and examine. This paper provides a performance evaluation of a test section using warm asphalt through the integrated laboratory and field study.

The dynamic modulus and the resilient modulus are the important performance and design parameters of the asphalt mixture. The dynamic modulus is measured over a range of temperatures and frequencies of loading which can then be shifted into a master curve for characterizing asphalt concrete for pavement thickness design and performance analysis. The resilient modulus testing involves applying cyclic loading to prepared samples and measuring the vertical and horizontal deformation. This testing is also conducted at three different temperatures starting with the lower temperatures and then proceeding to the higher temperatures. Both the dynamic and resilient modulus testing results were compared both with results from the previously conducted Ramara trial as well as the results from conventional HMA Asphalt.

In addition, field testing throughout the period continued to be carried out to achieve the actual performance comparison with conventional HMA asphalt. Permeability testing has been conducted at the site by CPATT. A pavement evaluation with Portable Falling Weight Deflection (PFWD) has also been done at the site, however, no distresses were observed during the evaluation.

Finally, the results on warm asphalt were analyzed and the conclusions and recommendations were developed.

3 Lab Testing

3.1 Specimen Preparation

A plate sample was received during the paving which was used to prepare all the samples that were made for testing in the laboratory. The samples were heated to a temperature of 110°C and then were compacted using a Superpave Gyratory compactor. In all 10 samples were prepared one of which collapsed during demolding due to the fact that the sample did not cool sufficiently prior to demolding.

The specimens were then cut and cored for the testing, in compliance with testing specifications. A 100 mm (4 inch) (inside diameter) coring bit was used to core the samples for the dynamic modulus. Two of the samples for resilient modulus were also cored using this bit. Samples for resilient modulus were cut from both 150mm (6 inch) and 100 mm (4 inch) specimens and they were cut to varying thicknesses to observe the affect of thickness of resilient modulus values. The top and bottom of the dynamic modulus samples were also cut in order to ensure that the samples were level prior to testing.

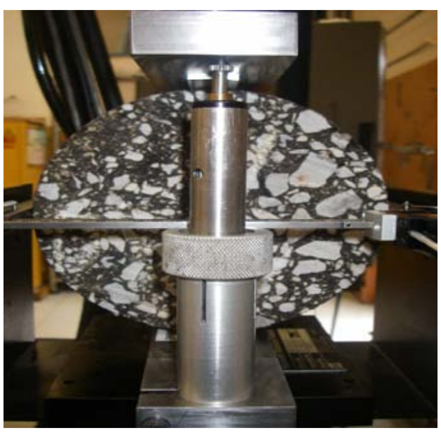
3.2 Resilient Modulus Testing

Resilient modulus testing was conducted on five samples according to AASHTO TP31-94 (AASHTO). Five specimens were prepared in total for resilient modulus testing. Table 1 shows the naming convention used and the dimensions of each of the five specimens**.**

Table 1: Summary of specimens prepared for resilient modulus.

Specimen ID	Thickness (mm)	Diameter (mm)
WMA_Mr4_1	38.51	98.54
WMA_Mr4_2	37.42	98.11
WMA_Mr6_1	75.08	150.01
WMA_Mr6_2	42.33	150.03
WMA_Mr6_3	40.86	150.04

The specimens were tested at three temperatures of 5°C, 25°C and 40°C. The specimens were first tested at room temperature as no preconditioning was required for this temperature. They were then placed in an environmental chamber at 5°C overnight in order to condition the specimens after which, they were all tested at that temperature. Once all the specimens were tested at 5°C the environmental chamber was heated to a temperature of 40°C and the samples were conditioned at that temperature for 3 hours after which they were tested. All samples were tested three times at each temperature and an average of the resilient modulus reading was taken for the three tests. Both vertical and horizontal deformations were measured during the testing, using extensometers for the horizontal deformation and Linear Variable Displacement Transducer (LVDT) for the vertical deformation. The sample was loaded along the diameter of the sample and both the horizontal and vertical deformations were also measured along the diameter of the sample. Figure 1 shows one of the test specimens set up in the testing apparatus.



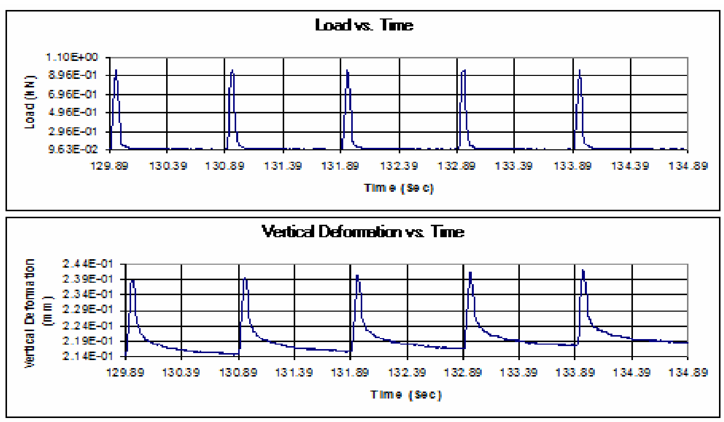


Figure 1: Specimen set up. Figure 2: Graphs for resilient modulus testing.

Figure 2 shows the typical graphs generated by the program when resilient modulus testing is conducted. The graphs that are produced are for load, horizontal deformation and vertical deformation against time. The graphs in the figures are for the sample WMA_Mr4_1 tested at 25°C. The load against time graph displays the type of loading that is applied to each sample during resilient modulus testing. A load of 1 kN is applied to the sample for a period of 0.1

seconds and then the load is dropped of to 0.1 kN and the sample is kept under that loading for a period of 0.9 seconds. This cycle of loading is continued for a period of 120 loading cycles and vertical and horizontal deformation are measure through each cycle.

Table 2 shows a summary of the test results for the five samples that were tested for resilient modulus. The measurements that were made during the testing were total and instantaneous resilient modulus as well as total and instantaneous Poisson ratio. These measurements are taken only for the last five cycles during each test and then the average of these values is reported. At 5°C the horizontal and vertical deformations are minimal and this is displayed in the fact that the Poisson ratio at this temperature is small or negative. The resilient modulus values are used to determine the thermal and fatigue cracking potential of asphalt pavement. The smaller 100 mm (4 inch) diameter specimens could not be tested at the higher temperatures due to the fact that at those temperatures under the loading the smaller specimens cracked.

3.3 Dynamic Modulus Testing

The dynamic modulus testing is used to determine the elastic properties of the material. This is done applying repeated and continuous sinusoidal loading at different frequencies. Dynamic modulus testing was conducted on 3 samples and it was also conducted at the 3 temperatures of 5°C, 25°C and 40°C. The test method that was used to conduct the dynamic modulus testing on these samples was ASTM 3497-79. The samples were tested at the three frequencies of 1, 4 and 16 Hz as was specified by the test method. Each sample was tested three times at each of the temperatures. The naming convention for the samples for dynamic modulus testing and the dimensions of the specimens are given in table 3.

Table 2: Dynamic modulus specimen dimensions.

Sample ID	Height (mm)	Diameter (mm)
WMA Md_1	153	100
WMA Md_2	147	100
WMA Md_3	146	100

Figure 3 shows the graphs that are produced during dynamic modulus testing. The graphs are produced for each of the frequencies and the graphs are for load and strain against time. The graphs that are shown in figure 4 are for sample number 1 at a frequency of 16 Hz.

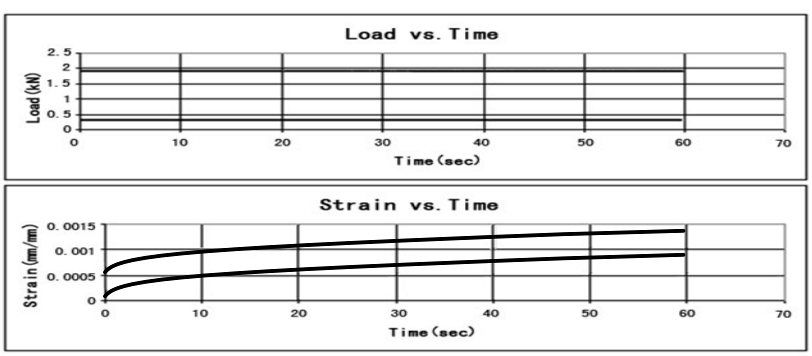


Figure 3: Graphs for dynamic modulus testing.

Table 3: Summary of Resilient Modulus Results for WMA.

Temperature		Specimen ID					Average
		WMA_Mr4_1	WMA_Mr4_2	WMA_Mr6_1	WMA_Mr6_2	WMA_Mr6_3	
5°C	**Total Resilient Modulus**	6416	2535	3441	4994	4897	4456
	Instantaneous Resilient modulus	6593	2683	3527	5161	5030	4599
	Total Poisson Ratio	-0.03	-0.20	-0.14	-0.04	0.03	-0.08
	Instantaneous Poisson Ratio	-0.03	-0.21	-0.14	-0.04	0.02	-0.08
25°C	**Total Resilient Modulus**	3433	3451	4136	3094	3238	3470
	Instantaneous Resilient modulus	3428	3461	4115	3123	3246	3475
	Total Poisson Ratio	0.24	0.26	0.27	0.22	0.31	0.26
	Instantaneous Poisson Ratio	0.25	0.27	0.25	0.22	0.31	0.26
40°C	**Total Resilient Modulus**	N/A	N/A	1197	1316	1245	1253
	Instantaneous Resilient modulus	N/A	N/A	1229	1184	1228	1214
	Total Poisson Ratio	N/A	N/A	0.51	0.77	0.63	0.64
	Instantaneous Poisson Ratio	N/A	N/A	0.53	0.84	0.65	0.67

The Dynamic Modulus, the phase angle, recoverable strain and load amplitude were measured during each test. Table 4 shows the average dynamic modulus values of each of the 3 samples tested at each of the 3 temperatures. The average dynamic modulus and the standard deviations of the dynamic modulus values are also presented in the table.

Table 4: Dynamic Modulus Values for WMA Specimens.

Sample Number	**Frequency (Hz)**	**Time (sec)**	**Average Dynamic Modulus (MPa)**		
			5°C	**25°C**	**40°C**
AVE.	16	0.0625	5.5681E+02	7.8914E+02	5.5059E+02
	4	0.25	5.3108E+02	6.8546E+02	4.4117E+02
	1	1	5.0917E+02	6.1732E+02	3.6709E+02
STD. DEV.	16	0.0625	169.234101	292.22419	105.1937472
	4	0.25	167.932129	263.560945	75.68229605
	1	1	160.549071	217.445706	55.57375398

Table 5 shows the phase angle of each of the samples that were tested at the three frequencies and temperatures. The table also presents the average phase angle for each frequency and the standard deviation for the measured phase angles. The average phase angle increased as the temperature increased, however, on average the phase angle decreased as the frequency decreased.

Table 5: Phase angles for WMA specimens.

Sample Number	**Frequency (Hz)**	**Time (sec)**	**Phase Angle (deg)**		
			5°C	**25°C**	**40°C**
AVE.	16	0.0625	8.99	10.66	15.04
	4	0.25	8.50	9.63	13.94
	1	1	5.73	10.18	12.72
STD. DEV.	16	0.0625	0.961	0.688903	1.086793
	4	0.25	0.791	0.269135	0.665544
	1	1	0.168	0.5533	0.675711

3.4 Comparison with previous results on WMA

Both the dynamic and resilient modulus testing results were compared both with results from the previously conducted Ramara trial as well as the results from conventional HMA Asphalt (Tighe 2006). The WMA and HMA were determined to be statistically the same for both the resilient modulus testing and the dynamic modulus testing over the various ranges of temperature and loading.

4 FIELD TESTING

4.1 Permeability Results

The permeability of asphalt mixtures could reflect the air void condition. The permeability testing was carried out with the CPATT Gilson Asphalt Field Permeameter as shown in Figure 4. In August 2007, CPATT carried out field permeability testing at the site. The test procedure is based on the falling head principle of permeability. Testing was carried out throughout the test sections. The tester was placed on the surface of the pavement and a moldable sealant was applied around the base of the permeameter. Three five pound weights were placed on the base of the permeameter to prevent a break in the sealant. Once the apparatus was secured, the pemeameter was filled with water at a steady rate. Once the water reached the top of the meter, it was allowed to settle. The water level change was then measured in 10cm increments. The change in head height (5cm) and the time (s) was recorded for each sequence. The sequence was completed several times at various locations on the mat, with particular emphasis on the Centre Line or Longitudinal Joint. The coefficient of permeability is then calculated as follows:

$$K = (a\ L\ /\ At)\ \ln(h_1/h_2) \tag{1}$$

Where, K is coefficient of permeability; a is inside cross-sectional area of the standpipe (cm^2); L is length of the sample (cm); A is cross-sectional area of permeameter through which water can penetrated the pavement area (cm^2); t is elapsed time between h_1 and h_2 (s); h_1 is initial head (cm); h_2 is final head (cm).

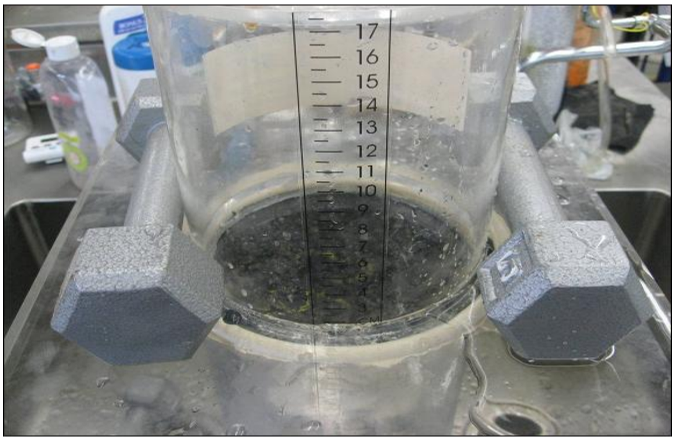


Figure 4: CPATT Gilson permeameter apparatus (Schaus 2007).

The permeability test was conducted at a water temperature of 26°C to 31°C, therefore a temperature correction factor in accordance with the actual temperature of the water was used to calculate the coefficient of permeability measurements as per the Florida Department of Transportation (FDOT) Method test for Measurement of Water Permeability of Compacted Asphalt Paving Mixtures (FDOT 2006). On Oct. 29 and Nov. 5 2008, CPATT carried out field permeability testing at the site again.

Table 6 summarizes a comparison of average coefficient of permeability rates of different periods for sites. It is observed that in August 2007, the average coefficient of permeability rates of warm asphalt was little bigger than the control SP12.5, and they became consistent after more than 1 year. They have similar air void ratios.

Table 6: Coefficient of permeability rate comparison during different measure.

	Time	**Air Temp (°C)**	**Section**	**Average K (cm/s)**
1	Oct.29,2008	1.5-2.8	WMA	0.0006
2	Nov.05,2008	13.8-17.5	Control SP12.5	0.0006
3	Aug,2007	26.4-29.0	WMA	0.0048
4	Aug,2007	28.7-33.3	Control SP12.5	0.0034

Table 7 summarizes a comparison of coefficient of permeability rates of various other materials to the porous asphalt (Schaus 2007). As noted, in the comparison with the WMA.

Table 7: Coefficient of permeability rate comparison.

Mix/Material	**Average Air Voids (%)**	**Average Coefficient of Permeability (cm/s)**
WMA City of Hamilton	TBD	.0006-.0048
SP12.5 City of Hamilton	TBD	.0006-.0033
Porous Asphalt PG 64-28	16.5	0.99
PG 70-28	17.1	1.00
Soils/Aggregates		
Gravel*	--	1.00
Sand**	--	3.53×10^{-4}
Silt**	--	7.06×10^{-5}
Clay**	--	7.06×10^{-6}
Dense-Graded Laboratory Mixes* **		
SP 9.5 mm fine (surface)	8.3	1.94×10^{-3}
SP 9.5 mm coarse (surface)	5.5	3.95×10^{-4}
SP 12.5 mm coarse (surface)	5.0	1.02×10^{-3}
SP 19 mm coarse (base)	7.1	2.34×10^{-3}
SP 25 mm coarse (base)	6.6	2.19×10^{-5}

* (Elgamal 2002) ** (PCA 2006) *** (Mallick 2003)

TBD: To Be Determined

4.2 Portable Falling Weight Deflectometer Results

The PFWD used in this study are owned and operated by CPATT at the University of Waterloo with the Dynatest KPI 100 and LWD 3031, which were used extensively for deflection data collection. The PFWD equipment is assembled and it is connected to the com pilot-palm device, through Bluetooth. The connectivity is checked through the blinking green light. Each point in a selected test section is tested six times and totally 17 sections are tested in the study. Based on information in the literature and discussions with the PFWD manufacturer it is generally recommended that a total of six reading be taken. The first reading is usually discarded and average of the remaining five readings is taken into consideration (Kestler 2005). The PFWD results of deflection and modulus are found in Table 8**.** The air temperature for WMA measure was 1.5 to 2.8 °C on Oct. 29, 2008, and the air temperature for Control SP 12.5 measure was 13.8 to 17.5 °C on Nov. 5, 2008. It is observed that warm asphalt paving has similar performance as compared with the section using conventional HMA. The results indicate typical valuation on the structure but longitudinal the joints in centre line (CL) are performing the same as the edge of pavement (EP).

Table 8: Summary of PFWD tests (Garth Street from Stone Church Road to Lincoln Parkway, Oct. and Nov. 2008).

Location	**WMA**				**Control SP12.5**			
	EP		**CL**		**EP**		**CL**	
	Def. (0.001mm)	**Mod.** (MPa)	**Def.** (0.001mm)	**Mod.** (MPa)	**Def.** (0.001mm)	**Mod.** (MPa)	**Def.** (0.001mm)	**Mod.** (MPa)
Mean	71	562	40	952	51	686	38	885
Standard Deviation	40	215	25	508	19	172	13	330
Mean+ 2Std Dev	151	993	91	1968	89	1031	63	1545

6 CONCLUSIONS AND RECOMMENDATIONS

It is observed that Evotherm® warm asphalt pavement performance is statistically the same as the conventional asphalt pavement from the laboratory and field study until now. The research team will continue to monitor performance. The comprehensive investigation and comparison should be carried out. Considering the environmental benefits of warm asphalt mix, the more warm asphalt mix should be applied in the future.

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