Paving The Way To Environmentally Friendly Pavements Through Innovative Solutions

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ABSTRACT

The concept of placing and compacting hot mix asphalt at lower temperatures provides many benefits to the environment. Lower temperatures can result in several construction-related and performance benefits as well, including reduced aging of the asphalt binder, reduced fumes and odours, reduced tenderness of the mix during compaction, increased usage of recycled asphalt pavement, and reduced drain-down with coarse mixes.

The Kyoto Accord protocols, as well as new environmental regulations that are coming into effect mean that pressure is mounting to reduce greenhouse gases. In fact, several Canadian cities are moving towards the implementation of smog days relating to paving and road resurfacing. The use of lower temperatures in the production of hot mix is one way of accommodating this reduction. However, it is also important that this associated reduction does not adversely compromise the long-term quality of the road mixes.

This paper describes a partnership between McAsphalt Industries, Miller Paving Limited, and the University of Waterloo's Centre for Pavement and Transportation Technology. It discusses the laboratory and field results of innovative warm mix trials placed in Canada in 2005. The trials to date have shown environmental benefits associated with the warm mix technology without compromising structural performance.

RÉSUMÉ

Le concept de pose et de compactage des enrobés bitumineux à chaud à des températures plus basses comporte plusieurs avantages pour l'environnement. Des températures plus basses peuvent procurer des avantages liés à la construction et à la performance incluant aussi bien vieillissement réduit du bitume, fumées et odeurs moindres, réduction de la sensibilité de l'enrobé durant le compactage, utilisation accrue des revêtements bitumineux recyclés et diminution du drainage vertical avec les enrobés grossiers.

L'entrée en vigueur du Protocole de Kyoto de même que celle de nouvelles règles environnementales montre clairement que la réduction des gaz à effet de serre est à l'ordre du jour. D'ailleurs, plusieurs villes canadiennes se dirigent vers la mise en oeuvre des jours de smog liés au revêtement et au resurfaçage des routes. Ainsi, l'emploi de températures plus basses dans la fabrication des enrobés à chaud est un pas dans la bonne direction. Cependant, il faut veiller à ce que cette réduction ne compromette pas la qualité des enrobés routiers à long terme.

Cet exposé décrit le partenariat noué entre les Industries McAsphalt, Miller Paving Limited et le Centre de Technologie des Chaussées et des Transports de l'Université de Waterloo. Il traite des résultats des tests effectués en laboratoire et sur chantier sur d'innovants enrobés tièdes posés au Canada en 2005. Ces essais ont montré à ce jour que la technologie des enrobés tièdes comporte de notables avantages environnementaux tout en ne compromettant pas la performance structurale.

1.0 BACKGROUND

The concept of placing and compacting Hot Mix Asphalt (HMA) at lower temperatures provides many benefits to the environment. In addition, lower temperatures for mixing can result in several construction and performance benefits including reduced aging of the asphalt binder, reduced fumes and odours, reduced tenderness of the mix during compaction, increased percentages of recycled asphalt pavement, and reduced draindown with coarse mixes.

The Kyoto Accord protocols as well as new environmental regulations that are coming into effect means the pressure is mounting to reduce greenhouse gases. In fact, a number of the large Canadian cities are moving towards the implementation of smog days relating to paving and road resurfacing. Thus the use of lower temperatures in the production of hot mix is one way of accommodating this reduction in greenhouse gases. However, it is also important that this associated reduction does not adversely compromise the long-term quality of the road mixes.

This issue could have serious ramifications for the hot mix industry, who will have to be proactive and reduce emissions. Lower temperatures can benefit both the material and the environment. With energy costs climbing the reduction in temperatures can greatly reduce energy consumption as well as lower emissions. The reduction in temperatures can also reduce oxidation of the mix during manufacture, which will translate into longer service life without reducing the quality of the mix.

2.0 INTRODUCTION TO WARM MIX ASPHALT PROCESSES

Several new processes have been developed to reduce the mixing and compaction temperatures of HMA. These processes are known as Warm Mix Asphalt (WMA). The lower temperatures should result in lower plant emissions and lower fuel consumption. Currently there are five processes being evaluated in North America and Europe:

- Aspha-min® zeolite developed by Eurovia.
- Sasobit® developed by Sasol International.
- WAM Foam by Shell and Kolo Veidekke.
- Low Energy Asphalt (LEA) by Fairco and Appia.
- Evotherm® developed by MeadWestvaco.

The Aspha-min® is produced in granular form [1]. The product contains approximately 20 percent water by weight. When the Aspha-min® is added to the mix, the water is released at elevated temperature, (100 to 200ºC) causing the asphalt cement to foam while mixing with the hot mix aggregate. The foamed asphalt has greater workability and allows for improved compaction and coating of the aggregate particles at a lower temperature.

Sasobit® is a Fischer-Tropsch wax [2] produced from coal gasification. The Sasobit® lowers the viscosity of the asphalt cement at the mixing and compaction temperatures but still maintains the original viscosity at in-service pavement temperatures. The Sasobit® can be combined with polymers to give the added benefit without creating issues with the warm mix temperatures. Typically the mixing and compaction temperatures can be lowered approximately 15ºC.

The WAM Foam process is a two-component binder system where a soft binder is used in conjunction with a foamed hard binder during the mixing stage [3]. The soft binder is mixed with the aggregate at a lower temperature (100 to 120ºC) and then a hard asphalt based emulsion is added and foaming occurs. The foaming action gives the mix workability at lower temperatures.

The Low Energy Asphalt (LEA) process is produced by only heating and drying the coarse aggregate fraction of the mix [4]. The second phase of the process is to add the fine aggregate portion of the mix to the hot asphalt coated coarse aggregate. The fine aggregate portion is in a cold and wet state. The LEA process utilizes the interaction of the hot asphalt with the water to create a low temperature mix (90 to 100ºC). Specifically formulated additives are added to the hot asphalt binder to allow for asphalt foaming and coating of the wet particles as well as to prevent stripping.

Evotherm is based on a chemical process that includes additives to improve coating workability, adhesion promoters, and emulsification agents [5]. The Evotherm product is delivered in the form of a high residue emulsion. Laboratory and field trials have shown that warm mixes can be produced below 100ºC and compacted as low as 60ºC.

3.0 FIELD TRIALS

During 2005, McAsphalt Industries placed three trials of warm mix asphalt using the Evotherm technology. These trials were placed in Aurora and Ramara Townships, near Orillia in Ontario, as well as in the City of Calgary, Alberta. Valuable information was obtained from the first two trials regarding the warm mix process.

An overview of the Aurora and Calgary trials is provided however, this paper will focus upon the Ramara trial in detail. This trial was a demonstration project involving HMA and WMA, as well as environmental emission testing. A large number of samples were also taken for performance testing, which will also be discussed.

3.1 Aurora Trial

The first Evotherm trial in Canada was placed at the marketing office of Miller Paving in Aurora, Ontario on August 8, 2005. The trial was placed in two separate areas; the mainline exit for concrete trucks and the parking area for employees. The existing mainline area had a Hot Laid (HL)8 base mix, as well as a HL3 surface mix placed over a foam-stabilized base. The parking area had a 50 mm lift of HL3 placed over the existing pavement. New parking areas incorporated a 50 mm lift of the Evotherm HL3 placed over a granular base. No hot mix was placed on this job. The base asphalt cement used in the Evotherm emulsion was the standard grade of Performance Graded (PG) 58-28 that was also used for the hot mix.

Aurora was the initial trial to evaluate the design and construction aspects of the warm mix technology. More specifically, this trial was designed to allow the team to answer a number of questions about the process. These included: What amount of time is required to properly mix the WMA? Can the plant mix the WMA at the lower temperature? Is the material evenly coated? In addition, it was determined that the batch process could successfully work with this material. Overall, the research team verified that these WMA could be successfully placed and compacted at lower temperatures as compared to conventional hot mix. It also gave the paving crew experience with this new and innovative technology. During this trial a number of samples were taken and tested in the laboratory, which further reinforced the fact that the process does work. Overall, after the trial, all parties confirmed that this mix could be designed and compacted without extensive changes to the conventional paving process.

3.2 City of Calgary

The second Evotherm trial in Canada was placed in a newly developed residential subdivision (Tara Lakes) in the northeast section of Calgary on September 30, 2005. The trial was placed using a Type ‘B’ mix using the Evotherm emulsion in place of the 150/200A penetration grade asphalt cement traditionally used in the City of Calgary. The mix was produced at the Lafarge Bow River asphalt plant and placed by the Lafarge personnel. The placement of the Evotherm ‘B’ mix was done in two areas; a 50 mm lift section over a hot mix base and a 50 mm lift over granular base. The Calgary trial used the softest grade of asphalt cement that had been used in any of the previous trials. A number of samples were also taken and tested in the laboratory. The data obtained from this trial was very similar to the information obtained from the Aurora trial. The physical properties were met, as well as the compaction results were within specification compliance.

3.3 Ramara Township

The third Evotherm trial in Canada was placed over a three-kilometre section of Road #46 in the Township of Ramara, near Orillia, Ontario on October 4 and 5, 2005. Miller Paving had been awarded the contract for the rehabilitation of this road and a presentation was made to Ramara council regarding the inclusion of a warm mix process trial. The council was receptive to the project with the addition of a warranty to protect the township.

The trial was placed using two mixes; HL4 hot mix on October 4, 2005 and the same HL4 mix using the Evotherm emulsion in place of the PG 58-28 on October 5, 2005. As in the case with the Aurora trial, the base asphalt cement in the emulsion was the same PG 58-28 used in the hot mix. The two mixes were produced at the Miller Paving asphalt plant located at the Carden Quarry near Brechin, Ontario. The paper will focus on the experiences at this trial.

4.0 RAMARA LABORATORY DATA

Aggregate samples were sent to the McAsphalt laboratory in order to evaluate the materials for the design of the WMA. The Evotherm process allows for the direct substitution of the asphalt cement with a specially formulated asphalt emulsion. The base asphalt cement used in the asphalt emulsion was the same asphalt cement used for the hot mix design. The existing HL4 mix prepared by Miller Paving was used for the Evotherm warm mix. The Marshall method of design was used incorporating 75 blows of the compaction hammer. All the mix properties had to meet the physical requirements for the Ontario Provincial Specification Standards (OPSS) 1150 [6]. Table 1 shows the mix design data for the mix used in the trial.

Table 1. Mix Design Data for Ramara Trial

Aggregate	Source	HL4
16.0 mm Clear Stone	Carden	45.9
Asphalt Sand	CBM	37.9
Unwashed Screenings	Carden	16.2
PG 58-28	McAsphalt	5.0
Evotherm *	McAsphalt	7.25
* Based on Evotherm emulsion residue of 69.0%		

Note: PG is Performance Grade, HL is Hot Laid

The Marshall physical properties on the two mixes performed by McAsphalt in their laboratory are shown in Table 2.

Table 2. Marshall Properties for Ramara Trial

Tests	HL4	
	HMA	Evotherm
Mixing Temperature (ºC)	150	125
Compaction Temperature (ºC)	138	95
Bulk Relative Density	2.406	2.386
Maximum Relative Density	2.501	2.487
% Air Voids	3.80	4.06
% VMA	14.1	14.8
Marshall Stability @ 60ºC	9,400	9,636
Flow Index @ 60ºC	8.5	8.6

Note: VMA is Voids in the Mineral Aggregate, HMA is Hot Mix Asphalt, HL is Hot Laid

Based on the data obtained in the laboratory, a mixing temperature of 125ºC and a compaction temperature of 95ºC was selected as the field mixing and compaction requirements for the Evotherm mix.

5.0 FIELD DATA

The following section will discuss the hot mix portion of the field trial.

5.1 HL4 Hot Mix Asphalt

5.1.1 Plant Production

Production of the conventional HL4 mix started at approximately 8:00 A.M. on October 4. The aggregate was heated to 155ºC and the Performance Graded Asphalt Cement (PGAC) was maintained in the storage tank at 150 to 155ºC. The plant operated with a dry mixing cycle of five seconds followed by the introduction of the PG 58-28 and a wet mixing cycle of 28 seconds. Figure 1 shows the Brechin plant in production.

Figure 1a. Brechin Hot Mix Plant

Figure 1b. Production of Hot Laid (HL)4 Hot Mix

Figure 1. Hot Mix Asphalt Plant Production

5.1.2 Field Production and Compaction

The existing asphalt was pulverized with 100 mm of the granular base and the shaped and compacted. This pulverized material was then covered with 150 mm of Granular 'A' to provide improved structural support. The new mix was placed over this new base at a compacted depth of 60 mm.

The construction equipment used on site was a standard highway spreader, a Roadtec Shuttle Buggy®, 12-ton double drum vibratory roller, 20-ton pneumatic tired roller, and 10-ton static steel. As noted earlier, the HL4 hot mix was produced at the plant at approximately 155ºC and was leaving the plant at a temperature of around 150ºC. The temperature of the mix at placement averaged 145ºC. The mat texture was very uniform and there was no evidence of segregation or tearing of the mat behind the screed **(**see Figure 2).

Figure 2a. Laydown with Shuttle Buggy

Figure 2b. Vibratory Breakdown Rolling

Figure 2. Hot Laid (HL)4 Hot Mix Placement and Compaction

The roller patterns used were the standard methods and the HL4 mix had an average compaction of 97.5 percent, which satisfied the specification requirements for this mix. There were approximately 970 tonnes of HL4 hot mix placed on the October 4, 2005.

5.1.3 Field Sample Testing

A number of HL4 samples were taken from the jobsite at various intervals. Three of the samples were tested in the laboratory for full Marshall testing and the results are as shown in Table 3. The Marshall properties (voids, stability, and flow index) are all within or exceed the OPSS 1150 requirements [6].

In typical hot mix production, the penetration values of PGAC recovered from field samples taken at the time of construction are normally about 60 to 70 percent or the original penetration. The penetration of the PGAC used to produce the both the HMA mix and the Evotherm emulsion had a penetration of 118 (see Table 5). The test data on the three samples of HL4 tested showed recovered penetrations of 80 to 83 or approximately 68.5 percent of the original penetration (Table 3). SHRP testing was conducted on the recovered asphalt and the data obtained will be discussed later in the Section 6.0 of the paper.

Table 3. Hot Laid (HL)4 Hot Mix Field Samples

Sieve	**Job Mix Formula**	**Sample # (Tonnage)**			**OPSS Form 1150 [6]**
		1 (433)	**2 (681)**	**3 (846)**	
19.0 mm	100	100	100	100	100
16.0 mm	99.5	98.2	98.0	97.6	98 – 100
13.2 mm	93.2	92.7	88.3	92.1	83 – 95
9.5 mm	77.9	76.4	74.9	76.4	62 – 82
4.75 mm	55.0	56.2	54.0	54.6	45 – 60
2.36 mm	48.3	49.0	47.8	47.8	27 – 60
1.18 mm	42.1	42.2	41.2	41.6	16 – 60
0.600 mm	34.1	33.4	32.7	33.2	8 – 47
0.300 mm	18.2	17.7	17.4	17.5	4 – 27
0.150 mm	6.8	6.6	6.5	6.5	1 – 10
0.075 mm	4.4	3.9	3.8	3.9	0 – 6
% Residual AC	5.0	4.90	4.79	4.80	5.0 min
% Moisture Content in Mix		0.19	0.09	0.11	not specified
Bulk Recompacted Density	2.383	2.379	2.371	2.375	
Maximum Theoretical Density	2.491	2.495	2.491	2.485	
% Air Voids	4.33	4.65	4.82	4.43	3 – 5
Marshall Stability	9,295	10,106	13,238	10,818	8,900 min
Flow Index	9.0	9.0	9.7	8.5	8.0 min
TSR %	not tested		78	not tested	80 min
Film Thickness micron	8.45	8.63	8.64	8.57	not specified
Recovered Penetration	not tested	83	80	81	

Note: OPSS is the Ontario Provincial Standard Specification
AC is Asphalt Cement
TSR% is the Tensile Strength Ratio in Percent

5.2 Evotherm Mix

5.2.1 Plant Production

The Evotherm warm mix was produced at the Miller Carden Quarry plant (Figure 3a). This plant is a 2-ton batch plant with a baghouse and has a production rate of 125 tons per hour. The Evotherm emulsion arrived on site at a temperature of 93 to 95ºC and was offloaded into one of the empty PGAC storage tanks. The storage tank was maintained at a temperature of 93ºC.

The Evotherm mix did not cause any problems in the plant with the mixing process or with the handling of the Evotherm emulsion. The only comment made by the plant operator was that the emulsion was slower to pump and that the batch size had to be reduced because of the capacity of the asphalt cement weigh hopper. This is because the emulsion is only 68 to 70 percent asphalt, which translates into 46 percent more liquid material needed per tonne of mix to give the proper residual asphalt cement.

The Evotherm mix was combined at a temperature of 125 to 130ºC with a target discharge temperature of 95ºC. The mix was very consistent in temperature and maintained this temperature for an extended period of time (see Figure 3b).

Figure 3a. Evotherm Production

Figure 3b. Evotherm Temperature Check

Figure 3. Production of Evotherm Mix

5.2.2 Field Production and Compaction

The temperature data on the first truckload showed an average of 85ºC in the hopper of the paver and 82ºC behind the screed. The screed heaters appeared to maintain the temperature of the mix very well. There were no differences in the rolling pattern from the HL4 mix (Figure 4a). The mix was placed to a compacted depth of 60 mm. A dilute Slow Set (SS)-1 tack coat was applied to the longitudinal joint. All three rollers could work the mix and the breakdown vibratory roller could ride right to the back of the paver with no evidence of pushing or shoving of the mat (see Figure 4b). The compaction test results showed an average value of 97.0 percent with a range of 95 to 98 percent. There were 615 tonnes of HL4 Evotherm mix placed within the trial section.

Figure 4a. Placement of Evotherm Mix

Figure 4b. Vibratory Compaction

Figure 4c. Intermediate Rolling of Evotherm Mix

Figure 4d. Rolling the Longitudinal Joint

Figure 4. Placement of Evotherm Mix on Ramara Road #46

5.2.3 Evotherm Field Mix Testing

As with the HL4 hot mix trial section, numerous samples of the HL4 produced with Evotherm were taken with three of the samples tested for compliance to the OPSS 1150 specification [6]. The test results obtained by the McAsphalt laboratory are shown in Table 4. The overall physical properties were good except that the stabilities were slightly lower than the HL4 hot mix. A possible explanation for the lower stability values will be discussed in the recovered binder section (Section 6.0).

The laboratory data obtained on the field samples of the Evotherm warm mix show that there does not appear to be any physical differences between the Evotherm mixes and the conventional hot mix. The mix results were very uniform with regard to aggregate gradation, asphalt cement content, percent air voids, and asphalt film thickness. As mentioned earlier, the Marshall stability values were slightly lower than the design value as well the HL4 hot mix results (Table 3).

Table 4. Evotherm Field Samples

Sieve	Job Mix Formula	Sample (Tonnage)			OPSS Form 1150
		1 (137)	2 (411)	3 (573)	
19.0 mm	100	100	100	100	100
16.0 mm	99.5	98.5	98.3	99.7	100
13.2 mm	93.2	92.7	88.3	90.1	98 – 100
9.5 mm	77.9	74.6	74.3	74.0	75 – 90
4.75 mm	55.0	52.8	53.2	53.9	50 – 60
2.36 mm	48.3	46.2	46.3	47.4	36 – 60
1.18 mm	42.1	39.9	39.8	41.0	25 – 58
0.600 mm	34.1	32.0	32.2	33.8	16 – 45
0.300 mm	18.2	17.5	17.9	19.1	7 – 26
0.150 mm	6.8	7.0	7.3	7.6	3 – 10
0.075 mm	4.4	4.5	4.5	4.6	0 - 5
% Residual AC	5.0	4.94	4.91	5.04	5.0 min
% Moisture	not tested	0.20	0.19	0.13	not specified
Bulk Recompacted	2.386	2.380	2.387	2.383	
Maximum Theoretical	2.487	2.472	2.473	2.474	
% Air Voids	4.06	3.72	3.48	3.68	3 – 5
Marshall Stability	9,636	8,114	8,535	8,114	8,900 min
Flow Index	8.6	8.9	9.0	8.7	8.0 min
TSR %	not tested			87	80 min
Film Thickness microns	8.45	8.52	8.36	8.25	not specified
Recovered Penetration	124	103	106	112	

Note: OPSS is the Ontario Provincial Standard Specification
AC is Asphalt Cement
TSR% is the Tensile Strength Ratio in Percent

6.0 RECOVERED BINDER TESTING

As part of the Ramara trial the asphalt cement was recovered from the Evotherm emulsion, as well as being extracted from the HL4 HMA and HL4 Evotherm warm mixes using the Abson recovery method ASTM International (ASTM) D1856 [7]. The asphalt cement was tested using the Strategic Highway Research Program (SHRP) protocols (including direct tension) [8] to determine whether or not the warm mix process was age-hardening the recovered asphalt in the same manner as conventional hot mix. Table 5 contains the SHRP data obtained in the laboratory for the various samples. The table compares the base asphalt used to produce the Evotherm emulsion and the hot mix with the recovered asphalt from the field samples for both the hot mix and warm mix trial sections.

The recovered penetration values showed the same trend as with the previous trials in Aurora and Calgary. The values ranged between 85 and 90 percent of the original penetration of the Evotherm emulsion used in the production of the mix. In order to obtain enough recovered material to complete all of the testing, including direct tension testing, the recovered asphalt from all three samples was combined. This process was used for both the Evotherm warm mix and the hot mix samples.

Table 5. SHRP Results on Lab and Field Data

Sample	**Base PGAC**	**Emulsion Residue**	**Recovered PGAC**	
			HMA	**WMA**
Tests on Original AC				
Rotational Viscosity @ 135ºC, Pa•s	0.285	not tested	not tested	
@ 165ºC	0.088			
DSR G*/Sin δ, kPa, @ 52ºC				
@ 58ºC	1.25	1.41		
@ 64ºC	0.57	0.65		
RTFO Residue				
Mass Change, %	0.400	NA	not tested	
DSR G*/Sin δ, kPa, @ 52ºC				4.81
@ 58ºC	3.00	3.03	2.80	2.17
@ 64ºC	1.30	1.29	1.28	
PAV Residue ºC	100	100	100	100
DSR G*x Sin δ, kPa, @ 19ºC	4,367	3,043	3,319	2,598
@ 16ºC	6,562	4,760	4,957	3,913
Bending Beam Rheometer (BBR)				
Creep Stiffness @ -12ºC, MPa				
@ -18ºC, MPa	252.0	204.0	228.0	209.0
@ -24ºC, MPa	482.0	474.0	493.0	520.0
Slope, m-value @ -12ºC, MPa				
@ -18ºC, MPa	0.301	0.326	0.314	0.309
@ -24ºC, MPa	0.241	0.256	0.255	0.256
PGAC Temperature Range (BBR Basis)	**59.7–28.1**	**60.2–30.2**	**59.8-29.4**	**57.9-29.0**
Thermal Stress or Strength MPa	**2.8**	**2.1**	**3.1**	**4.4**
PGAC Temperature Range (Direct Tension)	**59.7-25.8**	**60.2- 25.0**	**59.8-26.2**	**57.9-27.4**
Penetration @ 25ºC, 100g, 5 sec	129	124	81	107

Note: PGAC is Performance Graded Asphalt Cement, SHRP is the Strategic Highway Research Program
HMA is Hot Mix Asphalt, WMA is Warm Mix Asphalt
DSR is Dynamic Shear Rheometer, PAV is Pressure Aging Vessel
RTFO is Rolling Thin Film Oven
G* is the shear stiffness measured during viscosity testing
δ is the phase angle measured during viscosity testing

7.0 EMISSIONS TESTING

As part of the Evotherm development, emissions data was to be collected at the stack of the hot mix plant. One of the benefits of using the warm mix technology is the reduction in plant emissions compared to the hot mix process.

McAsphalt Industries employed the services of the Pinchin Environmental Limited to perform the emissions testing at the Brechin hot mix plant [9]. The purpose of the sampling program was to obtain data for combustion gases during the production of conventional hot mix asphalt and warm mix asphalt. Combustion gases included in the sampling program were Oxygen (O_2), Carbon Dioxide (CO_2), Carbon Monoxide (CO), Sulphur Dioxide (SO_2), and Oxides of Nitrogen (NOx).

Sampling was conducted through two ports at 90 degrees to each other that were installed on the dust collector exhaust stack as shown in Figure 5a. The sampling for the combustion gases was performed at a single point near the centre of the exhaust stack. Triplicate one hour tests were conducted for each of the gases (for each mix production run) following United States Environmental Protection Agency (USEPA) reference sampling methods that are recognized by the Ontario Ministry of Environment (MOE) for compliance sampling programs.

Figure 5a. Location of Sampling Ports

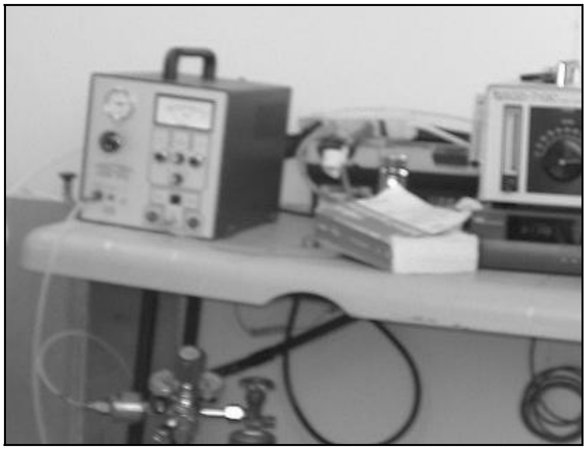

Figure 5b. Sampling Equipment

Figure 5. Emissions Testing Location and Equipment

The sampling methods used to measure the various combustion gases are summarized as follows in Table 6 and are the accepted methods used in North America.

Table 6. Sampling Methods

Combustion Gas	Test Method
Oxygen (O_2)	USEPA (40 CFR 60), Appendix A, Method 3A
Carbon Dioxide (CO_2)	USEPA (40 CFR 60), Appendix A, Method 3A
Carbon Monoxide (CO)	USEPA (40 CFR 60), Appendix A, Method 10
Sulphur Dioxide (SO_2)	USEPA (40 CFR 60), Appendix A, Method 6C
Nitrogen Oxides (NOx)	USEPA (40 CFR 60), Appendix A, Method 7E

Note: USEPA is United States Environmental Protection Agency

The hot mix combustion gas data was collected on October 4, 2005 and the warm mix (Evotherm) data was collected on October 5. The summary of the combustion gas data for both the hot mix production and the warm mix production are as shown in Table 7 [9].

Table 7. Combustion Gas Sampling Results [9]

Combustion Gas	Concentration		% Reduction
	Hot Mix	Warm Mix	
Oxygen	14.6 %	17.5 %	-19.9
Carbon Dioxide	4.8 %	2.6 %	45.8
Carbon Monoxide	70.2 ppm	25.9 ppm	63.1
Sulphur Dioxide	17.2 ppm	10.1 ppm	41.2
Oxides of Nitrogen (as NO)	62.2 ppm	26.1 ppm	58.0
Average Stack Gas Temperature	162ºC	121ºC	25.3

Note: ppm is Parts Per Million

Figure 6 shows the emissions data comparison from Table 7 graphically. With the exception of oxygen, the data showed that there was a tremendous decrease in all areas of emissions testing between the warm mix and the standard hot mix.

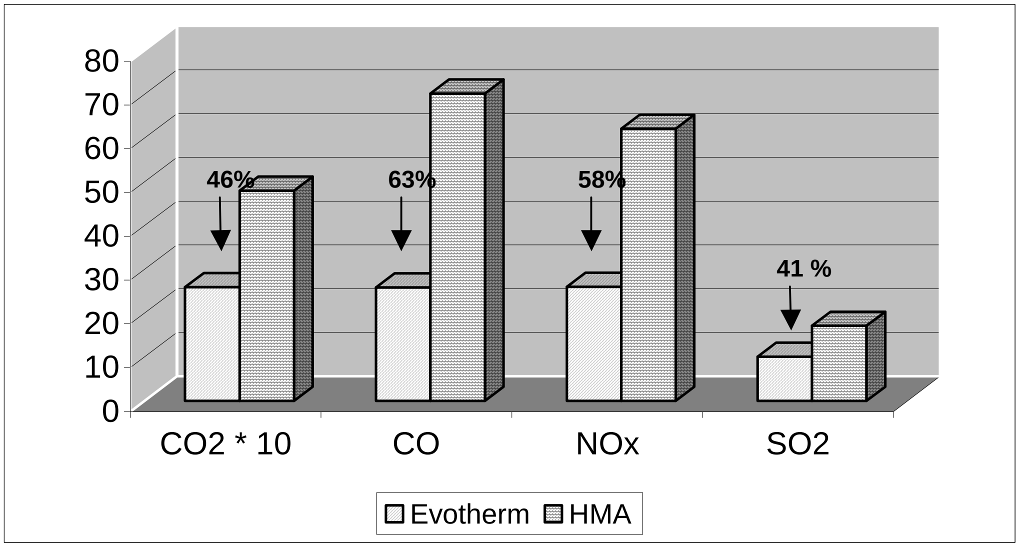

Figure 6. Emissions Data taken from Stack

8.0 FUEL CONSUMPTION

The fuel consumption was monitored throughout the trial and the data obtained on the tank dips is as shown in Table 8.

Typically hot mix plants use between eight and ten litres of fuel oil per tonne. Based on this information, the values obtained for the trial are quite reasonable and the Evotherm process shows a reduction in fuel consumption of approximately 55 percent. At today's fuel prices this reduction in fuel usage is a very significant decrease in energy costs.

Table 8. Fuel Consumption

Product	Dip Before (Litres)	Dip After (Litres)	Volume Used	Tonnage Produced	Volume per Tonne (litres)
Hot Mix	39,605.0	28,546.7	11,058.3	973	11.37
Evotherm Mix	28,546.7	25,347.6	3,199.2	615	5.20

9.0 FIELD CORES

A number of cores were taken from various locations within each test section and tested for field density. Table 9 contains the data obtained from the cores. The data has been consolidated into the overall average compaction percentage for each section.

Table 9. Core Data

	Main Lanes	
	HL4 HMA	**HL4 WMA with Evotherm**
In-Place Density	2.362	2.347
% Compaction	99.5	98.4
Range	96.4 – 99.8	96.7 - 99.2

Note: HMA is Hot Mix Asphalt, WMA is Warm Mix Asphalt, HL is Hot Laid

The core data indicates that the both mixes compacted very well and there were no issues with the ability for the warm mixes to be compacted at the lower temperatures.

10.0 OBSERVATIONS AND COMMENTS CONCERNING EVOTHERM WMA

Based on the field trial, the following comments and observations are made regarding plant production and field production:

10.1 Plant Production

There were no major issues during the production of the Evotherm mixes at the asphalt plant. The standard dry and wet mixing cycles were used and the finished mixes were both well coated and black in colour. The Evotherm emulsion was slightly slower to pump into the asphalt weigh hopper than normal asphalt cement, which caused a slight slowdown in production. The batch size had to be reduced due to the limitations in the capacity of the asphalt weigh hopper. Because the Evotherm emulsion is only 68 to 70 percent residue the quantity of emulsion needed per tonne of mix is 45 percent higher.

10.2 Field Production

Comments and observations made by different individuals regarding the Evotherm mix production in the field have been summarized into three areas; paver, compaction and post construction.

10.2.1 Paving

The comments from the paving crew around the spreader were that the mix was harder to work with when handwork was required but the fumes were much lower. The paver also appeared to have to work harder to lay the material, although the Evotherm mix flowed under the paver without any evidence of tearing behind the screed and there was no evidence of build-up on the augers or clumps of warm mix in the truckloads. One of the truck drivers mentioned that the truck box was very clean after the Evotherm mix was dropped into the paver hopper. The mix flowed out of the truck in the same manner as conventional hot mix and there was no evidence of the mix agglomerating due to the lower temperature.

10.2.2 Compaction

The breakdown roller could travel right up to the back of the paver without any evidence of pushing or shoving of the pavement mat and the use of the vibratory mode showed no evidence of cracking the mat. There was no steam coming off the mat during breakdown rolling or at any other stage in the rolling pattern. The longitudinal joint between lanes appeared to very tight. There did not seem to be any difference in compacting the HMA mix at 140ºC compared to compacting the Evotherm mix at 80ºC. Figure 7 shows the temperatures of the warm mix behind the spreader prior to the breakdown rolling (Figure 7a) and after the breakdown rolling (Figure 7b).

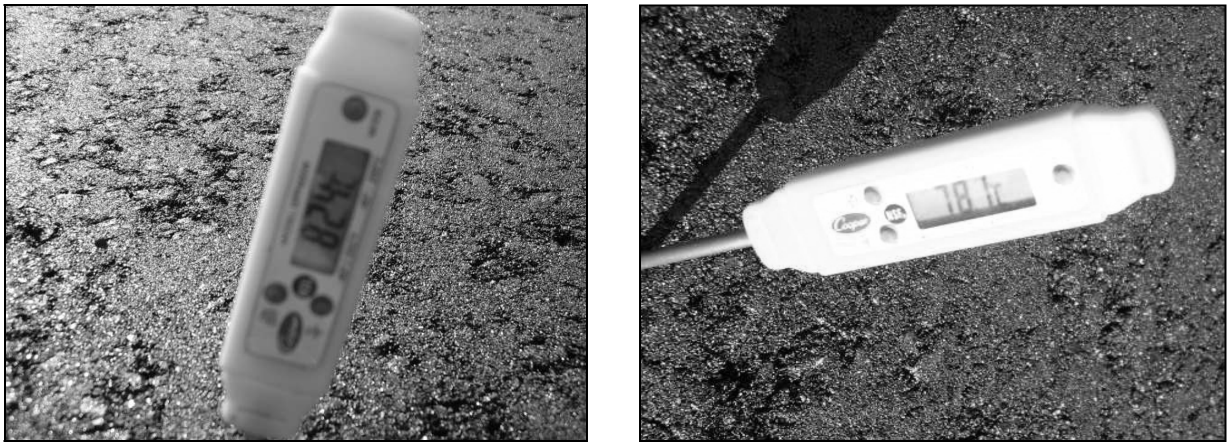

Figure 7a. After Spreader Prior to Rolling **Figure 7b. After Breakdown Rolling**

Figure 7. Laydown Temperatures of the Evotherm Warm Mix

10.2.3 Post Construction

The Evotherm mix has the appearance of conventional hot mix. The pictures in Figure 8 show the overall appearance of the project after seven months in service. The centerline longitudinal joint is excellent for both the hot mix and the warm mix.

Figure 8a. Hot Mix

Figure 8b. Warm Mix

Figure 8. Post Construction after Seven Months

11.0 PERFORMANCE TESTING

As part of the Ramara trial, samples of loose mix, as well as slabs and cores were taken from both the hot mix and warm mix sections. These samples were delivered to the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo for performance testing, including the resilient modulus and dynamic modulus tests. Creep compliance will be carried out at a later date.

11.1 Resilient Modulus

Both plate samples and field cores were used to test the samples. Although there were some differences in the plate and cored samples, the differences found to be statistically insignificant. Thus the data presented here is a summary of the detailed laboratory study. In total, 75 resilient modulus tests were carried out on the HMA and the WMA. The tests were carried out at several temperatures as noted in the AASHTO test method T322-03 [10]. Overall, the resilient modulus provides an indication of the fatigue and thermal cracking potential, as well as the quality of materials to be employed in the asphalt mixture. There are two procedures that may be used to quantify the resilient modulus; the tensile creep test with the tensile strength test, or the tensile strength test alone.

The former is focused on thermal cracking while the latter focuses on fatigue cracking. The tensile creep test incorporates a static load applied to the sample that must not exceed the linear viscoelastic range and must remain for 100 or 1,000 seconds depending on requirements. The result is a permanent deformation or deflection of the sample. The horizontal and vertical deformations are measured near the centre of the specimens whereby the Poisson’s ratio can be determined. The tensile strength test applies a constant rate of vertical deformation, typically 50 mm vertical displacement per minute, to an asphalt sample until failure. The sample is between 38 and 50 mm in height and 150 mm in diameter. This type of testing is required for Superpave^{TM} (Superpave) design levels 2 and 3 and is applicable for reheated asphalt mixes. A minimum of three temperatures are tested and the sample must be acclimatized to the specified testing temperatures prior to testing. The tensile creep and strength values are generated. The latter testing protocol was performed in this case. For this testing the samples were evaluated at four temperatures.

A sample resilient modulus report is provided in Figure 9. It provides a summary of the vertical and horizontal deformation associated with a typical resilient modulus test. As noted, deformation is measured as a function of time over a number of cycles.

Table 10 summarizes the resilient modulus data. The values in Table 10 represent an average of samples prepared from both plate samples and cores.

In order to determine if there were differences between the WMA and conventional HMA, an Analysis of Variance (ANOVA) was run to examine if there were statistical differences between the resilient modulus at the four temperatures. ANOVA is a statistical technique to identify variation in data. In this study, structural test data of two materials, warm asphalt and conventional hot mix are compared. As noted in Table 11, the F calculated is less than the F critical for all four temperatures. This indicates that there are no statistical differences between the WMA and the HMA at the four tested temperatures. This further validates that the material properties of the two mixes are statistically the same at a 95 percent confidence limit. It is also interesting to note that the variance between samples of WMA and HMA were also statistically the same. Although there were some differences in the laboratory prepared and field core samples, overall the variation between the WMA and HMA were statistically the same and the two materials may be considered structurally equivalent.

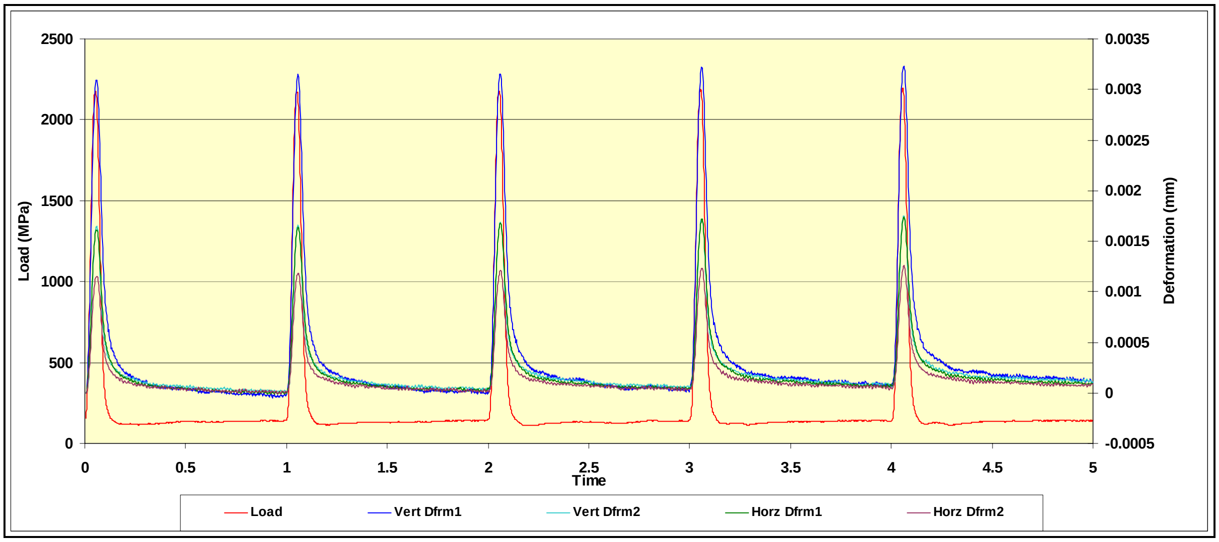

Figure 9. Typical Result from a Resilient Modulus Test showing Vertical and Horizontal Deformation - Ramara

Table 10. Resilient Modulus of Hot Mix versus Warm Mix - Ramara

Test Temperature °C	Warm Mix (MPa)	Hot Mix (MPa)
0	8,273	8,227
5	3,982	3,829
10	4,265	4,124
22	2,357	2,102

Table 11. ANOVA Summary of Differences Between Hot Mix and Warm Mix - Ramara

Temperature °C	F Calculated	F Critical	Number of Samples
0	0.001	6.6	5
5	0.22	5.32	9
10	5.98	6.61	6
22	0.82	4.54	16

Note: The F statistic is the mean square of the experimental factor divided by the mean square due to error. It is a function of the degrees of freedom and the significance level, which in this case is at the 95% confidence level.

11.2 Dynamic Modulus

The dynamic modulus test [11] is a measure of the elastic properties of a material or mixture that is subjected to a sinusoidal load. It can also be determined from the resilient modulus. This repetitive compressive stress is applied to a sample at a specified temperature and loading frequency. The testing is performed at specified temperatures at various loading frequencies starting at the lowest temperature and highest loading frequency. Samples are 100 mm in diameter and 200 mm in height. A master curve, which essentially summarizes the results from the dynamic modulus tests, is then developed. In total 38 samples were run at five loading frequencies.

Table 12 summarizes the dynamic modulus results for the WMA while Table 13 summarizes the dynamic modulus results for the HMA. Unfortunately, due to some technical issues the environmental chamber was not able to provide for the same temperatures for the two samples. However, Figures 10 and 11 show the frequency sweep dynamic modulus data and master curve for the WMA, respectively while Figures 12 and 13 show the results for the HMA, respectively. As shown, they are very similar for both materials. Again, this would further reinforce the fact that the materials are structurally the same based on the performance testing that was carried out in this study.

Table 12. Measured Dynamic Modulus – Warm Mix - Ramara

Frequency	Test Temperature °C			
	-3	**-2**	**21**	**38**
0.1	9,188	5,441	604	364
0.5	11,736	7,791	983	419
1.0	12,864	8,918	1,277	506
5.0	15,573	11,743	2,282	868
10	16,677	12,931	2,888	1,145
25	18,185	14,511	3,897	1,694

Table 13. Measured Dynamic Modulus – Hot Mix - Ramara

Frequency	Test Temperature °C				
	-5	**-1.9**	**21**	**37.8**	**45**
0.1	11,539	6,771	1,125	328	360
0.5	14,179	9,222	2,016	460	418
1.0	15,315	10,378	2,600	571	490
5.0	17,901	13,193	4,506	1,004	763
10	18,966	14,425	5,519	1,325	978
25	20,485	15,559	6,973	1,955	1,430

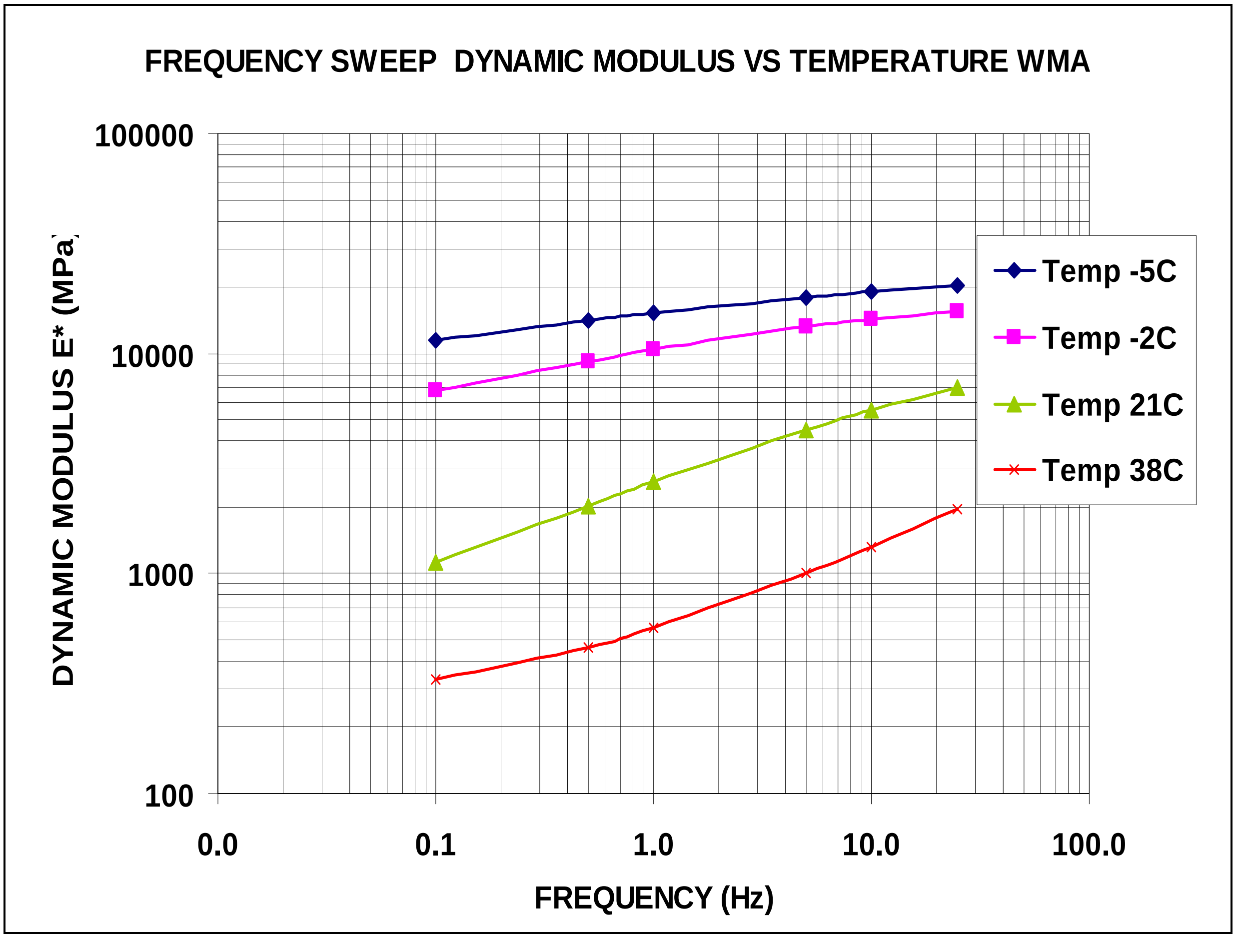

Figure 10. Frequency Sweep of Dynamic Modulus for Warm Mix Asphalt (WMA) - Ramara

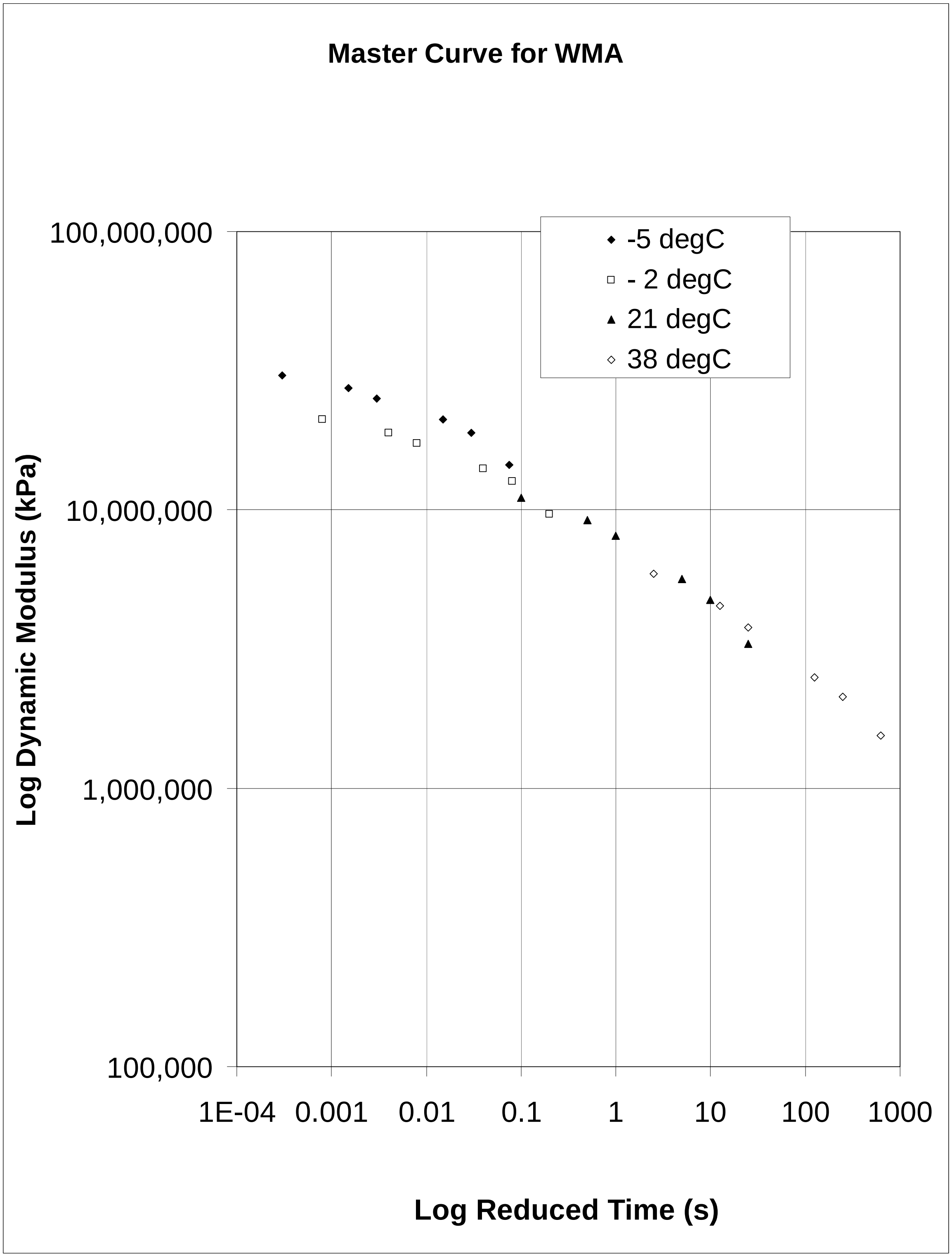

Figure 11. Master Curve for Warm Mix Asphalt (WMA) - Ramara Trial

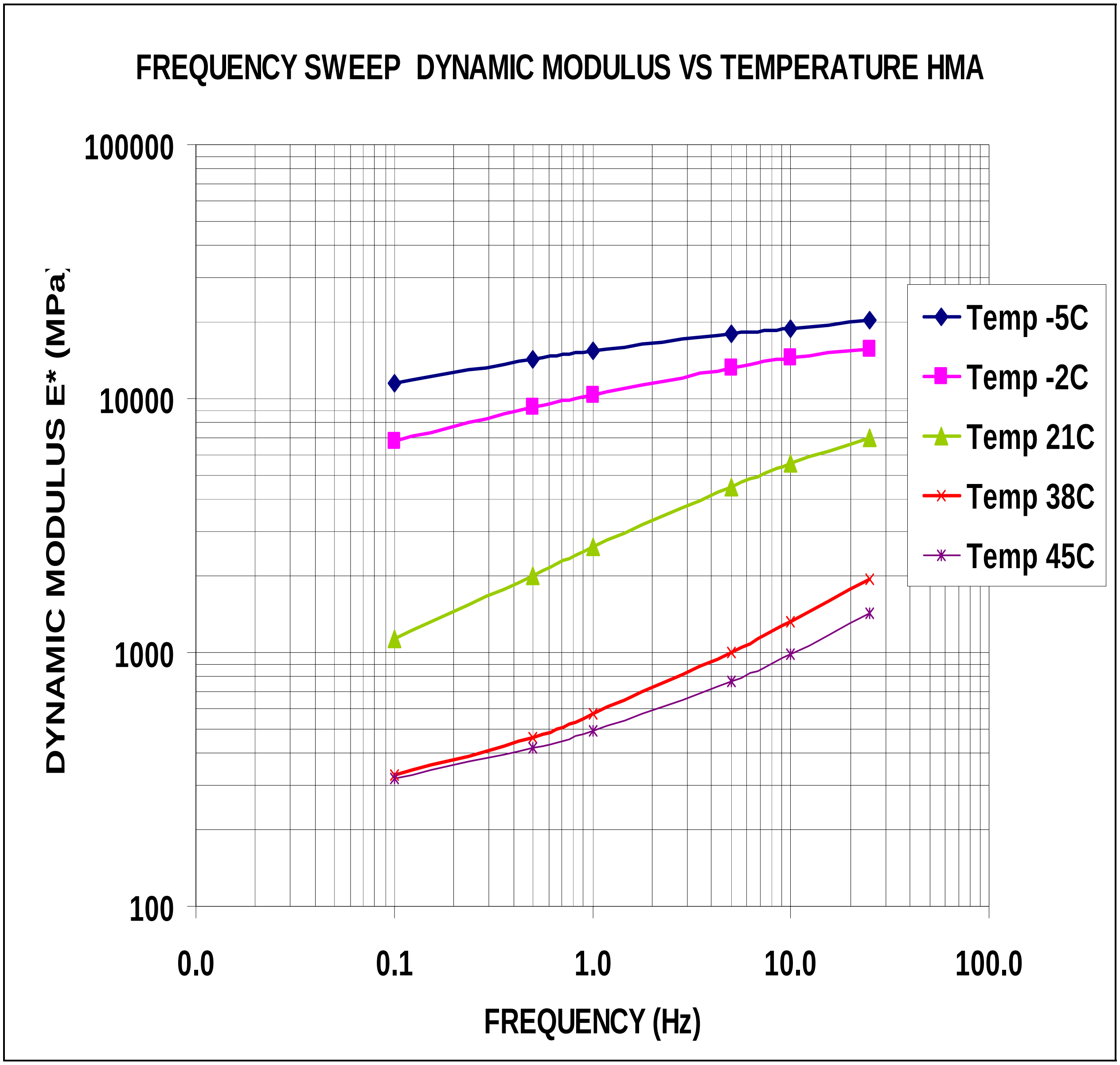

Figure 12. Frequency Sweep of Dynamic Modulus for Hot Mix Asphalt (HMA) - Ramara

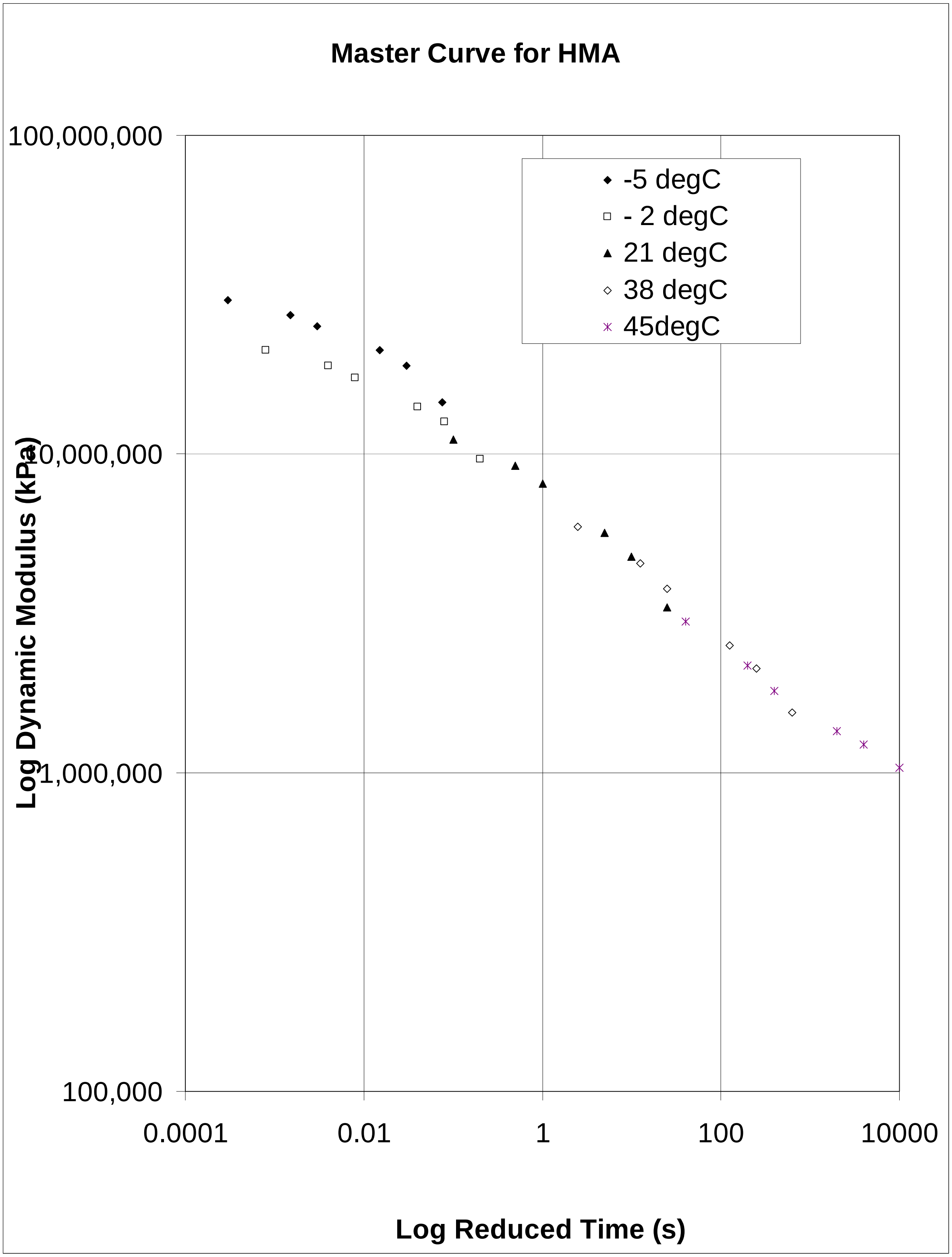

Figure 13. Master Curve Hot Mix Asphalt (HMA) - Ramara

12.0 CONCLUSIONS

Based on the trials that have been completed to date, the following conclusions may be drawn:

1. The warm mix technology can be implemented easily into the hot mix plant with minimum disruption or changes to the plant configuration or operation.

2. The mixing temperatures in the plant can be decreased 20 to 30°C and the compaction temperatures can be lowered 40 to 50°C without compromising the physical properties of the asphalt mixture.

3. The lower mixing temperatures substantially lower the aging properties of the asphalt binder, which suggests that the service life of warm mixes would be increased.

4. The lower mixing temperatures of the warm mixes significantly reduce the energy consumption required to produce a tonne of asphalt mix.

5. The production of greenhouse gases has been significantly reduced when using warm mixes compared to hot mix.

6. The resilient modulus and dynamic modulus testing performed on the hot mix and warm mix samples from Ramara Township have shown that there is no difference between the warm mix and the hot mix.

13.0 CLOSING REMARKS

The work carried out in this study has been a three-way partnership between McAsphalt Industries Limited, Miller Paving Limited, and the University of Waterloo's Centre for Pavement and Transportation Technology. The paper details the laboratory and field results of an innovative warm mix product, which was placed in Canada in 2005. Data from a trial section placed in Ramara Township has been presented. The mix data, field compaction, and performance testing have all shown the warm and the hot mix are very similar. However, the emissions testing effort has shown many additional benefits associated with the warm mix product.

The investigators will continue to monitor the performance of the warm mix over time. Data will continue to be analyzed and used in future performance modeling and life cycle economic analysis. It is expected that more trials using this warm mix process will be placed to further examine the long-term performance.

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