Environmental/Structural Evaluation of Warm Asphalt in the Canadian Climate

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Abstract

The concept of placing and compacting hot mix at lower temperatures provides many benefits to the environment. Lower temperatures 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 mean 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. 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 paper describes a three way 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 the environmental benefits associated with the warm mix technology. Finally the paper discusses the structural performance of warm mix compared to the equivalent hot mix with respect to various environmental and traffic conditions.

1. Introduction

Several new processes have been developed to reduce the mixing and compaction temperatures of hot mix asphalt. These processes are known as warm mix asphalt. The lower temperatures should result in lower plant emissions and lower fuel consumption. 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.

During 2005, McAsphalt Industries placed three trials of warm mix asphalt using the Evotherm technology. The Evotherm technology is based on a chemical process that includes additives to improve coating, workability, adhesion promoters and emulsification agents. The Evotherm product is delivered in the form of a high residue emulsion. Laboratory and field trials have shown that Evotherm warm mixes can be produced below 100ºC and compacted as low as 60ºC.

2. Field Trials

In 2005, McAsphalt Industries in conjunction with Miller Paving placed three trials of warm mix asphalt using the Evotherm technology. These trials were placed in Aurora, Ontario; the City of Calgary in Alberta and Ramara Township in Ontario near Orillia. 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 and involved Hot Mix Asphalt (HMA), Warm Mix Asphalt (WMA) as well as environmental emission testing. A large numbers of samples were also taken for performance testing, which will also be discussed.

2.1 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 HL8 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 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.

2.2 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.

2.3 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.

3. Field Data

3.1 HMA 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 1. The Marshall properties (voids, stability and flow index) are all within or exceed the Ontario Provincial Specification Standards (OPSS) 1150 [1].

In typical hot mix production, the penetration values of Performance Graded Asphalt Cement (PGAC) recovered from field samples taken at the time of construction are normally about 60 to 70 percent of 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 3). 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 1). Strategic Highway Research Program (SHRP) testing was conducted on the recovered asphalt and the data obtained will be discussed later in the Section 4 of the paper.

Table 1: HL4 Hot Mix Field Samples

Sieve Mixing Temperature Compaction Temperature	Job Mix Formula 150°C 138ºC	Sample # (Tonnage)			OPSS Form 1150 [1]
		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 (Newtons)	9295	10106	13238	10818	8900 min
Flow Index (0.25 mm)	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	

3.2 Evotherm Field Sample 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 (1) specification. The test results obtained by the McAsphalt laboratory are shown in Table 2. 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 4).

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 2).

Table 2: HL4 Evotherm Field Samples

Sieve **Mixing Temperature** **Compaction Temperature**	**Job Mix Formula** **125°C** **100ºC**	**Sample (Tonnage)** **1 (137)**	**2 (411)**	**3 (573)**	**OPSS Form 1150 [1]**
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 (Newtons)	9636	8114	8535	8114	8900 min
Flow Index (0.25 mm)	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	

4. 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 D1856) [2]. The asphalt cement was tested using the Strategic Highway Research Program (SHRP) protocols (including direct tension) [3] to determine whether or not the warm mix process was age-hardening the recovered asphalt in the same manner as conventional hot mix. Table 3 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. The less aging of the binder in the warm mix through the plant mixing contributes to the lower Stability values seen in the test data.

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 3: 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 @ 165ºC	0.285 0.088	not tested	not tested	
DSR G*/Sin δ, kPa, @ 52ºC @ 58ºC @ 64ºC	 1.25 0.57	 1.41 0.65		
RTFO Residue				
Mass Change, %	0.400	NA	not tested	
DSR G*/Sin δ, kPa, @ 52ºC @ 58ºC @ 64ºC	 3.00 1.30	 3.03 1.29	 2.80 1.28	4.81 2.17
PAV Residue ºC	100	100	100	100
DSR G*x Sin δ, kPa, @ 19ºC @ 16ºC	4367 6562	3043 4760	3319 4957	2598 3913
Bending Beam Rheometer (BBR) Creep Stiffness @ -12ºC, MPa @ -18ºC, MPa @ -24ºC, Mpa Slope, m-value @ -12ºC, MPa @ -18ºC, Mpa @ -24ºC, Mpa	 252.0 482.0 0.301 0.241	 204.0 474.0 0.326 0.256	 228.0 493.0 0.314 0.255	 209.0 520.0 0.309 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

5. Emission 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. 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), 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. 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. The summary of the combustion gas data for both the hot mix production and the warm mix production are as shown in Table 4 [4].

Table 4: Combustion Gas Sampling Results [4]

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 %	25.9 %	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

Figure 1 shows the emissions data comparison from Table 4 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.

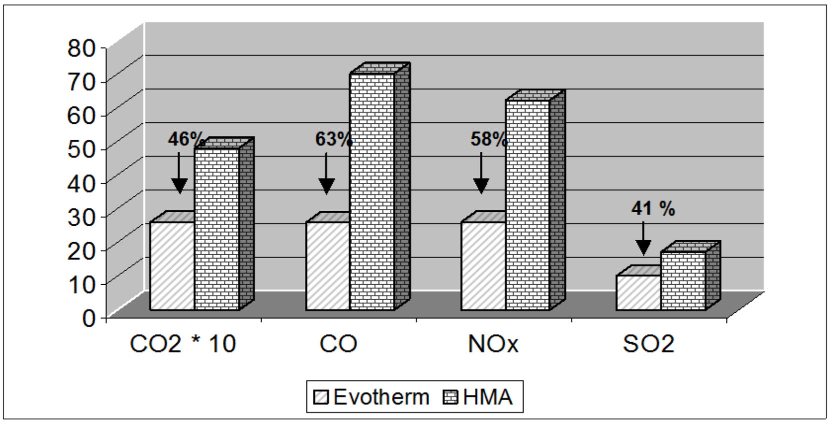

Figure 1: Emission Data Taken from Stack

6. Fuel Consumption

The fuel consumption was monitored throughout the trial and the data obtained on the tank dips is as shown in Table 5. Typically hot mix plants use between 8 and 10 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 5: Fuel Consumption

Product	Dip Before (Litres)	Dip After (Litres)	Volume Used	Tonnage Produced	Volume per Tonne (litres)
Hot Mix	39605.0	28546.7	11058.3	973	11.37
Evotherm Mix	28546.7	25347.6	3199.2	615	5.20

7. Field Cores

A number of cores were taken from various locations within each test section and tested for field density. Table 6 contains the data obtained from the cores. The data has been consolidated into the overall average compaction percentage for each section.

Table 6: Core Data

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

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.

8. 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.

8.1 Resilient Modulus

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 [5]. 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.

Table 7 summarizes the resilient modulus data. The values in Table 7 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. As noted in Table 8, 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% 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.

Table 7: Resilient Modulus of Hot Mix versus Warm mix - Ramara

Test Temperature °C	Warm Mix (MPa)	Hot Mix (MPa)
0	8273	8227
5	3982	3829
10	4265	4124
22	2357	2102

Table 8: 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

8.2 Dynamic Modulus

The dynamic modulus test [6] 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 pavement thickness and performance are the result of determining the dynamic modulus of a sample. 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 9 summarizes the dynamic modulus results for the WMA while Table 10 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 as noted in Figures 3 and 12 the master curves (shown as dashed lines) are very similar for both materials. The arrow on the curve indicates the principal of Time-Temperature Superposition and shows that the materials in this case are very similar. 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 9: Dynamic Modulus - Warm Mix - Ramara

Frequency	Test Temperature °C			
	-3	**-2**	**21**	**38**
0.1	9188	5441	604	364
0.5	11736	7791	983	419
1.0	12864	8918	1277	506
5.0	15573	11743	2282	868
10	16677	12931	2888	1145
25	18185	14511	3897	1694

Table 10: Measured Dynamic Modulus - Hot Mix - Ramara

Frequency	Test Temperature °C				
	-5	-1.9	21	37.8	45
0.1	11539	6771	1125	328	360
0.5	14179	9222	2016	460	418
1.0	15315	10378	2600	571	490
5.0	17901	13193	4506	1004	763
10	18966	14425	5519	1325	978
25	20485	15559	6973	1955	1430

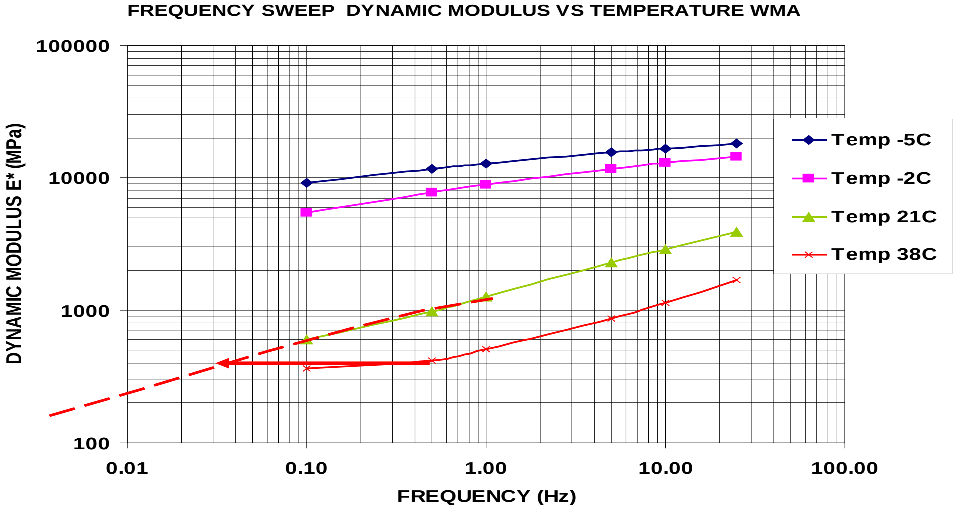

Figure 2: Frequency Sweep of Dynamic of Dynamic Modulus for Warm Mix – Ramara

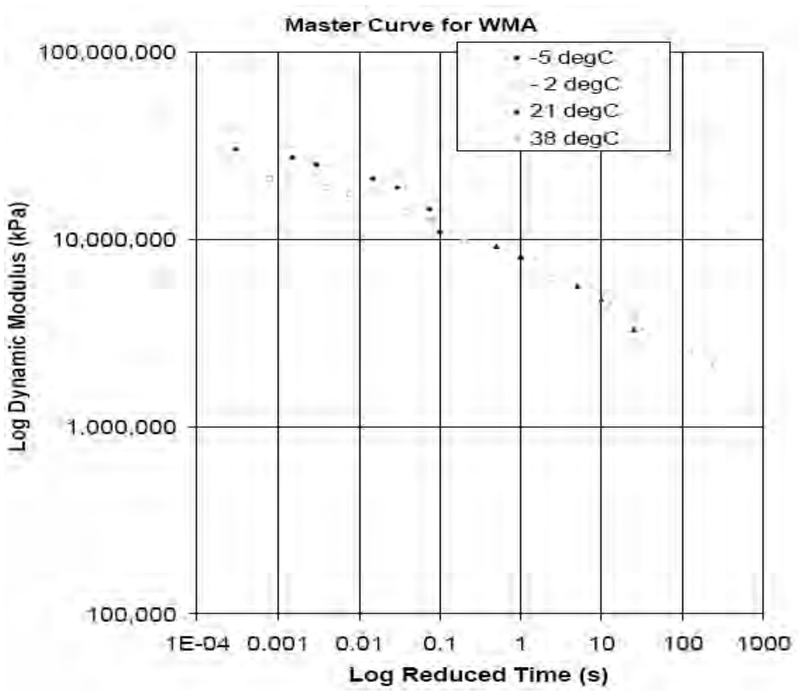

Figure 3: Master Curve for Warm Mix Asphalt (WMA) – Ramara

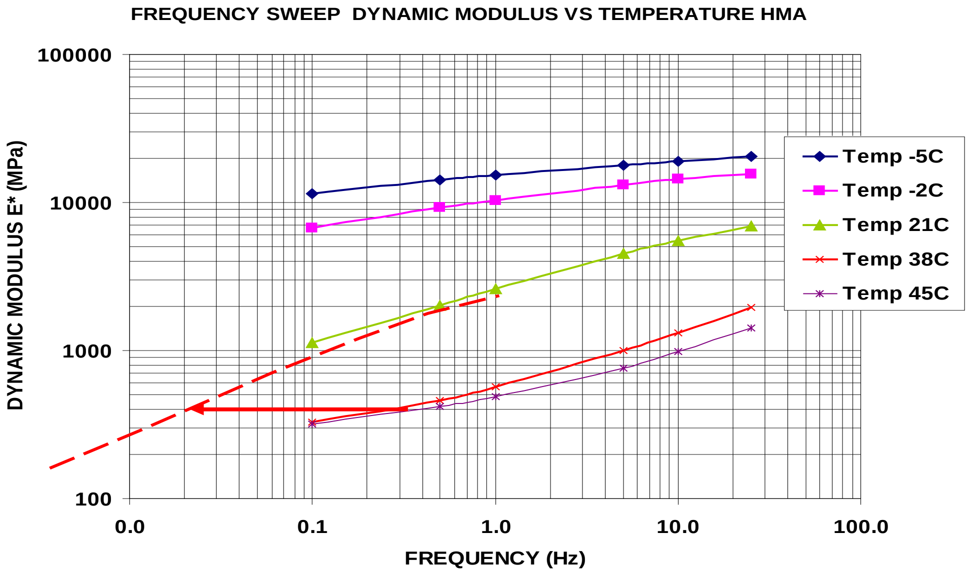

Figure 4: Frequency Sweep of Dynamic Modulus for Hot Mix Asphalt - Ramara

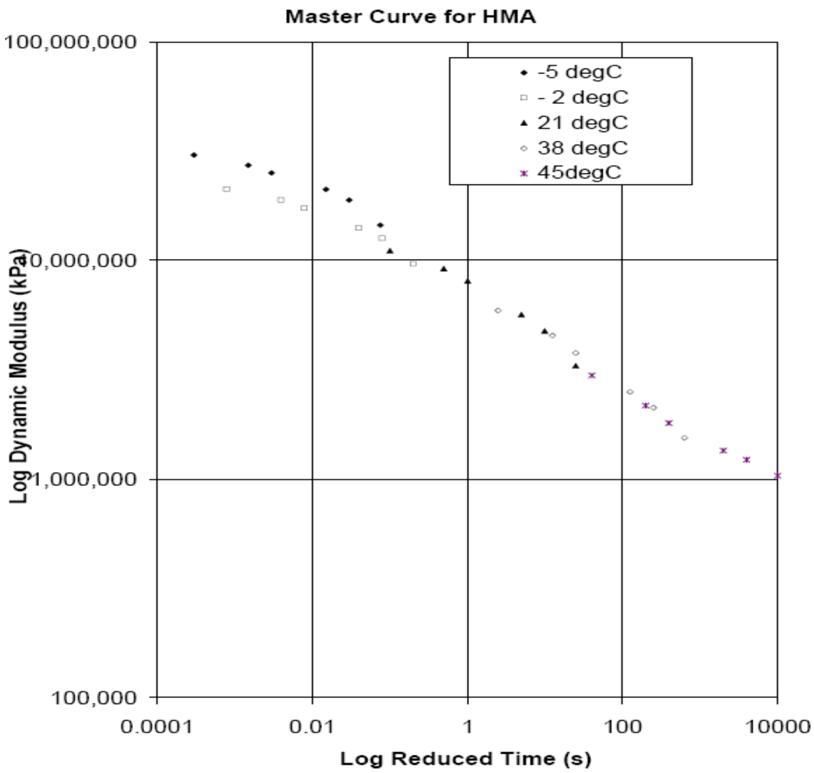

Figure 5: Master Curve for Hot Mix Asphalt (HMA) – Ramara

9. 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.

References

1. "Material Specification for Hot Mix Asphalt", OPSS 1150, Ontario Provincial Standard Specification (OPSS), Ontario Ministry of Transportation, Downsview, Ontario (November, 2002)

2. ASTM International (ASTM) D1856-95a(2003). "Standard Test Method for Recovery of Asphalt From Solution by Abson Method", Annual Book of ASTM Standards, Road and Paving Materials; Vehicle-Pavement Systems, 04.03, West Conshohocken, Pennsylvania (2003).

3. American Association of State Highway and Transportation Officials (AASHTO) M320-05. "Standard Specification for Performance Graded Asphalt Binder", Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 1B, 26th Edition, Washington, D.C. (2006).

4. Bingley M. and Girard P. "Report for a Combustion Gas Emission Testing Program at the Miller Aggregate Resources Facility in Brechin Ontario", Pinchin Environmental Report, October 7, 2005.

5. American Association of State Highway and Transportation Officials (AASHTO) T322-03, "Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device', Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2B, 23rd Edition, Washington, D.C. (2003).

6. American Association of State Highway and Transportation Officials (AASHTO) TP 62-03, "Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures", AASHTO Provisional Standards, June 2004 Edition, Washington, D.C. (2004).