Reducing Paving Emissions Using Warm Mix Technology

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ABSTRACT

Warm mix technology has become the latest buzz word in the area of asphalt technology. Worker health and safety, as well as environmental concerns have caused many people to look for different ways of producing asphalt concrete that maintain the physical properties and performance characteristics of traditional hot mix, but are more worker and environmentally friendly.

This paper discusses a project carried by McAsphalt Industries, TCG Materials and the City of London to study the effects of warm mix technology using Reclaimed Asphalt Pavement (RAP). The project involved the placement of three lifts of asphalt concrete on a prepared granular base. Bessemer Road was paved with two lifts of base hot mix and one lift of surface hot mix. Newbold Street received two lifts of base warm mix and a single lift of surface warm mix. All four mixes contained fifteen percent RAP. Environmental emissions testing was performed on both the hot and warm base mixes to monitor the greenhouse gases during production.

Based on the results achieved the warm mix technology provides lower emissions (greenhouse gases) than hot mix without compromising the performance properties of the mix. Also, it has shown that less oxidation is occurring in the warm mix, which certainly will translate into longer service life.

RÉSUMÉ

La technologie des enrobés chauds est devenue la dernière sensation dans le domaine de la technologie du bitume. La santé et la sécurité des travailleurs aussi bien que les préoccupations environnementales ont amené plusieurs personnes à chercher différents moyens de produire du béton bitumineux qui maintient les propriétés physiques et les caractéristiques de performance des enrobés à chaud traditionnels, mais qui sont plus gentils envers les travailleurs et l'environnement.

Cet exposé discute d'un projet mené par les industries McAsphalt,, les Matériaus TCG et la ville de London pour étudier les effets de la technologie des enrobés chauds avec des matériaux de revêtements recyclés RAP. Le projet comprend la pose de trois couches de béton bitumineux sur une fondation granulaire préparée. La route Bessemer a été recouverte de deux couches de base et d'une couche de surface d'enrobés à chaud. La rue Newbold a reçu deux couches de base et une couche simple de surface d'enrobés chauds. Tous les quatre enrobés contenaient quinze pour cent de RAP. Les essais des émissions dans l'environnement ont été réalisés sur les enrobés à chaud et sur les enrobés chauds de base pour suivre les gaz à effet de serre durant la production.

En se basant sur les résultats obtenus, la technologie des enrobés chauds fournit moins d'émissions (gaz à effet de serre) que les enrobés à chaud sans compromettre les propriétés de performance de l'enrobé. Également, ils ont montré que moins d'oxydation s'est produit dans l'enrobé chaud, ce qui se traduira certainement par une durée de service plus longue.

1.0 BACKGROUND

The use of warm mix technology has many benefits to the environment. Lower mixing and compaction temperatures can provide numerous construction and performance-related benefits including reduced aging of the binder, reduced fumes and odours at the paving machine, as well as increased percentages of Reclaimed Asphalt Pavement (RAP) within the mixes.

The Kyoto Accord protocols, as well as stricter environmental regulations coming into effect, indicate that pressure is mounting to reduce greenhouse gases throughout the country. The increased environmental pressure to reduce greenhouse gases has started to put pressure on industries to become more proactive in reducing emissions. Warm mix technology is one way of reducing greenhouse gases without adversely affecting the long term quality of the road mixes. Lower mixing temperatures can benefit both the contractor and the environment. As energy costs increase, reduction in mixing temperatures can greatly reduce energy consumption and lower emissions. With decreased mixing temperatures there is a reduction in the oxidation of the asphalt cement during the manufacturing process, which can translate into longer service life without compromising the quality of the paving mix.

In order to evaluate the warm mix process, field trials are required to compare the physical properties and performance of the warm mix to conventional hot mix.

2.0 INTRODUCTION TO WARM MIX TECHNOLOGY

As originally discussed by Davidson, Tighe and Croteau [1], 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. Currently there are five processes being evaluated in North America:

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

The Aspha-min® is produced in granular form [2]. The product contains approximately 20 percent water by weight. When the Aspha-min® is added to the mix the water is released under high temperatures. The high temperatures (100 to 200ºC) cause the asphalt cement to foam while mixing with the HMA 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 [3]. This wax is produced from coal gasification using the Fischer-Tropsch process. The Sasobit® lowers the viscosity of the asphalt cement at the mixing and compaction temperatures but still maintains the original viscosity at the 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 [4]. 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 process (LEA) involves the heating of only the coarse aggregate portion of the mix and the addition of the fine aggregate in a wet and ambient temperature condition [5]. This causes a foaming action and results in lower operating temperatures (90 - 100°C range). The technique creates savings in mixing energy with a reduction in gas emissions.

The Evotherm process is based on a chemical process that includes additives to improve coating, workability, adhesion and emulsification [6]. The Evotherm product is delivered in the form of a high residue emulsion containing between 67 and 69 percent residue.

3.0 LOCATION

The Evotherm trial was placed on Newbold Street and Bessemer Road in the City of London in June and July of 2006. Figure 1 shows the location of the Evotherm trial. The project involved the placement of three lifts of asphalt concrete on a prepared granular base. Bessemer Road received two lifts of HL8 binder mix (June 12th) covered with a HL3 surface lift (July 17th). Newbold Street was covered with two lifts of HL8 mix using Evotherm as the asphalt liquid (June 13th) followed by a lift of HL3 with Evotherm (July 10th). Both the HL8 and HL3 contained 15 percent RAP.

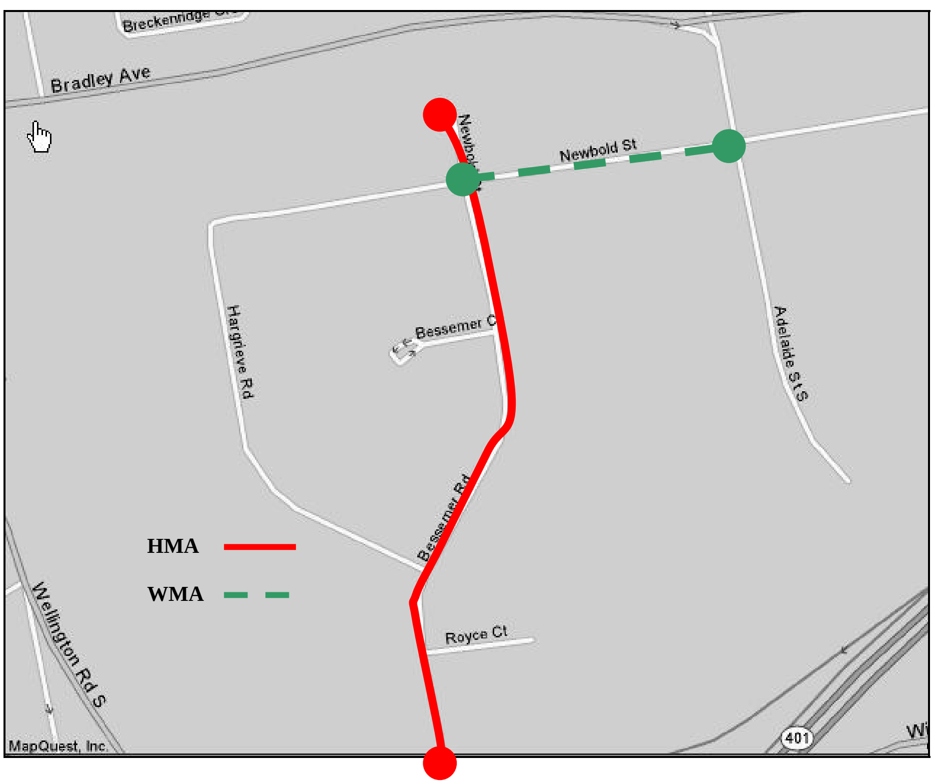

Figure 1. Location of Trial Section

4.0 MIX DESIGN

Table 1 shows the mix design blending data for the two mixes used in the London trial.

Table 1. Mix Design Blending Data for London Trial

Aggregate	Source	HL8	HL3
¾” Clear Stone	TCG	31.5	
HL3 Stone	TCG	11.5	36.4
Asphalt Sand	Towland	28.0	32.4
Asphalt Sand	TCG	14.0	16.2
RAP	TCG	15.0	15.0
PG 58-28	McAsphalt	4.1	4.4
Evotherm *	McAsphalt	6.07	6.52
* Based on Evotherm emulsion residue of 67.5%			

Note: PG is Performance Grade.
RAP is Reclaimed Asphalt Pavement.

The Marshall physical properties were tested by McAsphalt in their laboratory and are shown in Table 2.

Table 2. Mix Marshall Properties

Tests	HL8 Base		HL3 Surface	
	HMA	Evotherm	HMA	Evotherm
Mixing Temperature (ºC)	150	135	150	135
Compaction Temperature (ºC)	138	100	138	100
Bulk Relative Density (t/m^3)	2.398	2.386	2.390	2.373
Maximum Relative Density (t/m^3)	2.492	2.482	2.488	2.479
% Air Voids	3.8	3.87	3.9	4.28
% VMA	14.0	14.4	15.0	15.6
Marshall Stability @ 60ºC (N)	13733	11673	11701	9874
Flow Index @ 60ºC	9.7	9.3	9.0	9.0

Note: VMA is Voids in Mineral Aggregate.

Based on the data obtained in the laboratory, it was decided that a mixing temperature of 135ºC and a compaction temperature of 100ºC for the Evotherm warm mixes would satisfy the physical properties of the mix and specification.

5.0 PRODUCTION AND PLACEMENT OF MIXES

5.1 HL8-15% RAP Hot Mix

The hot mix production of the HL8 RAP was started at 6:30 am on June 12. The burner temperature was set at 232°C (450°F) to allow for the blending of 15 percent RAP into the mix at ambient temperature. The HL8 RAP mix was produced at approximately 155ºC and was leaving the plant at a temperature of around

150ºC (Figure 2a). The HL8 RAP mix was placed in two lifts over granular base on Bessemer Road, with each lift having a compacted depth of 50 mm.

The construction equipment used on site was a standard highway spreader, 12 ton double drum vibratory roller (Hamm), 20 ton pneumatic tired roller and small one ton static steel roller (Figure 2b).

Figure 2a: Plant Production

Figure 2b: Placement of HL8 RAP Mix

Figure 2. HL8 15 % RAP Production and Laydown

5.2 HL8-15% RAP Evotherm Warm Mix

The Evotherm warm mix was produced at the TCG Fanshawe plant. The TCG plant is a batch plant with a production rate of 200 tonnes per hour that uses a dry collector. The Evotherm emulsion arrived on site at a temperature of 85ºC and was offloaded into one of the plant asphalt cement storage tanks (Figure 3a). The emulsion was kept at a temperature of 82ºC (180°F).

Trial batch production started at approximately 7:00 am using a one tonne batch (Figure 3b). The burner was set at 193°C (380°F) to allow for the temperature drop due to the addition of 15 percent RAP and the Evotherm emulsion. The initial batch gave a discharge temperature of 94°C (200°F) out of the plant. The burner temperature was raised to 199°C (390°F) and this gave a mix discharge temperature of 100°C (212°F). To manufacture the warm mix, the objective is to determine at what temperature the burner must be set at in order to obtain a warm mix discharge temperature of 100ºC (212ºF). The plant operated with a dry mixing cycle of 5 seconds followed by the introduction of the Evotherm emulsion and a wet mixing cycle of 32 seconds. The jobsite is approximately 20 km from the plant (25 minute truck haul). The target temperature at the paver was set at 90 - 95ºC. The temperature loss during the haul was estimated at 5ºC. The target temperature at the plant in the truck was set at 100ºC.

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 batch size had to be reduced because of the capacity of the asphalt cement weigh hopper. This is because the emulsion is only 67 to 68 percent asphalt, which translates into 48 percent more liquid material, needed per tonne of mix to give the proper residual asphalt cement.

Figure 3a. Offloading of Evotherm Emulsion

Figure 3b. Production of Evotherm HL8 RAP

Figure 3. Plant Production of HL8 15% RAP Evotherm

The placement of the Evotherm HL8 RAP was like placing conventional hot mix (Figure 4). The mix was placed to a compacted depth of 50 mm and the resulting mat texture was very uniform with no evidence of segregation or tearing behind the screed. There were no differences in the rolling pattern for the warm mix as compared to the HL8 RAP hot mix and the breakdown roller was able to come right up to the back of the screed without any concerns of pushing or pickup on the drum. The workers comments on the Evotherm HL8 mix were that placement was very similar to hot mix, there were greatly reduced fumes, the paver was working harder and that handwork was more difficult due to the cooler temperatures of the mix. Also, the joints between the lanes seemed to knit together quite readily.

Samples were taken of the HL8 RAP hot mix and HL8 RAP Evotherm mix and brought back to the laboratory for testing. A number of the hot mix samples were tested for Marshall properties and the asphalt cement was recovered from the mixes so that Superpave™ testing protocols could be performed. In order to have enough material for the Superpave testing the recovered material from all the asphalt samples of each mix were combined into one sample. The test results on the mix and binder samples is discussed in Section 6.

Figure 4a: Placement of Bottom Lift

Figure 4b: Rolling First Lift of HL8 RAP Base

Figure 4c: Second Lane of First Lift

Figure 4d: Placement of Second Lift

Figure 4. Placement of Evotherm HL8 15% RAP Mix on Newbold Street

5.3 HL3-15% RAP Evotherm Warm Mix

The 50 mm surface lift of Evotherm HL3 was placed on July 10. The burner temperature was increased by five degrees from 199 to 201.5°C (390 to 395°F) from the HL8 mix due to the higher asphalt content in the HL3 mix. This burner temperature increase would keep the end discharge temperature of the mix at 100°C. There were no issues regarding the production of the mix at the plant.

The placement of the warm proceeded very smoothly and there were no issues or concerns with the mix. The mix was being placed between 90 - 95°C. The breakdown roller could come right to the back of the spreader. The pneumatic tired roller stayed back till the tires became warm and there was no evidence of pickup on the tires. Figure 5 shows pictures of the production and placement of the HL3 RAP warm mix. Approximately 450 tonnes of Evotherm HL3 warm mix were placed.

Figure 5a: Production of HL3 RAP Evotherm

Figure 5b: Placement of HL3 RAP Evotherm

Figure 5c: Placement of HL3 RAP Evotherm

Figure 5d: Rolling of HL3 RAP Evotherm

Figure 5e: Rolling Train – Evotherm HL3 Mix

Figure 5f: Construction Zone Traffic

Figure 5. Production and Placement of Warm Mix HL3 RAP Surface Lift

6.0 LABORATORY TESTING OF FIELD SAMPLES

Samples of the hot and warm mixes placed on Bessemer Road and Newbold Street were taken to McAsphalt's laboratory in Toronto and tested for compliance with the Ontario Provincial Standard Specification (OPSS) 1150 [7]. The following section details the test results obtained.

6.1 HL8-15% RAP Hot Mix

Two samples of HL8 15% RAP hot mix were taken from the jobsite at various intervals. The samples were tested in the laboratory for full Marshall testing. Table 3 shows that the results varied slightly above or below the target job mix formula - most likely due to RAP variations. As such, some of the Marshall properties (percent residual asphalt, 4.75mm sieve and percent air voids) are outside of the OPSS Form 1150 specification for Sample 2.

Table 3. HL8 15% Reclaimed Asphalt Pavement (RAP) Hot Mix Asphalt Field Samples

Truck/Load	**Job Mix Formula**	**1**	**2**	**OPSS Form 1150**
Time		**8:30 AM**	**3:46 PM**	
Sieve				
26.5 mm	100	100	100	100
19.0 mm	96.2	98.6	98.9	94 – 100
16.0 mm	86.8	91.1	90.4	77 – 95
13.2 mm	76.1	80.2	81.1	65 – 90
9.5 mm	64.3	69.4	68.8	48 – 78
4.75 mm	50.0	56.0	50.3	30 – 50
2.36 mm	42.1	47.7	43.1	21 – 50
1.18 mm	32.8	38.0	35.0	12 – 49
0.600 mm	18.5	20.2	19.1	6 – 38
0.300 mm	7.2	9.1	8.2	3 – 22
0.150 mm	4.3	5.3	4.6	1 – 9
0.075 mm	2.9	4.6	3.9	0 - 6
% Residual Asphalt	4.7	4.85	4.51	4.7 min
Bulk Recompacted Density (t/m^3)	2.398	2.363	2.347	
Maximum Theoretical Density (t/m^3)	2.492	2.477	2.488	
% Air Voids	3.8	4.6	5.7	3 – 5
Marshall Stability @ 60ºC (N)	13733	15942	13380	8000 min
Flow Index @ 60ºC	9.7	11.0	9.3	8.0 min
Penetration Recovered Asphalt Cement	116	48	50	

Note: OPSS is Ontario Provincial Standard Specification.

In typical hot mix production, the penetration values of asphalt cement recovered from field samples taken at the time of construction are normally about 60 to 70 percent or the original penetration (when no RAP is added to the mix). The recovered penetration values from the two HL8 15% RAP hot mix samples in Table 3 were 48 and 50, representing a reduction of 60 percent from the initial value of 116. However, the old Pen 4 program developed by the Ontario Ministry of Transportation (MTO) for predicting the recovered penetration when RAP is used in the mix accurately suggested that with 15% RAP (having a penetration of 16), the final penetration in the mix would be 52.

6.2 HL8 15% RAP Evotherm Warm Mix

As with the HL8 hot mix, three samples of the HL8 15% RAP produced with Evotherm were taken and tested for compliance to the OPSS Form 1150 specification (Table 4). Some variability in the split at the 4.75 mm sieve was observed, but overall the Marshall properties were considered acceptable. The test data on the three samples of HL8 warm mix tested show recovered penetrations of 80, 76, and 74 representing a 34 percent reduction from the initial value of 121 – almost half of the aging observed with the HL8 hot mix samples.

Table 4. HL8 15% Reclaimed Asphalt Pavement (RAP) Evotherm Warm Mix Samples

Truck	**Job Mix Formula**	**1**	**2**	**3**	**OPSS Form 1150**
Time		**8:40 AM**		**10:00 AM**	
Sieve					
26.5 mm	100		100	100	100
19.0 mm	96.2	100	98.1	98.2	94 - 100
16.0 mm	86.8	92.4	86.3	93.1	77 - 95
13.2 mm	76.1	82.4	73.1	81.1	65 – 90
9.5 mm	64.3	72.1	62.2	72.3	48 – 78
4.75 mm	50.0	60.2	52.8	60.5	30 – 50
2.36 mm	42.1	53.1	44.5	51.8	21 – 50
1.18 mm	32.8	43.7	35.6	40.9	12 – 49
0.600 mm	18.5	23.2	19.6	21.9	6 – 38
0.300 mm	7.2	9.8	9.0	9.6	3 – 22
0.150 mm	4.3	5.3	5.1	5.3	1 – 9
0.075 mm	2.9	4.6	4.3	4.5	0 - 6
% Residual Asphalt	4.7	4.84	4.60	5.16	4.7 min
Bulk Recompacted Density (t/m^3)	2.386	2.333	2.352	2.345	
Maximum Theoretical Density (t/m^3)	2.482	2.470	2.462	2.463	
% Air Voids	3.87	5.55	4.46	4.79	3 – 5
Marshall Stability @ 60ºC (N)	11673	9679	9786	9181	8000 min
Flow Index @ 60ºC	9.3	8.3	9.3	8.3	8.0 min
Penetration Recovered Asphalt Cement	121	80	76	74	

Note: OPSS is Ontario Provincial Standard Specification.

The results suggest that there are no production-related differences between the Evotherm HL8 mix and conventional HL8 hot mix, with the positive exception that less aging of the asphalt cement occurred with the Evotherm process. Furthermore, the use of RAP does not appear to affect the resulting properties of the warm mix to any greater degree than experienced with hot mix.

6.3 HL3 15% RAP Hot Mix

Two samples of HL3 15% RAP hot mix were taken from the jobsite at various intervals. The samples were tested in the laboratory for full Marshall testing and the results are as shown in Table 5. Based on the results obtained, the HL3 RAP mix is finer graded than the job mix formula and this is most likely due to RAP variations. The Marshall properties (voids, stability and flow index) fall within or slightly exceed the OPSS Form 1150 specification.

The recovered penetrations for the two HL3 HMA samples were 45 and 46, representing a 61 percent reduction from the original value of 116. The MTO Pen 4 program predicted a recovered penetration of 55.

Table 5. HL3 15% Reclaimed Asphalt Pavement (RAP) Hot Mix Samples

Truck/Load	**Job Mix Formula**	**1**	**2**	**OPSS Form 1150**
Time		**10:30 AM**	**4:45 PM**	
Sieve				
16.0 mm	100.0	100.0	100.0	100
13.2 mm	99.2	99.4	98.7	98 – 100
9.5 mm	88.4	90.8	86.7	75 – 90
4.75 mm	57.4	61.4	59.2	50 – 60
2.36 mm	47.7	50.5	49.0	36 – 60
1.18 mm	37.1	40.4	39.4	25 – 58
0.600 mm	20.8	22.8	22.5	16 – 45
0.300 mm	8.1	10.5	10.4	7 – 26
0.150 mm	5.0	5.4	5.3	3 – 10
0.075 mm	3.3	5.0	5.1	0 - 5
% Residual Asphalt	5.0	5.32	5.25	5.0 min
Bulk Recompacted Density (t/m^3)	2.390	2.361	2.366	
Maximum Theoretical Density (t/m^3)	2.488	2.462	2.457	
% Air Voids	3.9	4.1	3.7	3 – 5
Marshall Stability @ 60ºC (N)	11701	14649	14519	8900 min
Flow Index @ 60ºC	9.0	10.2	10.2	8.0 min
Penetration Recovered Asphalt Cement	116	45	46	

Note: OPSS is Ontario Provincial Standard Specification.

6.4 HL3 15% RAP Evotherm Warm Mix

Two samples of the HL3 15% RAP mix produced with Evotherm were taken and tested for compliance to the OPSS Form 1150 specification (Table 6). The results displayed higher asphalt content than the design but overall the Marshall properties were good.

The test data on the two samples of HL3 warm mix tested show recovered penetrations of 80 and 82 representing a reduction of only 32 percent from the original value of 118. This indicates that the recovered penetration values obtained on the warm mix samples with RAP are typical of what one would expect with a virgin conventional hot mix after going through the hot mix plant. Information gathered from previous warm mix trials has shown that the penetration drop with warm mix (with no RAP added) has been only 12 to 15 percent [1]. Certainly the lower age hardening should translate into longer service life for the warm mix (both virgin and recycled) as compared to the virgin or recycled hot mix. Future work will determine if this is the case.

Table 6. HL3 15% Reclaimed Asphalt Pavement (RAP) Evotherm Warm Mix Samples

Sample	**Job Mix Formula**	**1**	**2**	**OPSS Form 1150**
Sieve				
16.0 mm	100.0		100.0	100
13.2 mm	99.2	100.0	99.4	98 – 100
9.5 mm	88.4	85.5	88.4	75 – 90
4.75 mm	57.4	55.5	56.4	50 – 60
2.36 mm	47.7	46.4	47.0	36 – 60
1.18 mm	37.1	37.3	37.7	25 – 58
0.600 mm	20.8	20.9	21.0	16 – 45
0.300 mm	8.1	9.4	9.5	7 – 26
0.150 mm	5.0	5.0	5.0	3 – 10
0.075 mm	3.3	4.1	3.9	0 - 5
% Residual AC	5.0	5.25	5.21	5.0 min
Bulk Recompacted Density (t/m^3)	2.373	2.343	2.342	
Maximum Theoretical Density (t/m^3)	2.479	2.465	2.446	
% Air Voids	4.28	4.94	4.25	3 – 5
Marshall Stability @ 60ºC (N)	9874	9786	8683	8900 min
Flow Index @ 60ºC	9.0	13.3	13.0	8.0 min
Penetration Recovered Asphalt Cement	118	80	82	

Note: OPSS is Ontario Provincial Standard Specification.

6.5 Superpave Performance Graded Asphalt Cement Testing

Asphalt cement was recovered from the Evotherm emulsion, as well as extracted from the HL8 RAP and HL3 RAP samples (hot and warm) using the Abson recovery method [8]. The asphalt cement was tested according to the Superpave protocols [9] (including direct tension) to determine whether or not the warm mix was age hardening the recovered asphalt to the same degree as conventional hot mix. Table 7 contains the resulting data obtained from the hot mix samples and is compared to the base asphalt used to produce the hot mix. The base asphalt cement (PG 58-28) was supplied from the Port Stanley facility. Table 8 contains the data from the warm mixes. The Evotherm emulsion was produced at the Oshawa facility, which uses a slightly different PG 58-28 than the Port Stanley facility.

The data on the recovered asphalt cement from the conventional recycled hot mix shows the influence of the RAP. The high temperature results have increased three to four degrees from the original virgin binder, which is typical due to the RAP binder being heavily aged.

Table 7. Superpave Binder Data from Hot Mix Samples

Sample	**PG 58-28**	**HL8**	**HL3**	**Specified**
Tests on Original Asphalt				
Rotational Viscosity, Pa.s, @ 135ºC @ 165ºC	0.300 0.088	NA	NA	3.0 max
DSR, G*/Sin δ, kPa,@ 52ºC @ 58ºC @ 64ºC	 1.250 0.570	 NA	 NA	1.0 min
RTFO Residue (AASHTO T240)				
Mass Change, %	0.618	NA	NA	1.0 max
DSR, G*/Sin δ, kPa, @ 58ºC @ 64ºC @ 70ºC	3.220 1.44	4.00 1.77	 2.81 1.30	2.2 min
PAV Residue (AASHTO R18) ºC	100	100	100	
DSR, G*x Sin δ, kPa,@ 19ºC @ 16ºC	3982 6142	4758 6938	4604 6601	5000 max
Bending Beam Rheometer Creep Stiffness @ -12ºC, MPa @ -18ºC, MPa @ -24ºC, Mpa Slope, m-value @ -12ºC, MPa @ -18ºC, Mpa @ -24ºC, Mpa	 104.0 225.5 476.0 0.371 0.316 0.255	 99.4 210.5 456.0 0.356 0.315 0.262	 139.0 247.0 487.0 0.322 0.292 0.244	 300 max 0.300 min
Temperature Range (BBR Basis)	**59.7-29.3**	**62.4-29.7**	**65.9-27.0**	
Temperature Range (Direct Tension)	**59.7-28.7**	**62.4-28.5**	**65.9-28.1**	
Penetration @ 25ºC, 100g, 5 sec	116	49	45	

Note: PG is Performance Grade.
DSR is Dynamic Shear Rheometer.
PAV is Pressure Aging Vessel.
BBR is Bending Beam Rheometer.

The data in Table 8 shows that the Evotherm emulsion residue is very similar to the original base asphalt as far as the PG temperature range. The slight differences in the stiffness values could be attributed to the distillation method used to obtain the residue, as in order to remove all the water, the temperature was held at 150ºC for 30 minutes. The major difference arises in the material recovered from the field samples. There appears to have been almost no shift in the temperature range at the high end and the low end. This would indicate that the asphalt cement is not age hardening to the same extent going through the plant mixing and transportation stages of production as in the hot mix process. There is some influence of the RAP on the lower temperature but definitely not affecting the top. This could also explain the why the mix appears more tender and remains more workable at lower temperatures.

Table 8. Superpave Binder Data from Warm Mix Samples

Sample	PGAC	Emulsion Residue	**HL8**	**HL3**	**Spec**
Tests on Original Asphalt					
Rotational Viscosity, Pa.s, @ 135ºC @ 165ºC	0.321 0.109	0.325 0.115	NA	NA	3.0 max
DSR G*/Sin δ, kPa,@ 52ºC @ 58ºC @ 64ºC	 1.270 0.580	 1.28 0.59	 NA	 NA	1.0 min
RTFO Residue (AASHTO T240)					
Mass Change, %	0.251	0.371	NA	NA	1.0 max
DSR G*/Sin δ, kPa, @ 52ºC @ 58ºC @ 64ºC	 3.030 1.340	 2.58 1.15	 3.05 1.38	 2.45 1.10	2.2 min
PAV Residue (AASHTO R18) ºC	100	100	100	100	
DSR G*x Sinδ, kPa,@ 19ºC @ 16ºC	3333 5107	3433 5347	4577 6647	4541 6776	5000 max
Bending Beam Rheometer Creep Stiffness @ -12ºC, MPa @ -18ºC, MPa @ -24ºC, Mpa	 89.0 195.0 439.0	 73.3 179.0 469.0	 99.1 227.0 446.0	 102.0 218.0 467.0	 300 max
Slope, m-value @ -12ºC, MPa @ -18ºC, Mpa @ -24ºC, Mpa	0.364 0.318 0.269	0.385 0.333 0.268	0.364 0.314 0.258	0.371 0.315 0.231	0.300 min
Temperature Range (BBR Basis)	**59.8-30.2**	**59.2-31.2**	**60.5-29.5**	**58.8-29.1**	
Temperature Range (Direct Tension)	**59.8-29.1**	**59.2-27.6**	**60.5-28.4**	**58.8-29.1**	
Penetration @ 25ºC, 100g, 5 sec	121	118	77	81	

Note: PG is Performance Grade.
DSR is Dynamic Shear Rheometer.
PAV is Pressure Aging Vessel.
BBR is Bending Beam Rheometer.

7.0 EMISSIONS TESTING

As part of the Evotherm trial, emissions data was collected in the stack at the hot mix plant (Figure 6). 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 Ortech Environmental Limited to perform the emissions testing at TCG's Fanshawe hot mix plant [10]). 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).

Figure 6a: Location of Sampling Ports

Figure 6b: Sampling Equipment

Figure 6. Emissions Testing Location and Equipment

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 6a. 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 as listed in Table 9, which are recognized by the Ontario Ministry of Environment (MOE) for compliance sampling programs [11].

Table 9. Emissions Sampling Methods

Combustion Gas	Test Method
Oxygen (O_2)	US EPA Method 3A
Carbon Dioxide (CO_2)	US EPA Method 3A
Carbon Monoxide (CO)	US EPA Method 10
Sulphur Dioxide (SO_2)	US EPA Method 6C
Nitrogen Oxides (NOx)	US EPA Method 7E
Total Hydrocarbons (THC) as methane	US EPA Method 25A

The hot mix combustion gas data was collected on June 12, while the warm mix (Evotherm) data was collected on June 13 with the results reported in Table 10. Emissions data was only collected on the base mixes and not on the surface course mixes.

The initial testing on the hot mix had no interruptions in production and provided a continuous stream of data. During the warm mix testing, there were numerous process interruptions due to mechanical problems at a neighbouring TCG hot mix plant. Due to the problems at the other plant, TCG had to produce hot mix at the Fanshawe plant in order to satisfy their other customers. This caused interruptions in the production of warm mix and testing was stopped and started numerous times to accommodate both the hot mix and warm mix production.

Table 10. Combustion Gas Sampling Results

Combustion Gas	Concentration		% Reduction
	Hot Mix	Warm Mix	
Particulate Matter Concentration	379 mg/Rm^3 (1)	403 mg/Rm^3 (2)	
Oxygen (O_2)	15.85 %	16.48 %	
Carbon Dioxide (CO_2)	2.19 %	1.81 %	+17.35
Carbon Monoxide (CO)	41 ppm	33 ppm	+19.51
Sulphur Dioxide (SO_2)	2.9 ppm	3.4 ppm	-17.24
Oxides of Nitrogen (as NO_x)	30 ppm	24 ppm	+20.00
Total Hydrocarbons (THC) as methane	91 ppm$^{(2)}$	68 ppm$^{(2)}$	+25.27

(1) dry at 25°C and 1 atmosphere.
(2) dry by volume.
ppm is concentration in parts per million.

Figure 7 shows the emissions data comparison graphically.

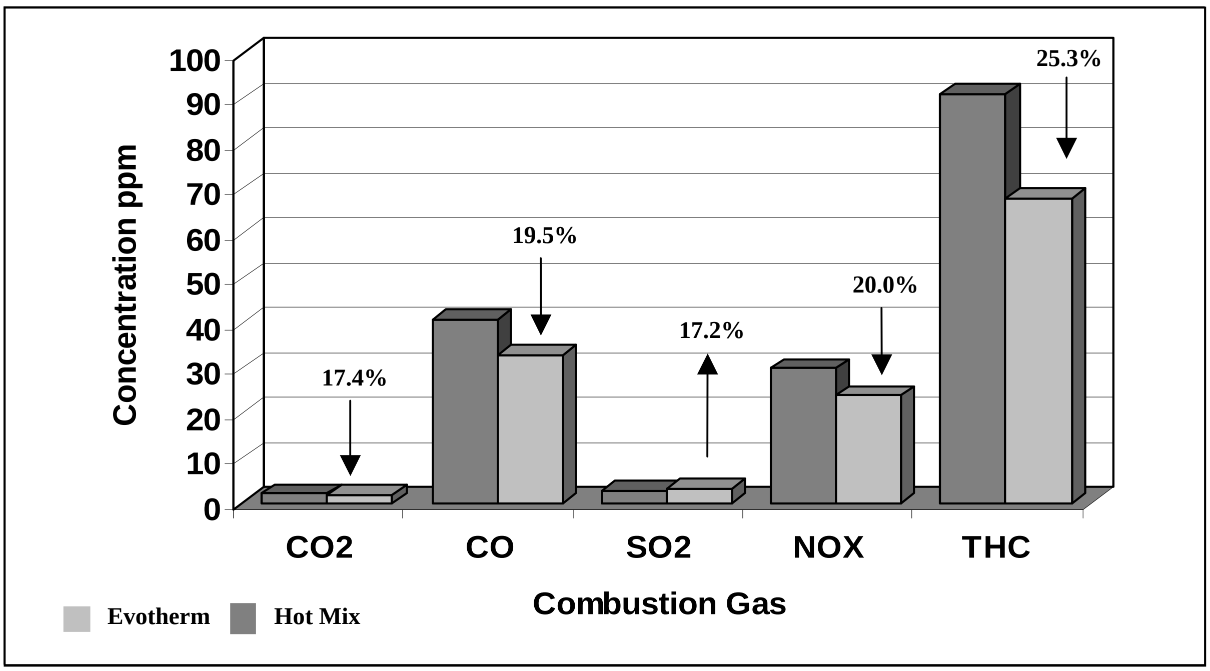

Figure 7. Emissions Data taken from Stack

8.0 ENERGY CONSUMPTION

Energy consumption during production of the hot and warm mixes was monitored and the data obtained is shown in Table 11. The data shows that there is a slight decrease in the quantity of fuel used to produce one tonne of the warm mix versus the equivalent hot mix. The TCG people mentioned that the Fanshawe plant is a very efficient plant as far as energy consumption, which may partially explain why there was only a slight decrease in consumption.

Table 11. Energy Consumption Data

Fuel	HL8 15% RAP		HL3 15% RAP	
	Evotherm	HMA	Evotherm	HMA
m^3/tonne	7.649	7.783	8.705	9.129
% Change	-1.75		-4.87	

Note: RAP is Reclaimed Asphalt Pavement.
HMA is Hot Mix Asphalt.

9.0 OBSERVATIONS AND COMMENTS

Based on the field trial, the following comments and observations are made regarding plant production, placement, compaction and post construction.

9.1 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 well-coated and black in colour. The batch size had to be reduced due to the limitations in the capacity of the asphalt weigh hopper. As the Evotherm emulsion is only 68 percent residue, the quantity of emulsion needed per tonne of mix is approximately 45 percent higher. The operating temperature of the aggregate dryer was 199°C for the HL8 warm mix compared to 232°C for the HL8 hot mix. The aggregate dryer temperature for the HL3 warm mix was 201.5°C, while the temperature for the HL3 hot mix was 235°C. The dryer temperature had to be increased due to the higher quantity of Evotherm emulsion in the mix. The HL8 mixes contained 4.7 percent residual asphalt while the HL3 was manufactured with 5.0 percent residual asphalt.

9.2 Paver

The comments from the paving crew included that the mix smelled slightly different, fumes were much lower and that it was harder to work with when handwork was required. The paver operator also mentioned that the paver had to work harder to lay the material and the sound of the machine was noticeably different. The Evotherm mix flowed under the paver screed without any evidence of tearing behind the screed. The mix flowed out of the truck the same as conventional hot mix and there was no evidence of the mix agglomerating in the bed of the truck due to the lower temperature. The paver crew summed it up that it was like laying conventional hot mix, with less irritating fumes. The lower temperatures also made the crew happy - especially on a hot day. Therefore, the only major drawback was that handwork was an issue, although every paving crew that has worked with warm mix has made this comment.

9.3 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. The use of vibratory mode on the breakdown roller showed no evidence of cracking of the mat. There was some evidence of some minor build-up of mix on the pneumatic tired roller, but nothing of significance. There was no steam coming off the mat during breakdown rolling. The longitudinal joint between lanes appeared to be very tight. There did not seem to be any difference in compacting the mix at 95ºC compared to compacting the mix at 80ºC. The mix compacted just like hot mix.

9.4 Post Construction

The Evotherm mix has the appearance of hot mix although it appears to stay tender for an extended period of time. It would seem to cool at a slower rate and remain more workable at the lower temperatures of 40 to 50ºC. The pictures in Figure 8 show the overall appearance of the project after nine months of service.

Figure 8a: Newbold Street (WMA) Looking East **Figure 8b. Newbold Street (WMA) looking West**

Note: WMA is Warm Mix Asphalt, HMA is Hot Mix Asphalt.

Figure 8c. Bessemer Road (HMA) looking North **Figure 8d. Bessemer Road (HMA) looking South**

Figure 8. Finished Evotherm Project After Nine Months

10.0 CONCLUSIONS

The Evotherm trial in London has confirmed what had been seen in other trials and alleviated many concerns related to a new process [12-14]. The following conclusions can be made:

1. The direct substitution of Evotherm emulsion for asphalt cement creates no issues.

2. The warm mix created no issues during production or placement.

3. The volumetric properties can be met and compare favourably with hot mix.

4. The warm mix can be compacted using conventional equipment and rolling patterns.

5. The use of RAP in the mix did not have any effect on the physical properties and had no effect on field production.

6. The process uses less fuel to produce a tonne of warm mix versus hot mix.

7. The greenhouse gas emissions are lower for the warm mix than the comparable hot mix.

The following recommendations should be implemented in further trials.

1. The use of higher RAP contents should be evaluated in future trials:

2. Future trials should always have a HMA control section using the same mix so that direct comparisons can be made with regards to emissions, energy consumption, as well as compaction and mix property data.

3. More extensive testing should be done on the materials such as creep compliance, fatigue testing and dynamic modulus.

4. The finished trials should be monitored on a regular basis. Cores should be taken regularly to monitor the age hardening of the warm mix in comparison to the hot mix.

REFERENCES

[1] Davidson JK, Tighe S, Croteau J-M. "Paving the Way to Environmentally Friendly Pavements Through Innovative Solutions", Proceedings, Canadian Technical Asphalt Association, 51, 97-121 (2006).

[2] Hurley GC, Prowell BD. "Evaluation of Aspha-Min® Zeolite for Use in Warm Asphalt Mixes", Report 05-04, National Center for Asphalt Technology (NCAT), Auburn, Alabama (June 2005).

[3] Hurley GC, Prowell BD. "Evaluation of Sasobit® for Use in Warm Asphalt Mixes", Report 05-06, National Center for Asphalt Technology (NCAT), Auburn, Alabama (June 2005).

[4] Koenders DA, Stoker DA, Robertus C, Larsen O, Johansen J. "WAM-Foam, Asphalt Production at Lower Operating Temperatures", Proceedings, Ninth International Conference on Asphalt Pavements, International Society for Asphalt Pavements (ISAP), Copenhagen, 2002.

[5] Romier A, Audeon M, David J, Martineau Y. "Low-Energy Asphalt (LEA) with the Performance of Hot-mix Asphalt (HMA)", European Roads Review, Special Issue 2, Revue Générale des Routes et Aérodromes, 20-29 (2004).

[6] Hurley GC, Prowell BD. "Evaluation of Evotherm® for Use in Warm Asphalt Mixes", Report 06-02, National Center for Asphalt Technology (NCAT), Auburn, Alabama (January 2006).

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

[8] ASTM International (ASTM) D1856, "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, Pennsylvannia (2005).

[9] 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).

[10] Belore C. "Particulate and Gaseous Emission Testing at TCG Asphalt Plant London, Ontario" Ortech Environmental Report, (July 14, 2006).

[11] U.S. Environmental Protection Agency, Federal Register, Part 60, Appendix A. July 2003.

[12] Davidson J. K., "Evotherm Trial, Aurora Ontario, August 8 2005", McAsphalt Engineering Services Internal Report, August (2005).

[13] Davidson J. K., "Evotherm Trial, City of Calgary, September 28 2005", McAsphalt Engineering Services Internal Report, (2005).

[14] Davidson J. K., "Evotherm Trial, Ramara Township Ontario, October 4, 5 2005", McAsphalt Engineering Services Internal Report, (2005).