ENVIRONMENTAL BENEFITS OF WARM MIX ASPHALT TECHNOLOGIES: EXPERIENCE OF THE CITY OF CALGARY

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ABSTRACT

Development of Sustainable pavement infrastructure development with environmentally friendly alternatives is preferred to reduce greenhouse gas emissions. Warm mix asphalt (WMA) is identified as one of the alternative to the typical hot mix asphalt (HMA) used on pavement construction to reduce these emissions. WMA technology allows an asphalt mix to be prepared and placed at lower temperatures than conventional hot mix. This study is focused on a comparative study of three WMA mixes and a HMA control mix used in the construction of an environmentally focused subdivision in the City of Calgary, Alberta, Canada. The scope of the study covers aspects related to asphalt plant production, asphalt plant emissions, construction, laboratory performance, and initial road performance with different WMA technologies in comparison to HMA. Paper reports on the findings related to the asphalt plant production, asphalt plant emissions, and construction stage of the study. The advantages of using WMA technology were evidenced during the mix manufacturing and road construction stages. The WMA mixes showed reduced emissions, lower fuel consumption, reduced smoke and odors, improved safety and working environment, improved mix workability, extended compaction time, more uniform compaction, and reduced thermal segregation. The laboratory evaluation showed that the WMA mixes behaved similar or superior to the HMA mixes. WMA mixes had similar rutting and fatigue resistance, better low temperature behavior, higher laboratory workability, and similar stripping susceptibility, than the conventional HMA mixes. However WMA mixes showed slightly lower mix stiffness at high temperature compared to HMA mixes.

Keywords: greenhouse gas emissions, warm mix asphalt, hot mix asphalt, plant emissions, environment

1. INTRODUCTION

1.1 Background

Warm Mix Asphalt (WMA) technology has gained acceptance as a feasible and reliable alternative to Hot Mix Asphalt (HMA) paving. The conventional HMA mixes can be produced at reduced manufacturing temperatures with the use of WMA technologies. The main benefits derived from the use of WMA technologies are: lower consumption of fossil fuels, reduced emissions, reduced smoke and odors, improved comfort, safety and working environment, improved workability, extended compaction time, more uniform compaction, reduced thermal segregation, proven performance in warm and colder climates, and ability to incorporate high contents of recycled materials (D'Angelo, J., et. al, 1988, Prowell, B., et, al, 2007, Corteau, J.M., et. al, 2008). There are different technologies available to produce WMA mixes. The Double-Barrel® Green System (DBG) requires an Astec Double Barrel® drum asphalt plant and uses a multi-nozzle foaming device (See Figure 1) to microscopically foam a standard grade asphalt binder with water (Astec, 2008). In the process, a small amount of water is introduced through the nozzles, causing the asphalt binder to foam. This foam temporarily lowers mixture viscosity and allows for the production, placement, and compaction of a high quality mix at lower temperatures than conventional HMA. In order to implement this foaming process on a Double Barrel® drum asphalt plant, the only plant modification involves the installation of the foaming manifold over the existing asphalt injection system on the outer drum of the plant and installation of corresponding asphalt binder and water feed lines into the manifold.

Figure 1: Double Barrel® Drum and Green System (Astec, 2008, Hot-Mix magazine, 2009)

The Gencor Ultrafoam GX™ process also uses the foaming action resulting when the hot asphalt binder contacts the water causing the water to be converted to steam. Figure 2 shows the Gencor Ultrafoam GX™ green machine system. The steam produced is contained within the asphalt cement in the form of small bubbles. The water and hot binder can be introduced at different flow rates, temperatures, and pressures. The system has a centrally located spring loaded water valve that will open when the pressure of the water is impressed behind the valve. This device has the advantage that it can be attached to a variety of drum mix plants (Kvasnak, A., et al., 2010).

Figure 2: GENCOR Ultrafoam GX™ System (Gencor, 2010)

A non-aqueous liquid warm mix additive called HyperTherm is another technology to produce WMA. The additive is either pre-doused or added in-line with the liquid asphalt cement. While the physical properties of the asphalt cement binder remain substantially unchanged, HyperTherm improves the coating properties which improve the mix workability. The enhanced workability allows asphalt mix to be produced and placed at lower temperatures than conventional hot mix temperatures (Manolis S. et al., 2008)

2. OBJECTIVE AND SCOPE

The objective of this study is to evaluate the performance of three WMA mixes produced by different WMA technologies in comparison to conventional HMA mix used in the construction of a residential subdivision in the City of Calgary.
Asphalt mixes used to construct the trial sections are produced by using following methods.

- WMA water-foaming processes - ASTEC's Double Barrel® Green system and GENCOR's Ultrafoam GX™ processes,
- WMA chemical additive - Hypertherm
- Conventional HMA

The two WMA mixes produced by the ASTEC's Double Barrel ® Green system and the GENCOR's Ultrafoam GX™ process will be referred to as ASTEC Foaming and GENCOR Foaming in this paper. The WMA mix produced by using the WMA additive HyperTherm was also produced in the GENCOR drum plant and will be referred to as GENCOR HyperTherm. Finally, the conventional HMA was also mixed in the GENCOR drum plant and will be referred to as GENCOR Conventional.

3. PROJECT DESCRIPTION

A residential subdivision in the neighborhood of "Garrison Green" in the South-West area of the City of Calgary was chosen for this study. The subdivision is located adjacent to Glenmore Trail between Richard Rd SW and Crowchild Trail (See Figure 3). The traffic in this area is mainly residential with an expected number of Equivalent Single Axle Loads (ESAL's) being lower than 500,000 ESAL's. The paving project was divided in four sections, one section for each one of the three WMA technologies and one section for the conventional mix (See Figure 3). Table 1 depicts the description of each section.

Table 1: Description of Experimental Sections

Section	Technology	Plant	Plant Type	Plant Manufactured Year
GENCOR Foaming	Water-foaming	Lafarge – Calgary Bow River	Counter-flow Drum	2000
GENCOR HyperTherm	Chemical additive	Lafarge – Calgary Bow River	Counter-flow Drum	2000
GENCOR Conventional	Conventional HMA	Lafarge – Calgary Bow River	Counter-flow Drum	2000
ASTEC Foaming	Water-foaming	Lafarge – Calgary Spy Hill	Double Barrel Drum	2008

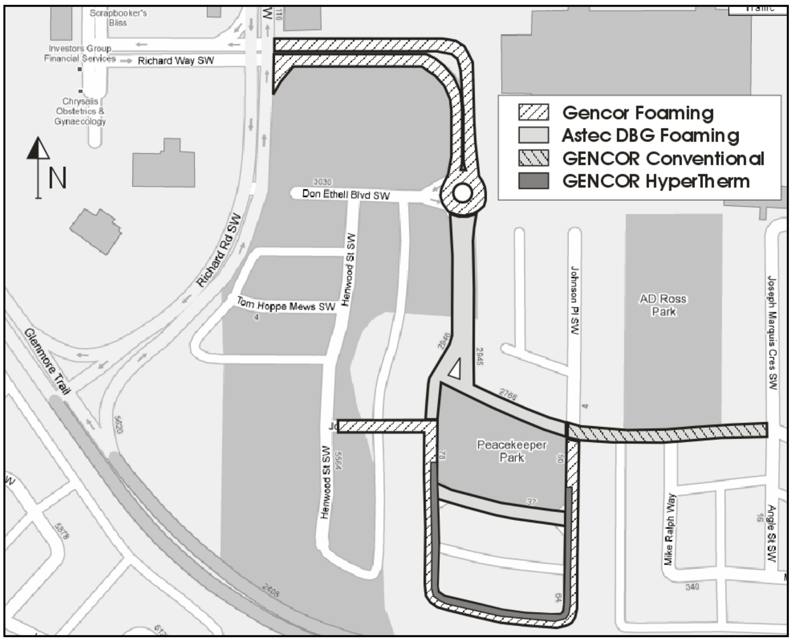

Figure 3: Project Location and Experimental Sections.

4. ASPHALT MIX DESIGN

Marshall Mix Design was used to prepare the asphalt mixes according to The City of Calgary standard specifications for asphalt concrete Mix (Type B-50) (Standard Specification, 2009). 15% of Reclaimed Asphalt Pavement (RAP) was also used in the mix design. Preparation of the asphalt mix samples was conducted in accordance with the Marshall Method of Mix Design as outlined in the 6th edition of the Asphalt Institute Manual Series No.2 (MS-2), and Alberta Transportation design procedure TLT-301 (2003). The design was based on a Marshall Hammer 50 blow per face compactive effort incorporating Imperial Oil 150/200A Grade asphalt cement. Liquid anti-strip (produced at a concentration of 0.3% by weight of binder) was added to all the mixes. At a design asphalt content of 6.0% by mass of total mix, the following Marshall properties were obtained (Table 2 and Table 3).

Table 2: Marshall Mix Design Properties

Sieve Sizes (mm)	Mix Design Results	City of Calgary B-50 mix Specification
A.C. Content, by Mix, (%)	6.0	6.0 min.
Voids in Mineral Aggregates, (%)	16.0	14.0 min.
Voids Filled with Asphalt, (%)	75.7	-
Air Voids, (%)	3.9	3.0 to 5.0
Marshall Stability, (kN)	9.4	7.1 min.
Flow, (0.25mm units)	11	10 to 16
Film thickness, (μm)	9.2	7.0 min.

Retained Stability, (%)	92.5	75.0 min.

Table 3: Mix Design Aggregate Gradation

Sieve Sizes (mm)	Mix Design Results	City of Calgary B-50 Specification
25.000	100	100 – 100
20.000	100	100 – 100
16.000	100	97 – 100
12.500	98	95 – 100
10.000	91	88 – 94
5.000	62	59 – 65
2.500	50	47 – 53
1.250	42	39 – 45
0.630	33	30 – 36
0.315	16	13 – 19
0.160	7.5	4.5 – 10.5
0.080	5.4	4.0 – 6.4

5. PLANT PRODUCTION

The asphalt plant settings were adjusted to produce WMA mixes at mix temperatures of 125±5ºC for all the three WMA mix types. A uniform coating of the asphalt was evident at this mix temperature for both the ASTEC Double Barrel and the GENCOR plant. The HMA mix was also produced following conventional procedures in the GENCOR drum mix plant. Table 4 depicts the plant production settings and recorded production data for the different types of mixes.

Table 4: Plant production data

Measurement	GENCOR Foaming	ASTEC DBG Foaming	GENCOR HyperTherm	GENCOR Conventional
Average Aggregate temperature, (ºC)	158	158	158	158
Average Asphalt cement temperature, (ºC)	137	151	138	135
Average Asphalt mix temperature, (ºC)	120	127	124	150
Water concentration - weight of AC, (%)	2.0	2.0	-	-
Baghouse inlet temperature, (ºC)	104	89	105	120
Baghouse outlet temperature, (ºC)	77	72	78	86
Plant production, (tonnes/hour)	171	225	177	176
Silo discharge temperature, (ºC)	122	126	127	150

The quality control properties of the plant produced mixes are depicted in Table 5. It is note that the measured moisture content of the conventional HMA mix is similar to the mix moisture contents of the three WMA mixes.

Table 5: Plant Produced Asphalt Mix Properties

Sieve Sizes (mm)	Mix Design	GENCOR Foam	ASTEC Foam	GENCOR HyperTherm	GENCOR Conventional	City of Calgary Specification
25	100	100	100	100	100	100 – 100
19	100	100	100	100	100	100 – 100
16	100	99.6	100	100	100	97 – 100
12.5	98	95.3	96.5	95.2	97.4	95 – 100
9.5	91	88.2	89.8	88.2	91.0	88 – 94
4.75	62	65.6	64.1	62.8	62.1	59 – 65
2.36	50	50.7	50.2	48.3	47.9	47 – 53
1.18	42	41.0	42.0	39.2	39.6	39 – 45
0.6	33	32.9	34.6	31.6	32.4	30 – 36
0.3	16	17.1	18.1	16.4	17.4	13 – 19
0.15	7.5	7.9	8.5	7.7	7.7	4.5 – 10.5
0.075	5.4	5.6	5.1	5.5	5.2	4.0 – 6.4
AC Content (%)	6.0	6.01	6.03	6.05	6.00	6.0 min.
Air Voids (%)	3.9	3.8	3.9	3.7	3.7	3.0 – 5.0
Mix Moisture	-	0.10	0.12	0.10	0.10	-
VMA	16.0	16.1	15.9	16.0	16.0	14.0 min
VFA	75.7	77.0	77.6	77.1	77.1	-

Note: AC is asphalt cement, VMA is voids in mineral aggregates, and VFA is Voids filled with asphalt.

One of the most important characteristics when using a WMA technology is the reduction of emissions during the manufacturing of WMA mixes. The testing of plant emissions were conducted on the stack of the baghouse with a flue gas analyzer during the production of the different mixes. The reduction in carbon dioxide, carbon monoxide and nitrogen oxides were determined. Both plants use a natural gas fuel source. As an example of the difference in emissions produced with the WMA and HMA mixes, Figure 4 illustrates the amount of emissions at the silo discharge for the GENCOR Conventional HMA mix and the GENCOR Foam WMA mix. Notice the lower amount of emissions produced with the use of a WMA technology for the production of asphalt mixes. Similar visual reduction in emissions was observed for the other WMA technologies. The reduction in carbon monoxide, carbon dioxide, and nitrogen oxide with the use of the WMA technologies are summarized in Table 6. The three WMA technologies indicated similar reduction in plant production emissions.

Figure 4: Example of Asphalt Mix Emissions at the Plant. Left GENCOR Foam. Right GENCOR Conventional

Table 6: Percentage Reduction in Plant Emissions

	GENCOR Foaming	**ASTEC DBG Foaming**	**GENCOR HyperTherm**
Carbon Monoxide (CO)	14.85%	10.4%	13.53%
Nitrogen Oxides (NO_X)	5.9%	8.3%	5.8%
SO2 (mg/m^3)	0.0%	- 14.3%	0.0%
Carbon Dioxide (CO_2)	10.0%	10.9%	10.0%

6. ROAD CONSTRUCTION

For the lay down and compaction of the different mixes, the paving of the experimental sections were scheduled in such a way that each mix was produced on a separate day. This allowed the required time to collect the plant, field data and the samples for the laboratory testing. The different mixes were produced and placed in consecutive days in order to maintain as close as possible the same environmental conditions. Mix temperature behind the paver, extended mix thermal segregation, extended mix cooling rate, and extended mix compaction were measured to evaluate the performance of the different mixes during road construction.

The reduction in plant emissions observed with the three WMA technologies was also observed during road construction operations where improved comfort, safety and working environment of the paving crew was evident (Figure 5). It was also observed that the mixes produced with the three WMA technologies do not require any special consideration with respect to haulage, material handling, placement and compaction.

Figure 5: Emission during Road Construction Operations. Left- GENCOR HyperTherm. Right- GENCOR Conventional

The difference in mix temperature between the WMA mixes and the HMA mix during the lay down operations was measured by infrared thermograph images. Figure 6 illustrates an example of a thermographic image taken behind the paver for the GENCOR HyperTherm mix and Figure 7 depicts the difference in temperature measured behind the paver for the different mixes. Notice the difference in temperature between the conventional HMA mix and the three WMA mixes. Thermographic pictures were also used to measure the difference in extended mix thermal segregation. Figure 8 depicts examples of thermographic pictures and Table 7 contains the standard deviation of temperatures and the difference between the maximum and minimum temperature for each type of mix. As noticed in Figure 8 and Table 7, the asphalt mixes prepared with the three WMA technologies have lower thermal segregation than the conventional HMA mix. The three WMA mixes depicted similar reduction in thermal segregation. Asphalt mixes with lower thermal segregation tend to have more uniform mat densification.

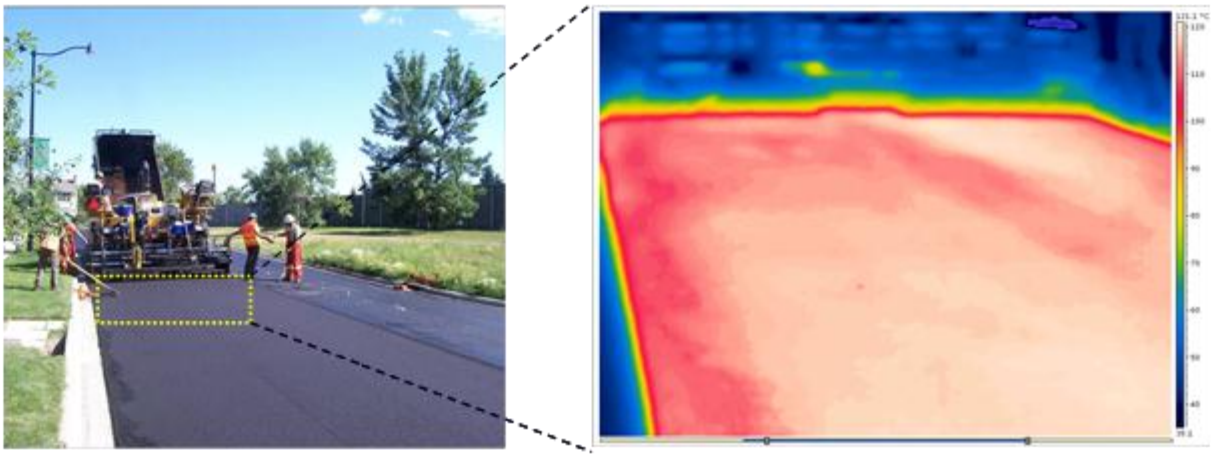

Figure 6: Example of a Thermograpic Image behind the Paver. GENCOR HyperTherm

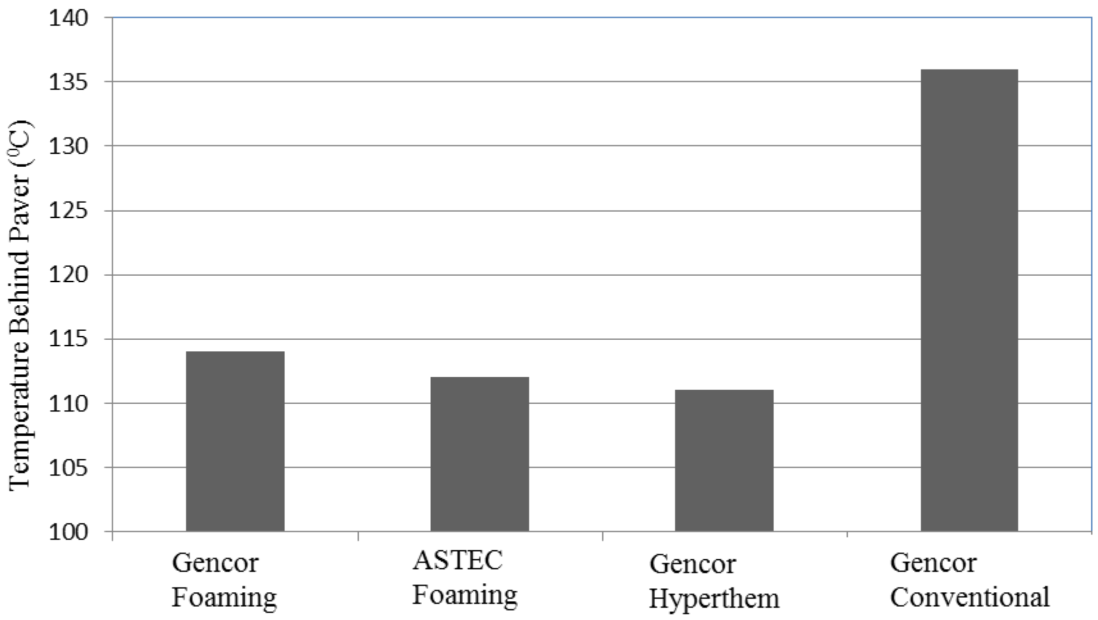

Figure 7: Temperature behind the Paver, ºC.

Table 7: Thermal Segregation

	GENCOR Foaming	ASTEC DBG Foaming	GENCOR HyperTherm	GENCOR Conventional
Temperature standard deviation	2.872	2.520	2.538	6.681
Maximum Difference (ºC)	16.0	14.9	15.2	35.6

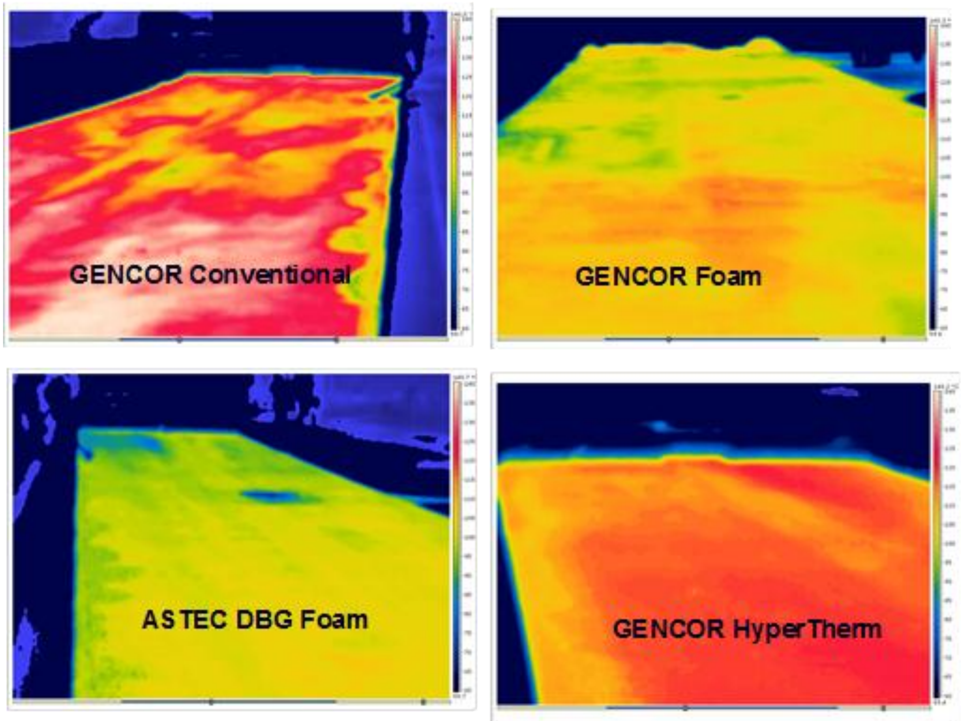

Figure 8: Mix Thermal Segregation, ºC.

Cooling plots of mix surface temperature were generated from thermographic images. For each mix type, consecutive images at the same spot were with the time. Figure 9 depicts the cooling plots for the different asphalt mixes. The three WMA mixes show similar cooling rates and a slower cooling rate than the conventional HMA mix. The slower cooling rates gained with the use of the WMA technologies increase the time available for compaction and can help in extending the paving season into the colder months of the year.

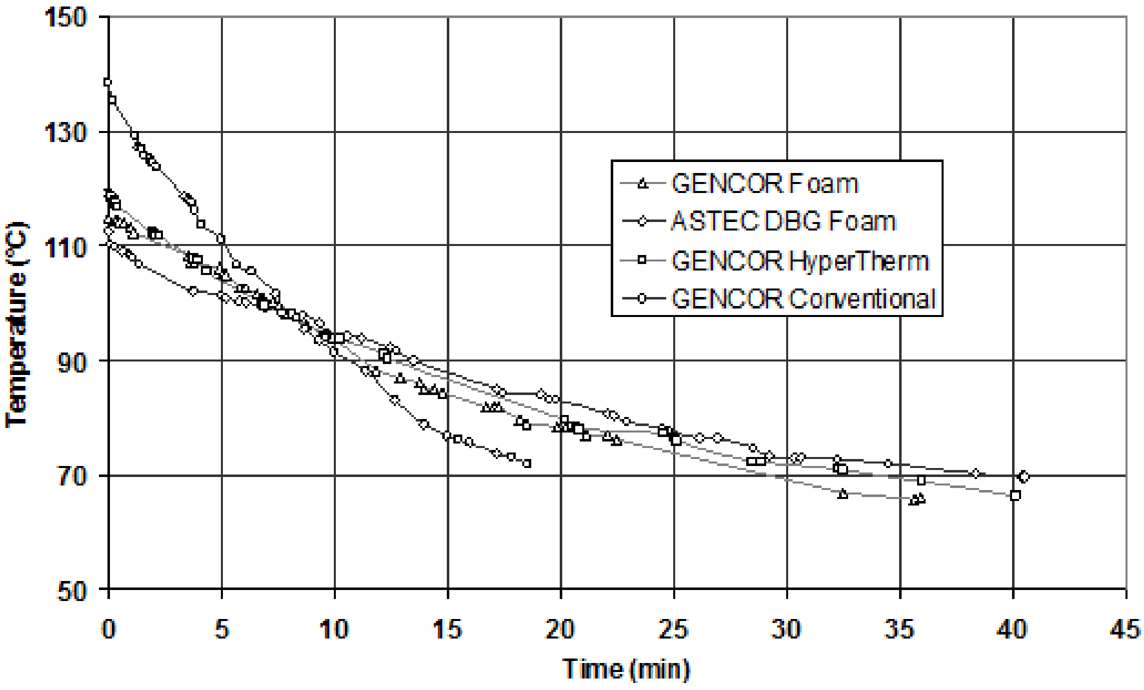

Figure 9: Cooling Curve of Mix Surface Temperature, ºC.

It was noticed that compaction using the WMA mixes was more readily achieved than the same mix produced in the conventional manner. These field observations were validated by laboratory measurements of mix workability. The higher workability noticed with the WMA mixes was also reflected in the evolution of mat densities. Densities in the asphalt mat were measured during the road compaction process for each type of mix. Figure 10 depicts the results of the road compaction profile for the different mixes where each value is the average of three measurements. The ease of compaction of the WMA mixes can be also noticed in Figure 11 which depicts, as examples, the pneumatic compaction stage for the GENCOR HyperTherm and GENCOR Foaming mixes. It was noticed that the window for compacting the warm mixes extended for a longer period of time and that the mix remained more workable at a lower temperature than the conventional mix. This could prove very beneficial in achieving mat density with harsh mixes or mixes that are difficult to compact; increased production rates if mixes compact more readily, increased haul distances, and the ability to pave in cooler temperatures.

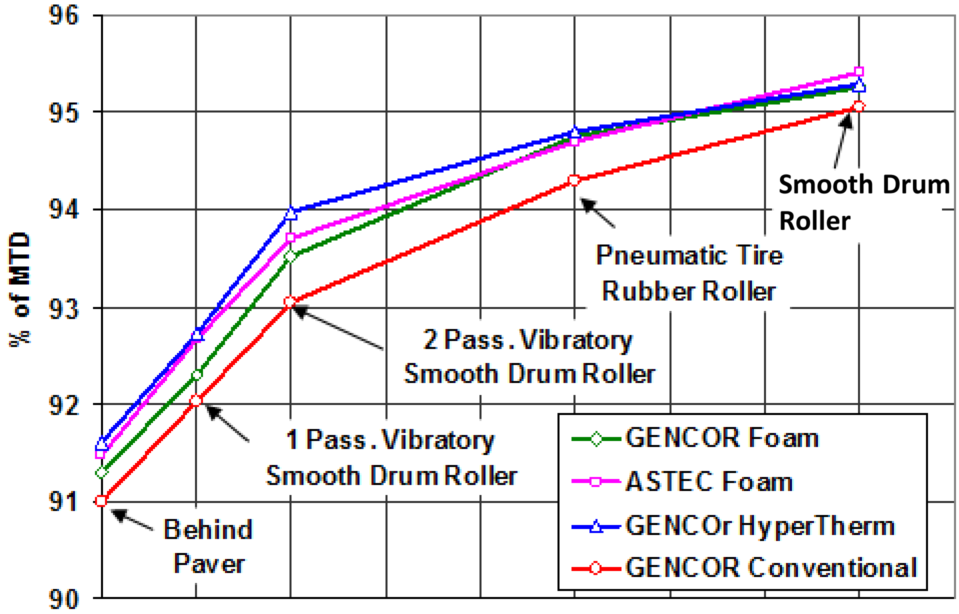

Figure 10: Road Compaction Profile

Figure 11: Road Compaction. Left GENCOR HyperTherm. Right GENCOR Foaming

7. LABORATORY EVALUATION

In order to evaluate the laboratory performance of the different mixes, loose mix samples were taken at the plant production sites. The mixes were sampled, then sealed in metal containers and treated accordingly with the testing protocol to represent real conditions as close as possible. WMA samples were sealed and tested in the lab as early as possible to prevent the loss of the foaming effect from the water based technologies. 150mm diameter core samples were also extracted from each mix placed at each section. Tensile strength ratio, rutting with Asphalt Pavement Analyzer (APA), complex modulus, flow number, workability with Universal Testing Machine (UTM-100), and fatigue test were conducted at the laboratory and the results were analyzed. Test results showed that the WMA mixes behaved similar or superior to the HMA mixes. WMA mixes had similar rutting and fatigue resistance, better low temperature behavior, higher laboratory workability, and similar stripping susceptibility, than the conventional HMA mixes.

8. CONCLUSIONS

An environmentally focused subdivision was constructed in the City of Calgary. A typical City of Calgary residential surface mix containing 15% RAP was produced as conventional hot mix asphalt (HMA) and three warm mix asphalt (WMA) mixes utilizing three WMA technologies: ASTEC's Double Barrel® Green and GENCOR's Ultrafoam GX™ processes, and a WMA chemical additive, HyperTherm were studied.

The advantages of the use of WMA technology were evident during the mix manufacturing and road construction stages. The use of WMA mixes indicated reduced emissions, lower consumption of fossil fuels, reduced smoke and odors, improved comfort, safety and working environment, improved workability, extended compaction time, more uniform compaction, and reduced thermal segregation. The laboratory evaluation indicated that the WMA mixes have similar rutting and fatigue resistance, better low temperature behavior, and slightly lower mix stiffness at high temperature, higher laboratory workability, and similar stripping susceptibility, than conventional HMA mixes.

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