An Assessment of The City of Calgary's First WMA Project

Lindsay Johnston, P.Tech.(Eng.), P.L.(Eng.)
Senior Engineering Consultant
Tetra Tech Canada Inc.

Art Johnston, C.E.T.
Principal Consultant, Transportation Practice
Tetra Tech Canada Inc.

Hawraa Kadhim, Ph.D., M.I.T.
Pavement Engineer
Tetra Tech Canada Inc.

Bryan Palsat, P.Eng.
Regional Manager – Pacific Transportation
Tetra Tech Canada Inc.

Nasir-ul Mulk, M.Eng., P.Eng.
Sr. Pavement and Materials Engineer, Pavements, Soil, and Asset Management (PSAM),
Construction, Roads
The City of Calgary

Paper prepared for presentation
at the 'Green Technology in Roadway/Embankment Materials and Geotechnical Engineering Session' of the
2022 TAC Conference & Exhibition, Edmonton, AB

Acknowledgements
The authors would like to acknowledge the financial support of The City of Calgary in completing this study, as well as their contributions in 2005. The authors would like to thank McAsphalt Industries, and specifically Jeff Jarvis, for the detailed binder testing analysis and tutelage on binder testing throughout this assessment. The authors would also like to acknowledge the contribution of Lafarge Canada in the successful completion of the 2005 Demonstration Project.

Abstract

The City of Calgary (The City) initiated one of the first Warm Mix Asphalt (WMA) technology projects in Canada in 2005 with Tetra Tech Canada Inc. A follow-up assessment of that project was completed in 2021. This paper discusses the evaluation of the 2005 project data and the outcomes of the follow-up investigation.

The Demonstration Project to evaluate WMA was constructed in Calgary in 2005. The project compared three surfacing mix types: a control mix and two WMA alternatives. The project successfully implemented the new technology.

The 2021 assessment had the objective of reviewing details from the original project, completing a field assessment of the current conditions, and implementing a suitable laboratory program to assist The City in determining the feasibility of future use of WMA technology.

The 2021 assessment studied the relative strength of the WMA layers and binder properties to determine the difference between Hot Mix Asphalt (HMA) and WMA. An industry assumption is that WMA is prone to reduced stiffness given the reduced mixing temperatures; however, the outcome of this trial project opposed this assumption and the results indicate that these WMA technologies could be considered equivalent to HMA in terms of design and performance.

Résumé

Abstracts provided in English will be translated to French and vice versa.

Introduction

Warm Mix Asphalt (WMA) technology was being used in Europe in the early 2000s with the goal of significantly reducing energy consumption and emissions associated with asphalt paving. The potential benefits of this technology in terms of reduced energy costs and reduced emissions during production and placement are well documented, particularly when applied in urban areas. With all these potential enhancements, WMA presented a significant advancement for the industry, for the environment, and for the workplace.

In March 2004, a demonstration of WMA processing and construction was made in Nashville, Tennessee, at the World of Asphalt trade show and conference. It is understood that this was the first introduction of this technology to North America. The City of Calgary (The City), impressed with the potential benefits of this technology, chose to initiate a project with the objective of evaluating this technology and its potential benefits within The City's road network. Tetra Tech Canada Inc. (Tetra Tech), formerly EBA Engineering Consultants Ltd. (EBA), partnered with The City to provide engineering consulting services for the WMA technology evaluation. A project team was established with industry stakeholders, including suppliers and contractors, who were collectively committed to delivery of the WMA Demonstration Project with the objective of finding an asphalt technology that could improve paving performance while also reducing emissions and improving the cost efficiency of paving operations.

This paper serves to review the details from the original Demonstration Project and to present our findings from the assessment of that Demonstration Project 16 years later to provide The City with information to determine the feasibility of further implementation of WMA technology in the future.

2005 WMA Technology Review

The project team began reviewing available information on WMA technology and looking for others with WMA experience. They found that European countries were implementing the WMA technology and were reporting the reduction of energy consumption and emissions, especially in urban areas. The project team completed an assessment of the available options for WMA production with a focus on selecting a process that was appropriate for Western Canada and sustainable for the future. Two of those options are presented herein. Several of the WMA processes, upon review, were proprietary, with significant restraints associated with the availability of specialized additives. For this reason, a modified version of the foamed WMA that was being used in Europe was selected for the Demonstration Project and would be referred to as WARM-Foam.

These were the three technologies employed to produce WMA in 2005:

- The first technology was a two-component asphalt binder system, which introduces one soft binder and one hard foamed binder at different stages of mix production at the plant to produce what we often call foamed asphalt or, for the purpose of this paper, will be called WARM-Foam.

- The second technology introduced mineral or organic additives to the asphalt binder prior to mix production at the plant. Some examples of additives used for WMA in 2005 were Aspha-Min® (a synthetic zeolite mineral), Sasobit®, and Sasoflex® (a paraffin-based organic).

- The third technology, which was new in 2005, was an asphalt emulsion product that was designed to improve upon the typical performance deficiencies of previous cold mix asphalt materials with a chemical structure developed specifically to optimize coating, workability, strength, and cohesion of mixtures. This emulsion was expected to also provide the same improvements in WMA.

- All three methods (foamed, mineral, and organic additives and emulsion) of WMA were established by reducing the viscosity of the asphalt binder during production. These technologies also presented the opportunity to lower production and placement temperatures by as much as 20% and could help reduce emission-control costs. The products also could make asphalt mixes easier to place, as the asphalt mix is more fluid, and thus it is possible to achieve compaction more easily. The initial results obtained from preliminary tests and the initial construction applications (in Europe) have shown that WMA performance has been equivalent, and in some cases superior, to traditional Hot Mix Asphalt (HMA) (Koenders et al. 2002 [1]).

Planning and Executing the 2005 Demonstration Project

After sufficient review of available WMA technologies, a Demonstration Project was constructed in Calgary, Alberta, in 2005. The WMA Demonstration Project is in the Taravista – Stage 2 Residential Subdivision Development located in the community of Taradale. The development is in northeast Calgary and is bounded by 80 Avenue to the north and lies east of Falconridge Boulevard and north of 64 Avenue NE.

The project compared three surfacing mix types:

- Conventional City of Calgary Mix Type B; and
- Two WMA alternatives:
  - WMA (WARM-Foam) technology, and
  - Evotherm® emulsion.

The same aggregate source and blend was used for each of the three mixes produced for the project.

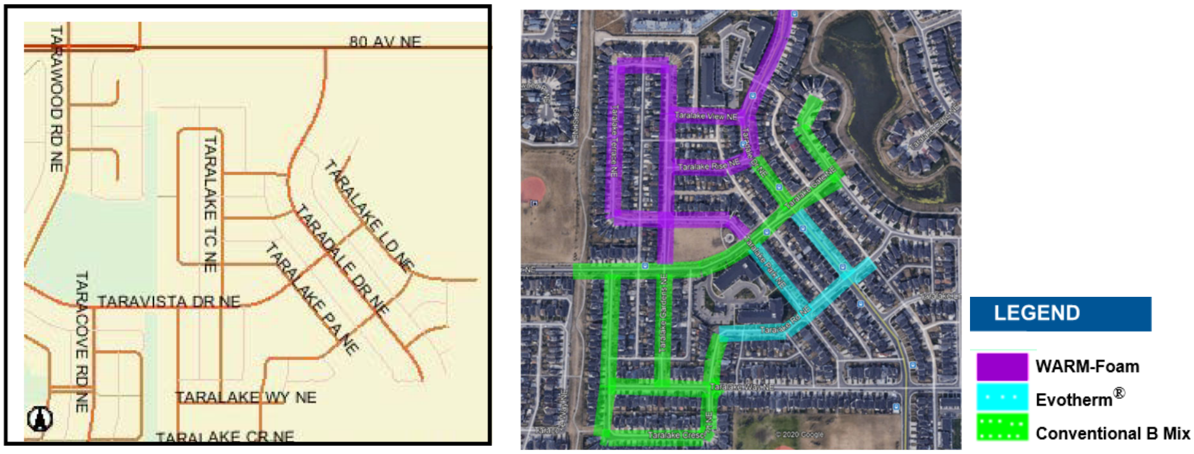

Figure 1. WMA Demonstration Project Location, Calgary, Alberta (Johnston [2])

All conventional and WMA construction comprised one lift of 50 mm thickness on both residential and collector roadways. For residential roadways, this represented the initial asphalt concrete on granular base. For collector roadways, the 50 mm WMA layer was placed over a previously constructed 60 mm thickness of City of Calgary Mix A base course asphalt concrete. In both cases, this comprised the initial stage of construction that received a final lift of City of Calgary Mix Type B asphalt concrete. The final lift thickness of this surfacing was 30 mm for residential roadways and 40 mm for collector roadways. The details of the mix placed in 2005 are presented in Table 1 and Table 2, below (Johnston et al. [2]).

Table 1. 2005 Demonstration Project

Mix Type	Dates Placed	Residential (linear m)	Collector (linear m)	Approximate Total Quantity (tonnes)
Conventional Mix Type B	Mid-July to September 2005	1,100	540	2,000
WARM-Foam	August 5 and 6, 2005	1,100	280	1,700
Evotherm®	September 30, 2005	550	130	650

Conventional Mix Type B

The conventional HMA for the project was the standard City of Calgary Mix Type B, which is a 12.5 mm mix. The mixing and compaction temperatures for this mix in 2005 were ±145°C and ±140°C, respectively. The mix represented the standard mix used in Calgary for most surfacing applications at the time. It was a 50 blow Marshall, using 150/200A penetration grade asphalt cement, with a typical design asphalt content of ±6.0%. The WARM-Foam and Evotherm® mix designs used the same design criteria and target binder characteristics as would be typical for the conventional Mix Type B.

WARM-Foam

> The WARM-Foam production process utilized a two-stage addition of the asphalt binders. In the first stage, a very soft binder was added to achieve a pre-coating of primarily the coarse aggregate. The properties of this soft binder control the minimum mixing and compaction temperatures for the mixture. Then a harder binder was added with a very small amount of water. The water causes the hard binder to foam and expand, which allows the expanded binder to coat the aggregate. Foaming the hard binder reduces the viscosity to enable proper coating and adherence to the aggregate at a lower temperature than the hard binder would typically be mixed at.
>
> For the WARM-Foam product, the soft binder was a product called V1500, supplied by Husky Energy, and the hard binder used was an 80/100A asphalt cement, supplied by Imperial Oil. A drum mix plant was retrofitted as necessary for WARM-Foam production. By adjusting the ratio of soft binder to hard binder, the ideal blend produced should provide an equivalent penetration grade to the typically used binder in Calgary in 2005, which was150/200A (Johnston et al. [2]).

Several plant trials were conducted to facilitate proper foaming of the hard binder and coordination of the soft binder, hard binder, and aggregate feed systems. Finally, a field trial, including lay-down and compaction operations, was undertaken to further evaluate the mix and construction process prior to construction of the Demonstration Project. The typical mixing temperature was ±110°C, with only the asphalt cement temperature being maintained above this level. The typical lay-down temperature was ±100°C.

Product delivery, placement, and compaction of the WARM-Foam material used the same equipment and procedures as conventional HMA. Field crews provided positive feedback regarding the workability of the material and the lack of fumes when material was discharged from the haul trucks. Some adjustments to binder and aggregate proportions were made during construction in response to quality control test results. Of note was that no exhaust was visible from the plant emission stack during mixing of the WARM-Foam.

Evotherm®

The Evotherm® WMA production required no plant modification, and no special mix design requirements were necessary. A 150/200A base asphalt cement was used to produce the emulsion, and an addition rate of 8.7% (by mass of mix) was selected with the intention of providing a target residual binder content of 6.0%. During the production of this mix, the aggregate was pre-heated to ±140°C such that when the emulsion was added, which was at ambient temperature, the resulting mix temperature was ±90°C. Some visible emissions from the plant stack were observed, but it was likely that the majority of this was steam. Initial production at a lower mixing temperature (±80°C) resulted in some uncoated coarse aggregate observed at the plant site but this was confined to only one load. The mixing temperature was increased until optimal aggregate coating was achieved. This resulted in a typical lay-down temperature of ±80°C.

Figure 2. 2005 Paving WMA

The Evotherm® product delivery, placement, and compaction used the same equipment and procedures as used for conventional HMA, as was the case with the WARM-Foam. Some flushing was noted during compaction, and some mix tenderness after compaction was observed. Technical specialists familiar with the Evotherm® product identified that in some cases the material requires some time to achieve the ultimate stiffness.

2005 Mix Characteristics

Quality control testing was performed by the contractor, and quality assurance testing was performed by the consultant during construction of all three mix types. Sampling and testing included hot mix samples for volumetric testing as well as extracting cores for compaction and thickness determination. As essentially the same aggregate source and Job Mix Formula (JMF) blend was used for each of the three mixes produced for the project matching the 2005 specification for City of Calgary Mix Type B, these characteristics were not evaluated.

A summary of those results from 2005 is shown in Table 2.

Table 2. Summary of Mix Characteristics and Compaction 2005

Property	Specified Limits	WARM-Foam		Evotherm®		Conventional Mix Type B	
		Mix Design Value	Test Result Average (Range)	Mix Design Value	Test Result Average (Range)	Mix Design Value	Test Result Average (Range)
Binder Content (%, by mix)	6.0 min.	6.0	6.1 (5.7 – 6.5)	6.0	6.0 (5.7 – 6.4)	6.0	6.3 (6.3 – 6.3)
Percent Passing 10 mm Sieve Size	85 – 95	90	88 (82 – 92)	93	91 (90 – 94)	90	94 (93 – 94)
Percent Passing 5 mm Sieve Size	-	64	62 (54 – 66)	67	64 (62 – 68)	64	69 (69 – 69)
Percent Passing 0.80 mm Sieve Size	3 – 8	7.0	7.3 (6.3 – 8.3)	7.0	7.6 (6.4 – 8.6)	7.0	5.9 (5.5 – 6.2)
Coarse Aggregate Fracture (%, 2 + faces)	70 min.	-	84 (83 – 84)	-	84 (82 – 85)	-	80 (78 – 81)
Film Thickness (mm)	7.0 min.	7.3	7.6 (6.8 – 8.4)	7.8	7.0 (6.9 – 7.2)	7.8	8.3 (8.0 – 8.5)
Bulk Relative Density (BRD)	-	2.365	2.345 (2.328 – 2.371)	2.318	2.339 (2.322 – 2.355)	2.345	2.312 (2.308 – 2.315)
Maximum Relative Density (MRD)	-	2.454	2.418 (2.402 – 2.447)	2.414	2.399 (2.381 – 2.412)	2.432	2.414 (2.408 – 2.419)
Air Void Content (%)	3 – 5	3.6	2.9 (1.5 – 3.8)	4.0	2.5 (1.1 – 3.4)	3.6	4.3 (3.9 – 4.6)
Voids in Mineral Aggregate (%)	14 min.	15.1	15.6 (15.0 – 16.2)	16.2	15.9 (15.8 – 15.9)	15.8	17.0 (16.6 – 17.4)

Property	Specified Limits	WARM-Foam		Evotherm®		Conventional Mix Type B	
		Mix Design Value	Test Result Average (Range)	Mix Design Value	Test Result Average (Range)	Mix Design Value	Test Result Average (Range)
Marshall Stability (kN)	7.1 min.	10.0	11.2 (9.9 – 12.4)	6.9	6.4 (5.8 – 6.9)	11.3	14.7 (12.7 – 16.7)
Marshall Flow (0.25 mm Units)	10 – 16	12.0	14.4 (13.6 – 15.1)	10.3	14.4 (11.3 – 17.4)	10.0	11.7 (11.3 – 12.0)
Compaction (% of BRD)	96 min.	-	99.7 (97.6 – 101.8)	-	98.9 (96.7 – 100.3)	-	100.1 (96.0 – 101.8)
Core Air Voids	-	-	4.0 (2.0 – 6.0)		4.3 (3.0 – 6.4)		4.8 (3.1 – 8.8)

The following observations are provided with respect to the mix characterization test data:

- Although some variability exists, the average binder content for each mix type is generally consistent with the design JMF and specified tolerances.

- The aggregate gradation values were generally within specified tolerances and consistent with the JMF with some minor deviations. In general, the two WMA products were marginally coarser than the JMF.

- It was noted that the dust content of the WMA products is marginally higher than the respective JMF values and higher than the conventional mix. This may be due, in part, to a reduction in dust loss during mixing associated with the lower dryer drum temperatures and associated air flow.

- The volumetric properties of the WMA products were generally characterized by lower Marshall air voids than the design JMF. In some cases, this resulted in air void contents below the specified range. This may be a consequence of the higher dust content previously noted.

- The Marshall stability values for the Evotherm® mix were below the specified minimum, as was the JMF value. The significance of this may depend on longer-term strength gain of the material and warrants further assessment.

- In all cases, the compaction achieved was above the minimum specified criteria. However, several field air void values were within a range that could be considered low (i.e., less than 3% in-place voids) and, therefore, could introduce some potential for flushing. This potential may not be of significant consequence given the relatively light traffic loading anticipated.

In summary, the three mix types as produced and constructed were considered, within the limits of practicality, similar enough to provide a legitimate performance comparison.

Evaluation of the Demonstration Project – 15 or 16 Years Later

The primary objective of this assignment was to focus on two fundamental pavement properties: the relative strength of the WMA layers and the properties of the asphalt binders used in the Demonstration Project after a longer period of performance.

As with many things in 2020, this evaluation project was derailed by COVID-19. Providing a 15-Year Evaluation of the Initial Canadian Experience with WMA had a great ring to it; however, the actual project was delayed, and it became a 15/16-Year Evaluation. The planned evaluation stages along with the years in which they were completed are as follows:

- Literature Review – to review the current state of WMA technology in North America was completed in 2021.
- Strength Evaluation – Falling Weight Deflectometer (FWD) testing of the Demonstration Project was completed in 2020.
- Asphalt Coring – 27 core samples of the WMA (9 per type) were taken from the roadways to perform a binder assessment on the three mix types, which was completed in 2021.
- Abbreviated Visual Condition Review – a brief visual review of the roadway condition was completed in 2021; however, as the WMA was surfaced with another layer of asphalt, this was somewhat limited.
- Binder Assessment – extraction and recovery of the WMA layer of the cores was completed for each of the three mix types in 2021. The recovered binder samples were sent to McAsphalt Laboratories for PG Binder Characterization, which was also completed in 2021.

Literature Review of the State of WMA Technology in 2021

From the time the initial Canadian experience with WMA was paved in 2005 to today, there have been many additional studies into the technology. Some of the more notable relevant projects in North America have been summarized in the following sections.

In cold-temperature areas, the asphalt paving season is relatively short. WMA technology provides the benefit of lowering the mixing and compacting temperature of the asphalt mix, and most research using WMA in North America indicates it can be used without compromising the performance of the asphalt pavement. Reportedly, the reduced difference between the asphalt mix and ambient temperature results in a lower cooling rate, thus allowing for longer haul times, sufficient compaction time, and late season projects compared to conventional HMA. This potential benefit provides an extended paving season in cold-temperature areas. Reduction in production temperature also generates other positive impacts both economically and environmentally. The first Canadian trials of WMA were in 2005 in Alberta, Ontario, and Quebec.

Some field studies that have been conducted in North America are summarized below:

- In New Brunswick, WMA is mandated and specified in the “Particular Specifications”. The New Brunswick Department of Transportation and Infrastructure has increasingly used WMA since 2008 in rehabilitation, levelling, bridge decks, reconstruction, and new construction projects (Sweezie 2020 [3]).

- In a recent study conducted by the City of Winnipeg and University of Manitoba (Materu [4]), the stiffness, rutting resistance, and moisture susceptibility for three WMA mixtures using three different chemical additive dosages were evaluated. This study confirmed that increasing the WMA additive resulted in an improvement in the Tensile Strength Ratio value. This shows that the used additive has some anti-stripping properties, which may increase the resistance to moisture damage.

- The Saskatchewan Ministry of Highways constructed a warm mix test section in October 2010 (Kelln et al. [5]). This research involved both mechanistic-climatic laboratory characterization and non-destructive field pavement testing to evaluate the properties of two warm mix chemical technologies, Advera™ and Evotherm®, relative to conventional HMA. The laboratory characterization results indicated that Advera™ improved the laboratory gyratory compactibility of the mix and the consistency of the compactive behaviour. In contrast, the addition of Evotherm® significantly increased the variability of the gyratory compactive effort without decreasing the compactive effort required. The mechanistic properties of the two warm mixes were found to be comparable to those of the conventional hot mix. However, observations during construction of the field test section indicated that both warm mix technologies exhibited tender mix behaviour during compaction.

- The British Columbia Ministry of Transportation and Infrastructure (MoTI) began evaluating WMA technology in their road infrastructure rehabilitation program in 2009 (Islam et al. [6]). Three different WMA technologies have been evaluated. Foamed Asphalt, Sasobit®, and Evotherm® were used to pave test sections on Highways 1, 3A, and 99 within the southern portion of the province. For each of these projects, adjacent sections were paved with HMA for control. The performance of three different WMA technologies were evaluated after one to three years of service on the basis of Pavement Distress Index, Bending Beam Rheometer testing, and longitudinal joint density. Overall, the performance of the MoTI WMA trials appears to be good based on this study. In two of the three trials, there was a significant reduction in the short-term aging of the binder that can be attributed to the WMA technology.

- The Ministry of Transportation of Ontario (MTO) completed a 67,000 tonne WMA paving contract on Queen Elizabeth Way in 2011. The field study indicated that the use of WMA provides environmental, performance, and economic benefits, with potential for improved pavement performance resulting in less maintenance/rehabilitation and lower overall life cycle cost of pavement structure.

- A five-year follow-up on the MTO-Centre for Pavement and Transportation Technology WMA usage survey took place in 2020. Nine provincial agencies and six municipalities in Canada participated in this survey. According to this survey, there has been a decrease in agencies using WMA in Canada over the years. Approximately forty percent of the participants indicated that there were no observed distresses with WMA technologies for the last five years of service in the field. Thirty-three percent indicated some distresses such as rutting and thermal cracking. Thirteen percent of the participants stated that there were dust balls in the mix due to lower mixing temperatures or micro-cracking in the jobs that used wax-based technology along with reclaimed asphalt pavement (RAP). The other respondents did not provide any comments. In addition, this survey showed that the chemical additive is the most common WMA technology.

- A field study conducted in 2018 (Shen et al. [7]) consisted of the evaluation of 28 WMA pavement projects along with their companion HMA pavements in four different climate zones across the United States. It was found that pavements containing various WMA technologies exhibited similar long-term field performance when compared with that of the companion HMA pavement in terms of transverse cracking, wheel path longitudinal cracking, moisture-related distress, and rutting.

- WMA mixtures containing RAP were evaluated in a field project in Ohio (Sargand et al. [8]). The project included using Aspha-Min®, Sasobit®, and Evotherm® in three test sections in addition to a control section so that a side-by-side comparison could be made between the WMA and HMA mixtures. The collected performance data indicated that the WMA and HMA sections had similar International Roughness Index values after 46 months of service, and no measurable rutting was observed in any of the test sections.

- According to the survey conducted in 2019 by the National Asphalt Pavement Association, there was a 4% increase of mixture produced with WMA technologies in the USA in 2019 as compared to 2018. The survey also showed a continued increase in the use of chemical additive WMA technologies, and a decrease in plant based foaming technologies has been seen in the survey since 2011.

Overall, there has been a notable increase in the use of WMA technologies in the past few years due to climate initiatives. In addition, field data showed equivalent performance of the WMA and HMA pavement sections over several years of service. To this date there have been no major issues with any of the WMA technologies being used around the world.

Field Activities and Sample Acquisition

Strength Evaluation

The Strength Evaluation entailed using FWD on the three different WMA types and using back-calculation to focus on the WMA layers. The relative strengths of the three installations (WARM-Foam, Evotherm®, and the Mix Type B control section) were assessed. The results were subjected to statistical analysis to determine the potential relative differences of the in situ strength properties.

FWD testing of the various roadway pavement elements was completed in late summer of 2020. In total, 146 individual FWD tests were completed at 50 m intervals. The pavement was tested using a Dynatest Model 8000 FWD with nine active sensors. To simulate standard 80 kN single-axle load, the target load during testing was 40 kN.

Coring Program and Binder Assessment

In July 2021, 27 asphalt cores were extracted from each section of the Demonstration Project with nine cores taken from each of the surfacing-type sections. The coring plan was calculated to collect enough cores to provide a sufficient sample size for each mix type to be able to recover asphalt binders in sufficient quantity to undertake three performance grade (PG) characterizations for each of the binders. These cores were measured for thickness and density and ultimately the layers that were placed in 2005 as part of the WMA Demonstration Project were separated, broken down, and the binder was extracted and recovered for PG characterization. Tetra Tech performed the binder extraction and recovery with care to ensure minimize potential no artificial hardening of the binders occurred during the recovery process. The actual PG characterization work was completed by McAsphalt Industries Limited, formerly GECAN, of Acheson, Alberta.

It has been hypothesized that WMA binder should age more slowly given the reduced mixing temperatures and resulting in lesser aging. It would be important to the industry to determine if this hypothesis is in fact valid and, if so, to quantify the differences between binders.

Abbreviated Visual Surface Condition Review

A brief visual condition survey was completed in the summer of 2021. The ability to visually review the condition of the specific WMA layers of the pavement was limited due to the WMA being covered with a surfacing lift of City of Calgary Mix Type B. The 16-year-old roadways were in very good overall condition. Drainage in all areas was still generally functioning as designed with minor areas of ponding or standing water noted at settlements adjacent to catchbasins. Some transverse cracking was observed on the roadway as well as random cracking around manholes, catchbasins, and valves in the roads. No rutting or shoving was noted on any residential or collector roads or in any of the stopping zones or at intersections. Longitudinal joint cracking was observed along mat joints and the cracking was more severe and pronounced on the collector roads, but this is associated with the surfacing lift of City of Calgary Mix Type B. In other words, there were no visible indicators suggesting any variation in the performance of the mix within the three demonstration project sections.

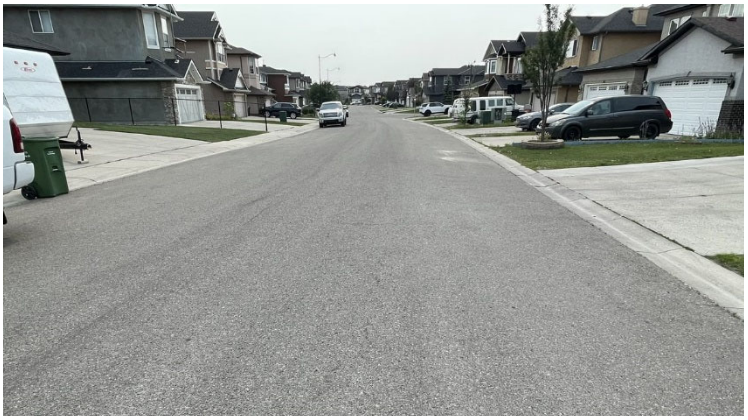

Figure 3. Typical View WARM-Foam Residential Roadway Section in 2021

Data Analysis and Review

A back-calculation analysis procedure was adopted to determine the pavement layer moduli from the 2020 FWD data deflection bowls. The moduli back-calculations were completed for the subgrade, granular base and total asphalt concrete pavement (ACP) layers using the Dynatest ELMOD back-calculation software. ELMOD analyzes the pavement response from the FWD data by determining the modulus, stress, and strain of each pavement layer. Different pavement layer configuration approaches were initially examined; however, given the combination of multiple thin asphalt concrete layers present in the total asphalt concrete thickness, a consistent reliable back-calculated modulus of individual mix types proved difficult, and ultimately a three-layer configuration was considered the most appropriate approach in comparing the stiffness of the pavement layers for the three different mix types for this project.

Table 3 summarizes the back-calculated moduli results for the subgrade, granular, and ACP layers for the three mix types obtained from ELMOD 5 software.

Table 3. Comparison of the Stiffness of the Three Mixes

Mix Type	Statistical Calculations	E1	E2	E3	Sample Count
WARM-Foam Mix	Median (Mpa)	4102	269	89	62
	Average (Mpa)	4033	270	95	
	Standard Deviation (Mpa)	1125	55	27	
Warm Mix – Evotherm®	Median (Mpa)	5308	341	104	46
	Average (Mpa)	5511	402	103	
	Standard Deviation (Mpa)	1997	118	24	
Conventional B-Mix	Median (Mpa)	4483	265	81	48
	Average (Mpa)	4620	299	84	
	Standard Deviation (Mpa)	1663	130	28	

E1 = Stiffness of total ACP layer (MPa).
E2 = Stiffness of total granular material (MPa).
E3 = "Unadjusted" stiffness of subgrade soil (MPa).

Observations pertaining to the information presented in Table 3 are provided below:

- The back-calculated modulus for layers E2 and E3 (unadjusted) are generally consistent across the three areas of focus. The Warm Mix-Evotherm® section did show a higher reported E2 and E3 (base granular and subgrade modulus) compared to the other two sections, but the values for all areas are generally what is typically expected for granular base and subgrade moduli for the Calgary areas.

- A noted variability in the back-calculated E1 (asphalt concrete) was noted across the three areas of focus, with:

  - The Warm Mix-Evotherm® section having the highest (stiffest) back-calculated modulus;

  - The Conventional Mix Type B having the second highest back-calculated modulus; and

  - The WARM-Foam Mix having the lowest (least stiff) back-calculated modulus.

- The back-calculation provided both expected and unexpected results, whereby:

  - Over a 15-year service life, the WARM-Foam Mix showed a lower total asphalt concrete modulus compared to the Conventional Mix Type B. This result was expected.

  - Conversely, over a 15-year service life, the Warm Mix-Evotherm® showed a higher total asphalt concrete modulus compared to the Conventional Mix Type B. This result was unexpected.

As noted, the calculated E1 presented an overall representation of the total asphalt concrete layer and comprised both warm mix and conventional mix layers, and therefore, the results are influenced by several contributing factors. To assist with assessing the significance of these observations, an assessment of variance and statistical analysis was undertaken.

The ANOVA approach was used to conduct a statistical analysis on the effect of WMA mix on the stiffness of the ACP layer. ANOVA is a statistical tool used for determining the relative difference between means for different data sets. A single-factor ANOVA was carried out with the data of all samples of the three mix types. The significance level (α) or confidence level (%) determines the degree of evidence at which the difference (variability) in the variables is unlikely to have arisen by chance. A 95% confidence level ($\alpha = 0.05$) was used in the report. A null hypothesis (H0) is paired with an alternative hypothesis (H1) to examine the variability of the alternative hypothesis.

In this case, the null hypothesis was “Using WMA, Foam, or Evotherm® does not affect the stiffness of ACP layer (E1)” whereas the alternative hypothesis was the opposite.

ANOVA uses the F-test to determine whether the variability between group means is larger than the variability of the observations within the groups. If that ratio is large, it is concluded that not all the means are equal. $F_{Calculated}$ and $F_{Critical}$ can be used to support or reject the null hypothesis.

In other words, if $F_{Calculated} > F_{Critical}$, the H0 is rejected, concluding that there was a significant change in the stiffness of the warm mix (Foam or Evotherm®) compared to the control mix. On the other hand, if $F_{Calculated} < F_{Critical}$, a weak conclusion could be drawn or indicates a lack of statistically significant evidence of variation. In this case, the control and alternative (i.e., warm mixes) variables are statistically observed to be consistent with each other and perform the same. Table 4 confirms that using WMA has a statistically significant effect on the stiffness of the ACP layer. The reported variability in the E1 layer modulus is likely influenced by the presence (or absence) of WMA layers, therefore validating the summary of general observations.

Table 4. ANOVA for E1 Values

Mix Type	$F_{Calculated}$	$F_{Critical}$	Remark
WARM-Foam Mix	4.85	3.93	The effect of WMA on E1 is statistically significant (WARM-Foam mix is significantly less stiff than Mix Type B).
Evotherm® Warm Mix	5.55	3.95	The effect of WMA on E1 is statistically significant (Evotherm® mix is significantly stiffer than Mix Type B).

Photographs of the asphalt concrete cores showing the configuration of WMA and conventional mix lift thicknesses are presented as Figure 5.

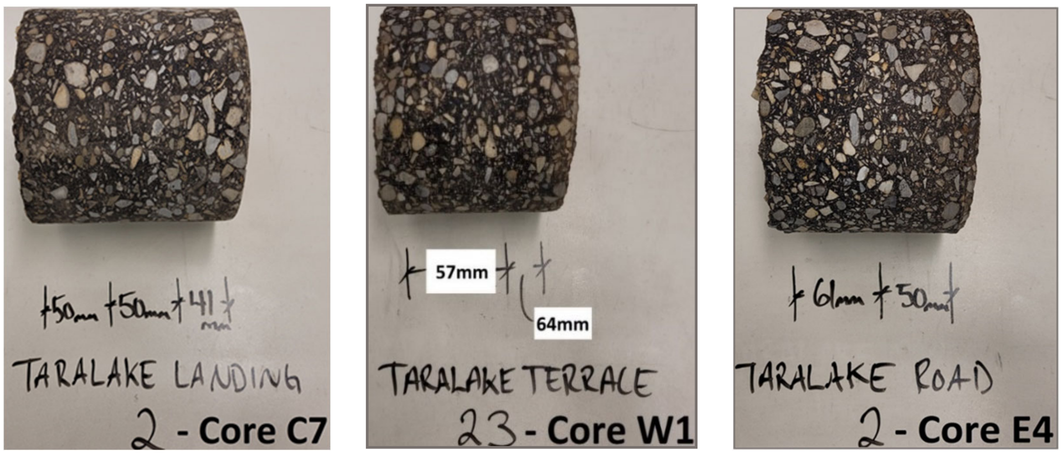

Figure 4. Conventional Mix Type B (left), WARM-Foam (centre), Evotherm® (right)

A broad perspective of this data is that for the ACP layer of the pavement structure (the layer of particular interest) the stiffness of the WARM-Foam is significantly less than the Control Mix

Type B. Secondly, the stiffness of the Evotherm® mix is significantly stiffer than the Control Mix Type B. This data appears to differentiate between the two WMA products, with the Evotherm® mix being superior in terms of strength contribution to both the Control Mix Type B and the WARM-Foam mix. In review of Table 3 above, the median of E1 of Warm Mix (Evotherm®) is significantly higher than the other two mixes. This was also statistically confirmed using ANOVA test. Therefore, and based on the statistical analysis, the Evotherm® mix is significantly stiffer than the other two mixes. It should be noted that ANOVA test, in this case, could be considered limited as it is based on one paving installation.

This data suggests that there may be a rationale to utilize different pavement layer coefficients for different WMA products, recognizing that WMA products are not the same in terms of structural contribution to the overall pavement system. In other words, “not all WMA products are equal”. It should be recognized that this finding is specific to the conditions that exist at this project and may or may not be transferrable to other WMA products.

WMA Asphalt Binder Assessment

Tasks for the binder assessment included extraction of the subject asphalt binder using the centrifuge method followed by asphalt binder recovery by the rotary evaporation method, using the Rotovap™ device. Note that centrifuge extraction and rotary evaporation are the only methods endorsed by American Association of State Highway and Transportation Officials because of the reduced potential for altering the characteristics of the recovered binder. The samples were used to provide a full PG binder characterization of the three binders in triplicate (i.e., nine characterizations).

The cores were dedicated to the extraction, recovery, and preparation for binder characterization. The extraction and recovery testing was performed by Tetra Tech and the binder PG characterization was performed by McAsphalt Laboratories.

Binder Recovery and PG Characterization

After the non-destructive testing of the core samples was complete, the cores were extracted for the asphalt binder using solvent centrifuge, with high-speed centrifuge fines recovery. The asphalt binder was then recovered from the effluent using rotary evaporation. The resulting samples were then tested for PG characterization.

As the parent material had already been plant mixed, the binder samples were not subjected to Rotating Thin Film Oven conditioning, which is typically performed to replicate the short-term aging that occurs as a result of plant mixing. Instead, the samples were tested using the Pressure Aging Vessel (PAV), which is designed to replicate long-term aging of the asphalt binder. However, because the material has already been in service for more than 15 years, in terms of low temperature characterization, two separate approaches were taken regarding PAV conditioning:

- No PAV Conditioning – At the time of coring, the subject pavements were 16 years old and had been used as the wearing surface of the roadways for roughly three years after paving, at which time they were surfaced with a final lift of City Mix Type B, which would act as the wearing surface from that point on. Therefore, it could be suggested that the age of these mixes was greater than that represented by PAV conditioning.

- PAV Conditioned – This was done to be consistent with typical PG protocols. In addition, if the PAV conditioning simulates 7 to 10 years of service for these materials, this would represent ±25 years of service, which is generally consistent with the initial service life of these types of pavements.

Binder Data Analysis and Review

The following table summarized the binder analysis of each WMA mix type.

Table 5. WMA Binder Analysis

Test Property	WARM-Foam Binder	Evotherm® (150/200 A)	Conventional Control (150/200 A)
High Temperature Dynamic Shear Rheometer Predicted Failure Temperature (°C)	64.1	64.1	62.0
No PAV Conditioning			
Intermediate Temperature Dynamic Shear Rheometer Predicted Failure Temperature (°C)	12.4	12.3	10.3
Low Temperature Bending Beam Rheometer Creep Stiffness @ 60 sec. Failure Temperature (°C)	-34.7	-35.4	-36.8
Low Temperature Bending Beam Rheometer Slope (m) @ 60 sec. Failure Temperature (°C)	-37.5	-37.9	-40.9
“True” Performance Grade M320 (No PAV)	64.1 – 34.7	64.1 – 35.4	62.0 – 36.8
PAV Conditioning			
Intermediate Temperature Dynamic Shear Rheometer Predicted Failure Temperature (°C)	17.0	15.7	15.0
Low Temperature Bending Beam Rheometer Creep Stiffness @ 60 sec. Failure Temperature (°C)	-33.6	-33.2	-34.0
Low Temperature Bending Beam Rheometer Slope (m) @ 60 sec. Failure Temperature (°C)	-33.8	-33.2	-34.2
“True” Performance Grade M320 (PAV)	64.1 – 33.6	64.1 – 33.2	62.0 – 34.0

Several observations can be made with respect to the data in Table 5. Firstly, with respect to high temperature grading, the WMA products were graded marginally stiffer than the conventional HMA binder. This might be considered counterintuitive in that most practitioners might expect the WMA products to be less stiff than HMA due to less aging during production.

In terms of intermediate temperature, the results are generally consistent with the conditioning protocols (i.e., higher stiffness for more rigorous conditioning). Without PAV conditioning, the results are generally similar, ranging from 10.3°C to 12.4°C. With PAV conditioning, the results are again similar with values ranging from 15.0°C to 17.0°C. In both cases, the conventional HMA had a lower stiffness, which again could be considered counterintuitive.

The results for low temperature grading are interesting. Without PAV conditioning, the low temperature grading of the two WMA products is very similar; -34.7°C for WARM-Foam and -35.4°C for Evotherm®. The result for the HMA was -36.8°C, or less stiff than the WMA products. With PAV conditioning, the low temperature gradings were all similar, with all results ranging from -33.2°C to -34.0°C. These results are generally stiffer than the "no PAV conditioning", which is consistent with what would be expected.

Although this testing could be considered limited, and based on one paving installation, the results are interesting and potentially contrary to some current beliefs regarding WMA binders.

Environmental Benefits

A benefit of WMA is a reduction in emissions from burning fuels, fumes, and odours generated at the plant and the paving site (Corrigan [9]). If a 10°C to 15°C reduction in the asphalt mix production process is achievable, there can be a significant reduction in energy consumption. This could translate into future cost savings for asphalt producing plants. The savings for asphalt plants would come in terms of emission control costs, which can account for 30% to 50% of plant operation costs. Quantifying these benefits, however, remains a challenge due to the numerous types of WMA technology available. Each technology comes with its own additional cost implications that may or may not be offset by the savings achieved by emissions. Many foamed asphalt technologies require asphalt plant modifications with considerable maintenance required for the system. Chemical additives add additional cost to the mix, which will affect overall mixture and project pricing.

Figure 5. WMA paving (left); HMA paving (right)

As reported by the European Asphalt Pavement Association (EAPA) (2021 [10]), because of the lower production temperature of WMA, less fuel is needed to heat the aggregate. This results in lower emissions of the asphalt plant. The actual reductions vary based on several factors and should be considered on a case-by-case basis, but generally we do know the following:

- The reduction of the production temperature in the WMA leads to significant reductions of stack emissions.
- The reduced fuel and energy usage gives a reduction of the production of greenhouse gases and reduces the CO_2 / carbon footprint; and

- The lower mixing and paving temperatures help to minimize fumes, emissions, and odours and a subsequent reduction of workers' potential for exposure to fugitive emissions from the plant.

According to the EAPA (2021 [10]):

> The lower mixing and paving temperatures achieved by using WMA minimize fume and odour emissions and create cooler working conditions for the asphalt workers. As a rule of thumb, the release of fume is reduced by around 50% for each 12°C reduction in temperature. So, a temperature reduction of 25°C will lead to fume emission reduction of about 75% (see graph).

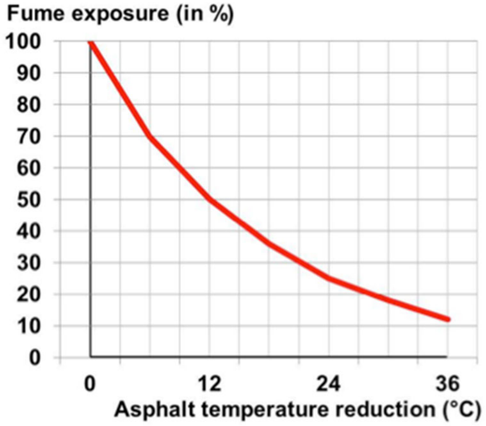

Figure 6. Emission Reduction from Use of WMA as Reported by the EAPA [10]

When The City's WMA Demonstration Project was constructed in 2005, the purported advantages of WMA were significant. Not only did these advantages include environmental benefits, but there were also related advantages such as extending the construction season, improved workability and compaction, and enabling the presence of asphalt plant facilities in urban areas. Initial information provided from field trials by Kolo Veidekke in Norway indicated reductions in fuel consumption of 25%, reduced CO_2 emissions of 40%, and reduced dust emissions of 80%.

It was anticipated at the time that there would be factors that would "drive" the implementation of WMA technology. These factors included more stringent environmental regulations, including emission credits and penalties, and escalating fuel costs. To a large extent, these factors have driven the implementation of WMA technology and may be, at least in part, the reason for some slowing of WMA technology.

Summary Observations

This assessment represents one of the first "longer-term" evaluations of WMA technology, in this case 16 years. Some of the findings appear to be counterintuitive to what might be considered commonly accepted opinion.

The results of the FWD structural evaluation provided "mixed" results with the Evotherm® layer being relatively stiffer than the Control. In the case of the WARM-Foam, the layer was less stiff than the Control. Some practitioners may believe that WMA might provide a more flexible layer, particularly over the long term. This was not confirmed for both cases based on the findings of this study.

The results of the binder assessment provided some very interesting results. It might be expected that the reduced mixing temperatures for WMA products would result in reduced aging, thus preserving the low temperature characteristics of the binder. Based on this assessment, this was not the case. In both cases, the WMA products indicated more susceptibility to low temperature induced cracking than the Control.

It must be recognized that this assessment was very limited in terms of the extent of the work completed in 2005. The evaluation related to a “foam” product that has not been used since the 2005 construction. The ability to determine the similarity to current foam technologies is likely limited at best. In the case of the Evotherm® product, it is understood that the composition of the product in 2005 is similar to that used today. In all cases, the breadth of the available data suggests that these results will need to be supplemented with additional installations by others.

One of the objectives of this evaluation was to provide an indication of the future of WMA technology in Calgary, as well as other regions. An opinion of the authors is that the implementation of WMA has reached a barricade. That barricade is that contractors are becoming hesitant to pursue WMA technology at their own expense. Currently, the only incentive for a contractor to implement WMA is the potential fuel savings, which do not appear to be significant, and optimization of their chance for compaction bonuses, which typically are not significant either. The future of WMA technology is in the hands of owners. Unless owners are willing to provide incentives to suppliers and contractors that will reap all the benefits of WMA (environmental, economic, and societal), the technology will continue to be underutilized as is currently the case.

Future Use of WMA

The future of WMA usage is unclear. While there are several positive benefits to using WMA technology, there are factors to consider that are preventing regular use by some contractors. Some of these factors include:

- Not enough silo space to produce and store HMA and WMA in the same day.
- Transitioning between HMA and WMA in a single day can be challenging and there are not enough WMA projects to run WMA all day.
- There are no cost/project incentives being offered by owners or agencies to encourage the use of WMA technology.

In theory, producing WMA and compacting WMA can be done at lower temperatures than HMA. This can be achieved by producing WMA at HMA temperatures so the ambient air temperature will affect it less by allowing placement and compaction temperatures to remain in the WMA range. However, many specifications also contain limitations for paving when ambient air temperatures or surface temperatures of the paving base are too low, and research into the effects of placement when these conditions are low or even the effects of frost or frozen base materials should be reviewed and considered in this theory.

Although much of the industry experience to date has focused on the environmental benefits of WMA, there is a significant benefit associated with expected pavement performance. Aside from reducing mixing and laydown temperatures, there is also potential to maintain conventional mixing temperatures and reap the benefits of increased compaction. These include decreased air and water infiltration (less aging), better durability, and increased strength. It is commonly accepted that a 1% increase in pavement compaction can provide a 10% or greater pavement service life. It seems that this benefit alone could potentially offset the cost of WMA production.

Another potential issue, from an agency perspective, is the development of specification criteria for WMA mixtures. This is common to many technologies such as RAP, Reclaimed Asphalt Shingles (RAS), fibre reinforcement, etc. It is the belief of many practitioners that agencies/owners should not be prepared to accept a product quality that is lower than their conventional practice. In other words, it is not advisable to have a set of criteria to assess rutting, cracking, strength, etc., that is less than what would be expected for conventional HMA. For example, an appropriate criterion for moisture susceptibility would be prudent for any asphalt material, WMA or HMA, and those criteria currently exist and should not be "lowered" to allow WMA use.

References

1 Koenders BG, Stoker DA, Robertus C, Larsen O, Johansen J. "WAM-Foam, Asphalt Production at Lower Operating Temperatures", Proceedings, 9th International Conference on Asphalt Pavements, International Society for Asphalt Pavements (ISAP), Copenhagen, Denmark (2002).

2 Johnston A, Yeung, K, Bird J, Forfylow B. "Initial Canadian experience with warm mix asphalt in Calgary, Alberta." Proceedings, Canadian Technical Asphalt Association, 51, 369-386 (2006).

3 Sweezie M. "Warm Mix Implementation: New Brunswick's Experience". OAPC 2020 Fall Asphalt Seminar (2020)

4 Materu S. "Evaluation of warm mix asphalt technology for urban pavement rehabilitation projects*",* Master's thesis, University of Manitoba (2020).

5 Kelln R, Haichert R, Berthelot C, Anthony A. "Mechanistic Evaluation of Warm Mix Asphalt Surfacing for CS 35-14", Proceedings, Canadian Technical Asphalt Association, 56, 151 (2011).

6 Islam R, Laxdal J, and Finlayson D. "Evaluation of Warm Mix Asphalt Binder Rheology and Longitudinal Joint Performance: A British Columbia Study", Proceedings, Canadian Technical Asphalt Association, 57, 431 (2012).

7 Shen S, Zhang W, Wu S, Mohammad L, Muhunthan B. "Long-term field performance of flexible pavements using warm mix asphalt technologies", Journal, Association of Asphalt Paving Technologists, 87, 163-198 (2018).

8 Sargand S, Nazzal MD, Al-Rawashdeh A, and Powers D. "Field evaluation of warm-mix asphalt technologies", Journal of Materials in Civil Engineering, 24(11), 1343-1349 (2012).

9 Corrigan M. "Warm Asphalt Mix Technologies and Research", Federal Highway Administration (FHWA). http://www.fhwa.dot.gov/pavement/asphalt/WMA.cfm (February 20, 2005).

10 European Asphalt Pavement Association. "Warm mix asphalt" https://eapa.org/warm-mix-asphalt/ (January 11, 2021). Retrieved March 22, 2022.