Evaluating Warm Asphalt Technology as a Possible Tool for Resolving Longitudinal Joint Problems

Susan Tighe, Ph.D, P.Eng.
Canada Research Chair and Associate Professor of Civil and Environmental Engineering
University of Waterloo
Waterloo, Ontario

Gary Moore, P.Eng.
Manager Design Section
City of Hamilton
Hamilton, Ontario

Carl MacTaggart,
Sales Manager GTA
McAsphalt Industries Limited
Scarborough, Ontario

Keith Davidson, P.Eng.
McAsphalt Industries Limited
Scarborough, Ontario

Acknowledgements

Special appreciation is extended to University of Waterloo Centre for Pavement and Transportation Technology Research Technician Jodi Norris, Lori Schaus a former Research Assistant, and Eugene Kim a former co-op student who assisted with testing the laboratory samples and some of the field work. In addition, the author's appreciate the effort of Roger Hutter, John Hutter and Todd Stewart of King Paving for their assistance during construction. This assistance is greatly appreciated and acknowledged.

ABSTRACT

This paper summarizes preliminary findings from an integrated laboratory and field study that is currently underway in the City of Hamilton to examine the impact of warm asphalt and how it can be used as a possible tool for examining longitudinal joint problems. It is a partnership between the City of Hamilton, the Centre for Pavement and Transportation Technology located at the University of Waterloo, and McAsphalt Industries. There are several reasons to consider reducing the temperature at which a hot mix is placed in the field. Lowering the mix temperatures could result in several construction and performance benefits including reduced aging of the asphalt binder, reduced fumes or odours, reduced tenderness of the mix during compaction and reduced draindown with coarse mixes.

A longitudinal joint is the interface that exists between two Hot Mix Asphalt (HMA) lanes that are paved one after another. Premature failure of these longitudinal joints can vary from slight ravelling at the joint to complete erosion of the mix at the longitudinal joint leaving a large gap in the pavement.

Overall, this paper shares some of the key findings from the initial laboratory and field evaluation. This includes Dynamic Modulus and Resilient Modulus results observed from the laboratory prepared samples. In addition, findings from the field evaluations, including longitudinal joint permeability testing and surface distress surveys are presented.

RÉSUMÉ

Cet exposé résume les résultats préliminaires d’une étude intégrée de laboratoire et de chantier qui se tient présentement dans la ville de Hamilton pour examiner l’impact de l’enrobé tiède et son utilisation potentielle comme outil éventuel pour l’étude des problèmes de joint longitudinal. C’est un partenariat entre la ville de Hamilton, le centre de technologie des chaussées et des transports de l’université de Waterloo et McAsphalt Industries. Il y a plusieurs raisons de considérer la réduction de la température de pose des enrobés bitumineux à chaud en chantier. L’abaissement des températures de malaxage pourrait entraîner plusieurs avantages de construction et de performance incluant le vieillissement réduit du bitume, la réduction des gaz ou des odeurs, la diminution de la sensibilité de l’enrobé durant le compactage et la réduction de la ségrégation avec les enrobés grossiers.

Le joint longitudinal est l’interface qui existe entre deux voies d’enrobé bitumineux à chaud posées l’une après l’autre. La détérioration prématurée de ces joints longitudinaux peut varier d’un léger arrachement au joint à l’érosion complète de l’enrobé au joint longitudinal laissant une large brèche dans le revêtement bitumineux.

En général, cet exposé partage certains résultats clés de l’évaluation initiale de laboratoire et de chantier. Cela comprend les résultats de module dynamique et de module résilient observés sur les échantillons préparés en laboratoire. De plus, on présente les résultats des évaluations en chantier comprenant les essais de perméabilité du joint longitudinal et les relevés des détériorations de surface.

1.0 INTRODUCTION

1.1 Background

The Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo, in cooperation with the City of Hamilton, McAsphalt Industries and King Paving Ltd. is currently investigating the use of Warm Mix Asphalt (WMA) technologies for environmental reasons, as well as to examine whether they can provide improved longitudinal joint performance. A proposal was accepted by the City of Hamilton to investigate the performance of WMA relative to a conventional Hot Mix Asphalt (HMA). There are several reasons to consider reducing the temperature at which HMA is placed in the field. Lowering the mix temperatures could result in several construction and performance benefits, including reduced aging of the asphalt binder, reduced fumes or odours, reduced tenderness of the mix during compaction, and reduced draindown with coarse mixes [1]. This paper provides a summary of work to date.

Failure at longitudinal joints is a recurring problem for many transportation agencies. Several techniques have been utilized in order to improve the quality of longitudinal joints in roads with varying success. The purpose of this project is to evaluate the use of Warm Mix Asphalt (WMA) as a means of improving the quality of longitudinal joints and also to resolve other issues that arise with longitudinal joints.

WMA technology is a new technology which originated in Europe. It is currently extensively being used in Europe on highways and on some airport pavements. In North America the technology is still in its test stages and a number of test sections have been paved through out the United States and Canada. Traditional HMA paving is completed at high temperatures and at these temperatures, there is a large volume of greenhouse gases being emitted. The high temperatures required for paving also reduce the number of days in a year in which paving can take place.

WMA technology increases the workability of the asphalt mixes at lower temperatures by the addition of viscosity reducing agents, coating enhancers, or through the temporary foaming of the asphalt cement. WMA reduces the energy consumption of asphalt plants significantly and this reduction can be as high as 30 percent in some cases. This could possibly mean reduced costs for the asphalt plant and possibly less wear and tear on the plant equipment [2]. Another important benefit of the reduced production temperatures is that the emissions from the plant are also reduced greatly.

There is a decrease in production of toxic gases such as nitrates and sulphates, as well as a decrease in other greenhouse gases. Some studies also show that that the gases that are produced during production may also be less toxic at these lower temperatures of production [3]. Apart from the above mentioned environmental benefits, WMA also serves as a compaction aid due to the reduced viscosity of the mix. The lower temperature required for compaction also results in an extended paving season, longer haul paving, and the mix can be handled with greater ease.

There are a number of new products in the market that have been used in the WMA industry including Evotherm®, Sasobit®, Aspha-min®, WAM-Foam, etc. In the following sections the effectiveness of these products will be discussed in greater detail.

1.2 Study Motivation

This study attempts to determine how WMA performs, and more specifically, attempts to do some preliminary evaluation of how it might assist with minimizing distresses associated with longitudinal joints. It has been proposed that WMA may produce a tighter joint as the temperature differential for continuous lane paving is reduced. The heat loss associated with WMA is less, which makes it more versatile during various weather conditions. Furthermore, this enables WMA to be transported and subsequently placed long distances from the plant location because it will not adversely impact constructability and/or workability of the product. Furthermore, it has been suggested that the joint may be more workable and less inclined to future distress. The actual benefits with respect to improvements at joints require a long term performance evaluation. However, this paper presents some of the initial findings from the preliminary research. It also recognizes that the WMA does provide environmental benefits. Although there are various positive aspects of utilizing WMA, it is important to carry out performance testing on the mixes and examine the possibility of using this technology to solve longitudinal joint failures, especially given that the City of Hamilton has had performance issues with longitudinal joints in the past.

A literature review of appropriate information and details of the trial and laboratory results are presented herein. The research team has also collected the material in conjunction with King Paving and the McAsphalt Group. The material has been prepared in the CPATT laboratory and has been tested. In addition, field permeability testing was carried out across the pavement surface to test consistency. Pavement distress measurements were carried out on the sections and these will serve as a benchmark for future comparisons. Further field testing will also be carried out and will include: density testing at the longitudinal joints in the field, and Portable Falling Weight Deflectometer testing throughout the mat will be carried out over the next season. Ultimately the work will provide direction to the City of Hamilton and others with respect to using WMA and provide some details on how it might assist with mitigation of future distresses. The overall research plan is shown in Figure 1.

2.0 BACKGROUND

2.1 WMA Background

The progression of Warm Mix Asphalt can be traced as follows [4]:

- 1995 Preliminary Lab Experiments
- 1997 German Bitumen Forum
- 2000 First International Conference of Asphalt Pavements (Sydney)
- 2000 Second Euroasphalt & Eurobitume Congress (Barcelona)
- NAPA 2002 European Scan Tour (Germany and Norway)
- NAPA 2003 Annual Convention (San Diego)
- McAsphalt 2006: First Canadian Trials in Ramara Township, Calgary, London

In the United States in March 2005, the Environmental Protection Agency signed the Clean Air Interstate Rule which caps sulphur dioxide (SO_2) and nitrogen oxides (NO_x) in 28 eastern states and the District of

Columbia with eventual 70 and 60 percent reductions of 2003 levels [5]. Thus, pressure is mounting to reduce production temperatures without sacrificing quality. Some of this can be accommodated by lowering asphalt plant temperatures. However, the thought of using a product that is also well suited for mixing and placement at a lower temperature offers many benefits.

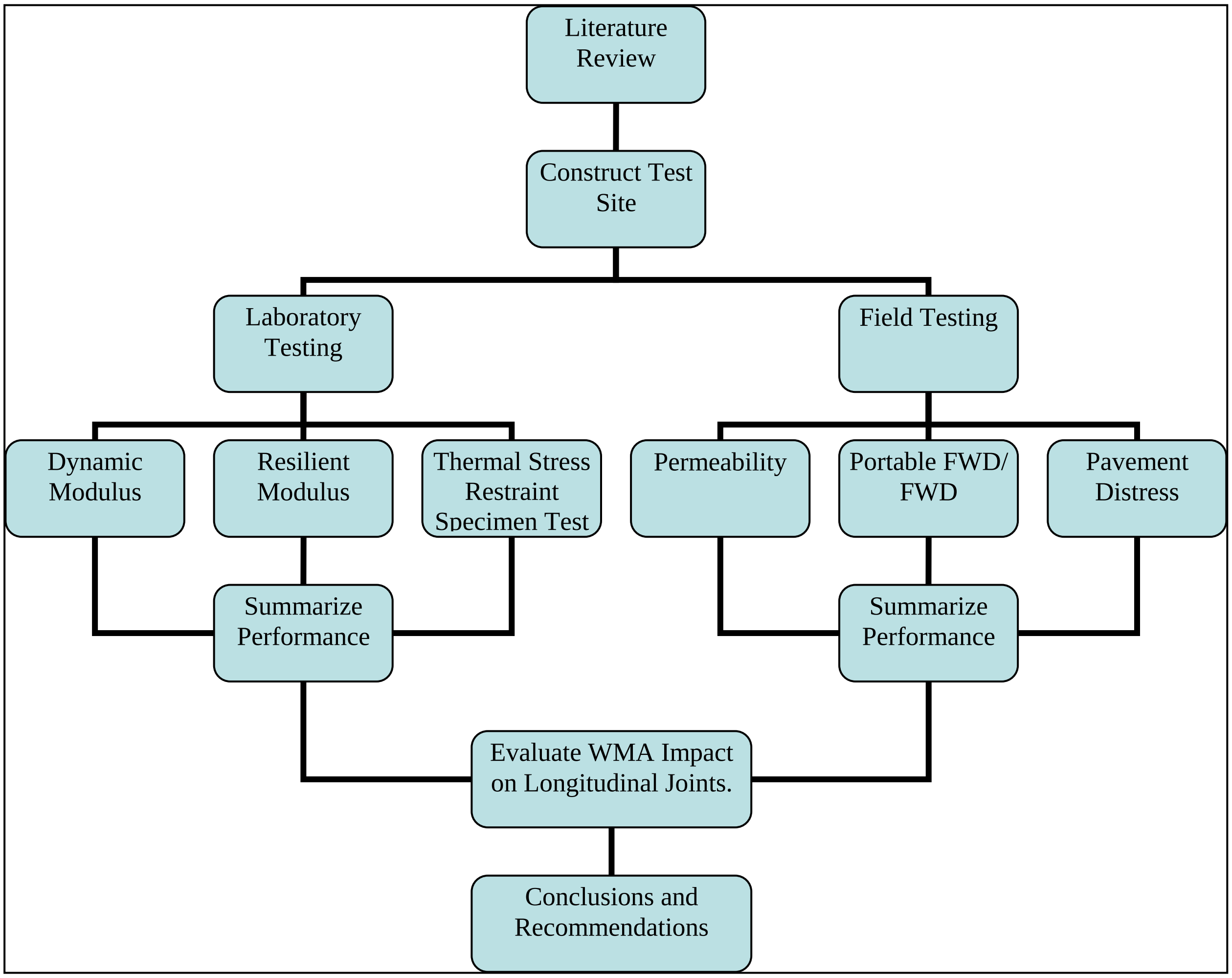

Figure 1. Research Plan

Some of the notable advantages of the WMA technology include [4]: heating cost for aggregate is greatly reduced, it reduces the environmental impact of fumes, NO_x and SO_x are cut in half, there are several procedures including Aspha-Min® (Zeolite additive), Evotherm® (emulsion additive), Sasobit® (wax additive), WAM-Foam® (foamed in the mixer), and all procedures run at lower placement temperature, which is typically 90 to 125°C.

Some of these proprietary approaches are being examined at the National Center for Asphalt Technology at Auburn University. While there are definite reductions in fumes, emissions and energy consumption, several questions are still being asked [6]:

- Will success in Europe translate to North America?
- How will the binder grading be handled given the way the mix behaves during construction?
- How will rutting be addressed?
- Will traffic be able to travel on these products as fast as we currently allow?
- How much will the new technology cost?

One of the most compelling reasons to examine WMA technology in Ontario and Canada at large, is the fact that many cities and regions are moving toward smog regulations relating to paving and road resurfacing, with most of these tending to be located in southern Ontario. These regulations often state that on days declared smog days or smog alert days, a smog response plan should be initiated. In the smog response plan, it often states that road paving and resurfacing should not occur between 9 am and 3 pm. All the cities and regions state that on smog days, paving will be suspended or it is highly recommended that it be suspended, however there is no mention as to any penalty if paving is not suspended [7].

Overall, smog is very heavy from Windsor to Quebec City although information on smog plans was only readily available for the areas of London, the Greater Toronto Area (GTA), Hamilton, Kingston, and Waterloo. Smog is also noted to be heavy in the southern Maritimes, as well as Vancouver in many articles but the cities themselves do not seem to have policies or by-laws relating to smog and road paving [7].

2.2 Longitudinal Joints

2.2.1 Definition

A longitudinal joint is the interface that exists between two HMA lanes that are paved one after another. The lane that is first paved is referred to as the cold lane and the one that is paved second is referred to as the hot lane. Premature failure of these longitudinal joints can vary from slight ravelling at the joint to a complete a complete erosion of the mix at the longitudinal joint leaving a large gap in the pavement.

2.2.2 Low Densities at the Joint

One of the main factors that cause failure at the longitudinal joints is the low density (high air void content) of the mix often present at the joint. This causes the mix to be weaker and the joint is more susceptible to ravelling. A well constructed longitudinal joint usually has a density 1 to 2 percent lower than the rest of the paved lane, however a poorly constructed longitudinal joint can have a density up to 5 to 10 percent lower than the rest of the paved surface. The main reason of the lower densities at the joint is due to the compaction of the first lane and the subsequent joint.

When the first lane is paved, the edges of the lane are unrestricted and upon compaction the edges begin laterally deform instead of compacting properly, thus leaving greater air voids. When the second (hot) lane is compacted, the edge of the hot lane at the joint is restricted by the cold lane and improved density may be achieved, but primarily for the hot lane alone. The mix also has to be correctly compacted to achieve the required densities at the joint. If the roller is placed just over the unrestricted edge or before the unrestricted edge the mix at the edge tends to laterally displace rather than compact.

2.2.3 Overlap of Mix from the Cold Lane to the Hot Lane

If too much mix is placed at the joint overlap, the excess mix will have to be removed using raking which weakens the joint. When the mix at the joint is raked onto the hot lane, it results in there being too little mix at the joint and too much mix on the hot lane directly adjacent to the joint, causing the joint to fail prematurely. If too little mix is placed at the joint overlap then this causes a depression in the joint on the side of the hot lane, once again resulting is a weak longitudinal joint.

2.2.4 Construction Solutions When Using HMA

The following would be proposed as possible ways of assisting with problems:

- One solution to longitudinal joint failure is to remove the joint altogether by paving the whole road simultaneously. However, this option is only viable on low traffic roads and on narrow lanes due to the limitation on the screed widths that are available.
- Echelon paving is another method by which the density of the longitudinal joint can be increased. In this method in this method two rollers run side by side paving the two lanes simultaneously, with one roller slightly lagging behind the other. This ensures that neither side of the joint is unrestricted and results in better compaction at the joint.
- During compaction of the cold lane the roller should be placed roughly six inches over the unrestricted edge to achieve maximum compaction and minimum lateral displacement of the joint.
- When compacting the joint the roller should be on the hot lane with one end of the roller overlapping the cold lane by approximately six inches. This method achieves best compaction at the joint and is most efficient in the sense that it compacts the joint and the hot lane at the same time.
- The correct amount of mix should be placed at the joint overlap as this means that no raking of excess mix is required. If too much mix is placed at the joint then it should not be raked; to be removed it should be shovelled off. If the correct amount of mix is placed, there is sufficient material at the joint for sufficient compression thus minimizing the air voids and increasing the density at the joints.
- Using a Notched Wedge joint increases the compaction at the joint by removing the very thin portions at the extremities of the joint which would cause higher air voids in the joint. Notched wedge joints can be created by placing attachments on the paver screed. Notched wedge joints also have the added advantage of providing a safer ramp for traffic to flow from the cold lane to the unpaved portions of the hot lane.
- There are two methods that can be used to better adhere the cold lane and the hot lane at the joint. The cold lane can be heated using an infrared heater mounted on the paver before placing the hot lane. This causes the mix on the cold lane to become less viscous and more adhesive. The other possibility is to place an adhesive material on the cold side before placing the hot lane.

2.2.5 WMA Impact on Longitudinal Joints

WMA can possibly assist with longitudinal joint problems by providing better compaction, due to the ability to achieve densities with less effort. In fact, because WMA is mixed and placed at a lower temperature, there is less concern about a shorter compaction window. In addition, longitudinal joint problems for construction projects where a long haul is required (i.e. the asphalt plant is located far away from the construction job) may be minimized due to the fact that there is less heat loss and the material would still be readily compacted as compared to a conventional hot mix where the long haul may result in difficulty in compacting the material.

3.0 TRIAL SECTION PLACEMENT CITY OF HAMILTON

During June 2007, a WMA trial section incorporating Evotherm® was placed by King Paving Ltd., in partnership with McAsphalt Industries on Garth Street between Stone Church Road to approximately 200 m north of the Lincoln Parkway in Hamilton. The primary goal of this test section was to investigate if the WMA could be used as a possible solution to mitigate longitudinal joint cracking. A control section was placed prior to the WMA trial.

Figures 2 through 4 show Garth Road prior to the WMA placement. These include photos of preconstruction, the prepared surface and exposed underlying concrete. As noted in the Figures, there was a range of cracking on this section of roadway. The surface was milled and cleaned prior to placement of the WMA. The weather conditions were warm and sunny that day with temperatures reaching 30^{o}C on the WMA placement day. Figures 5 and 6 show the placement of the mat on June 14, 2007. As part of this project, an Open House was hosted whereby several municipalities and contractors came to learn about the technology.

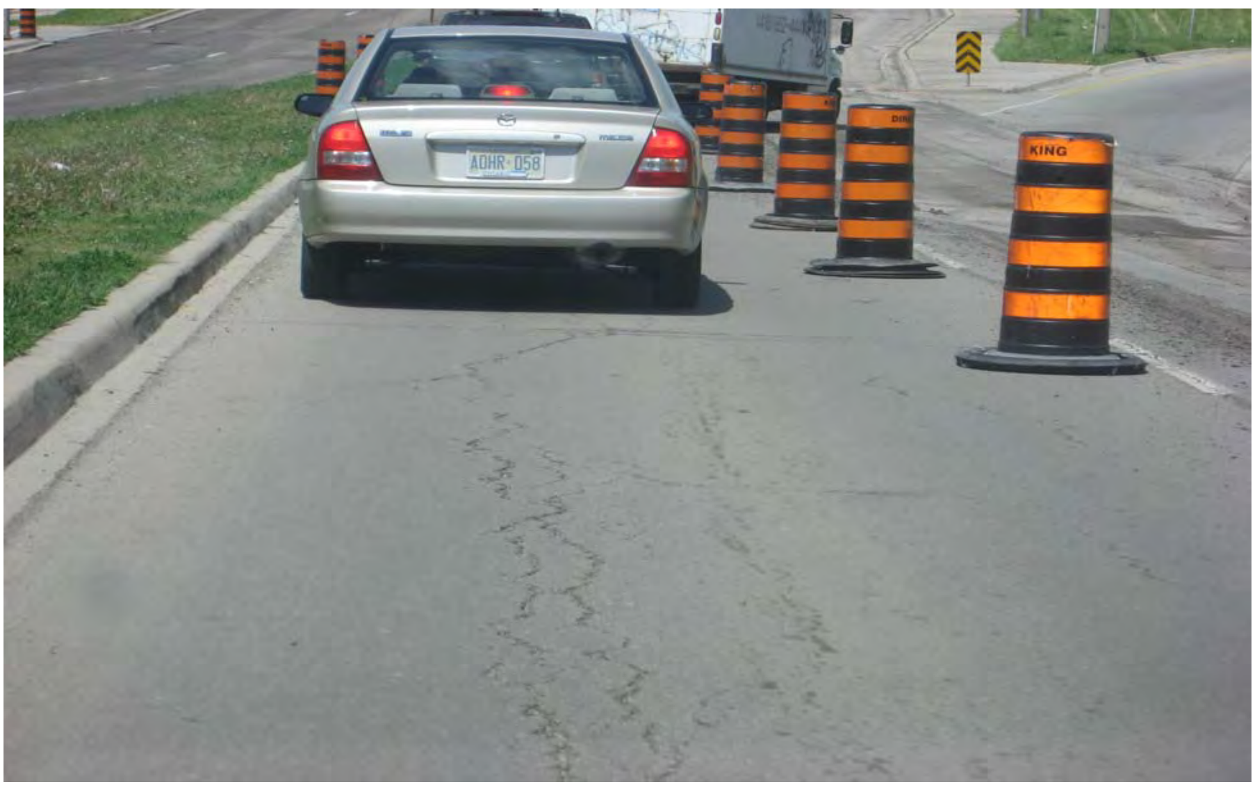

Figure 2. Garth Street Prior to Warm Mix Asphalt Placement

Figure 3. Sweeping the Milled Surface of Garth Street Prior to Warm Mix Asphalt Placement

Figure 4. Garth Street – Prepared Milled Surface Prior to Warm Mix Asphalt Placement

Figure 5. Warm Mix Asphalt (WMA) Mat on Garth Street, June 14, 2007

Figure 6. Warm Mix Asphalt (WMA) Mat on Garth Street, June 14, 2007

4.0 FIELD TESTING PERMEABILITY RESULTS

4.1 Pavement Distress Measurements

Three pavement distress surveys have been carried out to since placement of the WMA. At the time this paper was prepared, no major distresses were identified. Distress monitoring will continue throughout the evaluation of the test section.

4.2 Permeability Measurements

The permeability testing was carried out with the CPATT Gilson Asphalt Field Permeameter as shown in Figure 7. The test procedure is based on the falling head principle of permeability. Testing was carried out throughout the test sections. The tester was placed on the surface of the pavement and a moldable sealant was applied around the base of the permeameter. Four five pound weights were placed on the base of the permeameter to prevent a break in the sealant. Once the apparatus was secured, the permeameter was filled with water at a steady rate. Once the water reached the top of the meter, it was allowed to settle. The water level change was then measured in 10 cm increments. The change in head height (5 cm) and the time (s) was recorded for each sequence. The sequence was completed several times at various locations on the mat, with particular emphasis on the Longitudinal Joint (LJ). In addition measurements were taken on the Wheel Paths (WP) and Centre of Mat (CM). The coefficient of permeability is then calculated using Equation 1.

$$K = (a\,L \,/\, At)\ \ln (h_1/h_2) \qquad (1)$$

Where:
- K = coefficient of permeability
- a = inside cross-sectional area of the standpipe (cm^2)
- L = length of the sample (cm)
- A = cross-sectional area of permeameter through which water can penetrated the pavement area (cm^2)
- t = elapsed time between h_1 and h_2 (s)
- h_2 = final head (cm)
- h_1 = initial head (cm)

The permeability test was conducted at a water temperature of 26 to 31°C, therefore a temperature correction factor in accordance with the actual temperature of the water was used to calculate the coefficient of permeability measurements, as per the Florida Department of Transportation (FDOT) Method test for Measurement of Water Permeability of Compacted Asphalt Paving Mixtures [8]. The permeability testing results are found in Table 1.

Table 2 summarizes a comparison of coefficient of permeability rates for the WMA mix, of various other materials to the porous asphalt [9]. As noted, in the comparison of the City of Hamilton WMA City of Hamilton and SP 12.5 City of Hamilton results are very consistent with those found in the literature. In short, both mixes are impermeable at this point in time. Continued evaluations will be carried out at the joints. In addition, Portable Falling Weight Deflectometer (PFWD) and potentially Falling Weight Deflectometer (FWD) will also be used to evaluate performance at the joint. Next steps will also include investigating the use of the ultrasonic pulse velocity method for condition assessment.

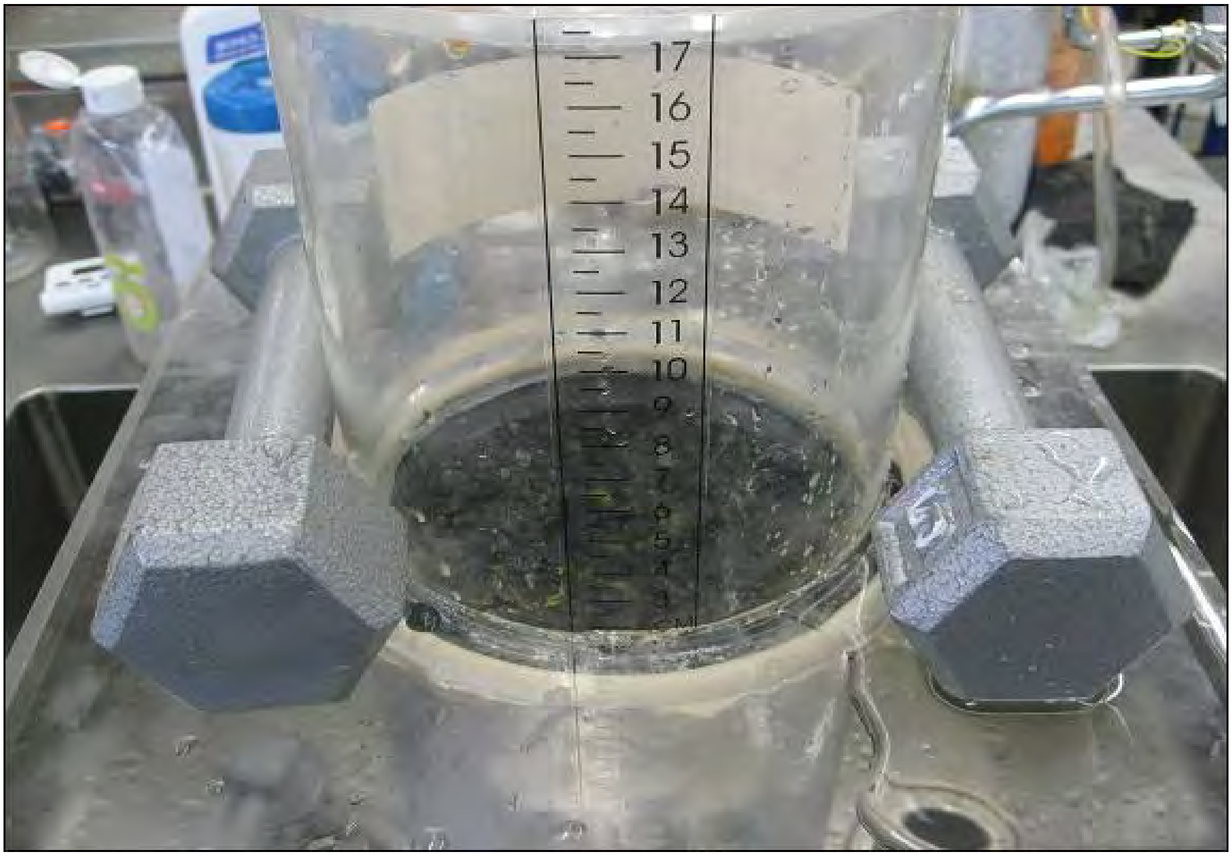

Figure 7. CPATT Gilson Permeameter Apparatus

5.0 LABORATORY TESTING

5.1 Specimen Preparation

A plate sample was received from King Paving that was used to prepare all the samples that were made for testing in the laboratory. The samples were heated to a temperature of 110°C and then were compacted using a Superpave Gyratory compactor. Of the ten samples prepared, one collapsed during demoulding due to insufficient cooling. The specimens were then cut and cored for the testing, in compliance with testing specifications. A 4 inch (inside diameter) coring bit was used to core the samples for the dynamic modulus. Two of the samples for resilient modulus were also cored using this bit. A 60 mm (2.5 inch) coring bit was used to core the specimens that were used for Thermal Stress Restrained Specimen Tension (TSRST) testing. Samples for resilient modulus were cut from both 150 mm (6 inch) and 100 mm (4 inch) specimens and were cut to varying thickness to observe the affect of thickness on resilient modulus values. The top and bottom of the dynamic modulus and TSRST specimens were also cut in order to ensure that the samples were level prior to testing.

Table 1. Permeability Tests, Garth Street from Stone Church Road to Lincoln Parkway

Location		Water Temp. (^oC)	Section	K(cm/s)
1	LJ	26.4	WMA	0.0029
2	LJ	27.3	WMA	0.0000
3	LJ	27.4	WMA	0.0000
4	WP	28.2	WMA	0.0025
5	CM	29.0	WMA	0.0097
6	JL	29.0	WMA	0.0084
7	WP	26.9	WMA	0.0000
8	LJ	26.7	WMA	0.0109
9	WP	27.0	WMA	0.0057
10	WP	27.1	WMA	0.0072
11	CM	27.0	WMA	0.0054
12	LJ	27.2	WMA	0.0039
13	LJ	27.4	WMA	0.0042
14	WP	27.6	WMA	0.0069
15	LJ	28.0	WMA	0.0020
16	LJ	28.0	WMA	0.0022
17	LJ	28.0	WMA	0.0007
18	WP	28.0	WMA	0.0025
19	LJ	28.0	WMA	0.0050
20	CM	27.7	WMA	0.0064
21	LJ	28.1	WMA	0.0086
22	LJ	28.0	WMA	0.0058
23	LJ	28.0	WMA	0.0059
24	LJ	27.8	WMA	0.0097
25	WP	27.8	WMA	0.0028
26	LJ	28.7	Control SP12.5	0.0017
27	LJ	29/8	Control SP12.5	0.0016
28	LJ	30.3	Control SP12.5	0.0031
29	LJ	29.6	Control SP12.5	0.0018
30	WP	30.6	Control SP12.5	0.0013
31	LJ	31.2	Control SP12.5	0.0015
32	LJ	31.8	Control SP12.5	0.0032
33	WP	30.4	Control SP12.5	0.0021
34	CM	31.3	Control SP12.5	0.0065
35	LJ	32.0	Control SP12.5	0.0087
36	LJ	33.3	Control SP12.5	0.0043
37	LJ	31.6	Control SP12.5	0.0039
38	WP	30.6	Control SP12.5	0.0073
39	LJ	31.2	Control SP12.5	0.0025
40	LJ	32.0	Control SP12.5	0.0019
41	LJ	32.6	Control SP12.5	0.0026
42	WP	32.0	Control SP12.5	0.0029

LJ is Longitudinal Joint, WP is Wheel Path, CM is Centre of Mat, WMA is Warm Mix Asphalt

Table 2. Coefficient of Permeability Rate Comparison

Mix/Material	Average Air Voids (%)	Average Coefficient of Permeability (cm/s)
Warm Mix Asphalt (WMA) City of Hamilton	NA	.0048
Superpave SP12.5 City of Hamilton	NA	.0033
SP 9.5 mm fine (surface) ***	8.3	,00194
SP 9.5 mm coarse (surface) ***	5.5	.000395
SP 12.5 mm coarse (surface) ***	5.0	.00102
SP 19 mm coarse (base) ***	7.1	.00234
SP 25 mm coarse (base) ***	6.6	.0000219
Porous Asphalt PG 64-28***	16.5	0.99
Porous Asphalt PG 70-28***	17.1	1.00
Soils/Aggregates		
Gravel*	--	1.00
Sand**	--	.000353
Silt**	--	.0000706
Clay**	--	.00000706

* [8] ** [9] *** [10]
NA: Not Available

5.2 Resilient Modulus Testing

Resilient modulus testing is used to determine the quality of the materials used in the pavement mix by quantitatively describing the thermal and fatigue cracking potential of the pavement structure. Resilient modulus of the pavement can be back calculated using deflection data from a Falling Weight Deflectometer (FWD). These back calculated values can be compared to laboratory resilient modulus results in order to evaluate the field placed performance of the pavement. Resilient modulus testing was conducted on five samples according to the American Association of State Highway and Transportation Officials (AASHTO) Test Protocol 62-03 [10]. Five specimens were prepared in total for resilient modulus testing. Table 3 shows the naming convention used and the dimensions of each of the five specimens.

The specimens were tested at three temperatures of 5, 25 and 40°C. The specimens were first tested at room temperature as no preconditioning was required for this temperature. They were then placed in an environmental chamber at 5°C overnight in order to condition the specimens, after which they were tested at that temperature. Once all the specimens were tested at 5°C, the environmental chamber was heated to a temperature of 40°C and the samples were conditioned at that temperature for 3 hours, after which they were tested.

All samples were tested three times at each temperature and an average of the resilient modulus reading was taken for the three tests. Both vertical and horizontal deformations were measured during the testing, using extensometers for the horizontal deformation and a Linear Variable Displacement Transducer (LVDT) for the vertical deformation. The sample was loaded along the diameter of the sample and both the horizontal and vertical deformations were also measured along the diameter of the sample. Figure 8 shows one of the test specimens in the testing apparatus.

Table 3. Summary of Specimens Prepared for Resilient Modulus

Specimen ID	Thickness (mm)	Diameter (mm)
WMA_Mr4_1	38.5	98.5
WMA_Mr4_2	37.4	98.1
WMA_Mr6_1	75.1	150.0
WMA_Mr6_2	42.3	150.0
WMA_Mr6_3	40.9	150.0

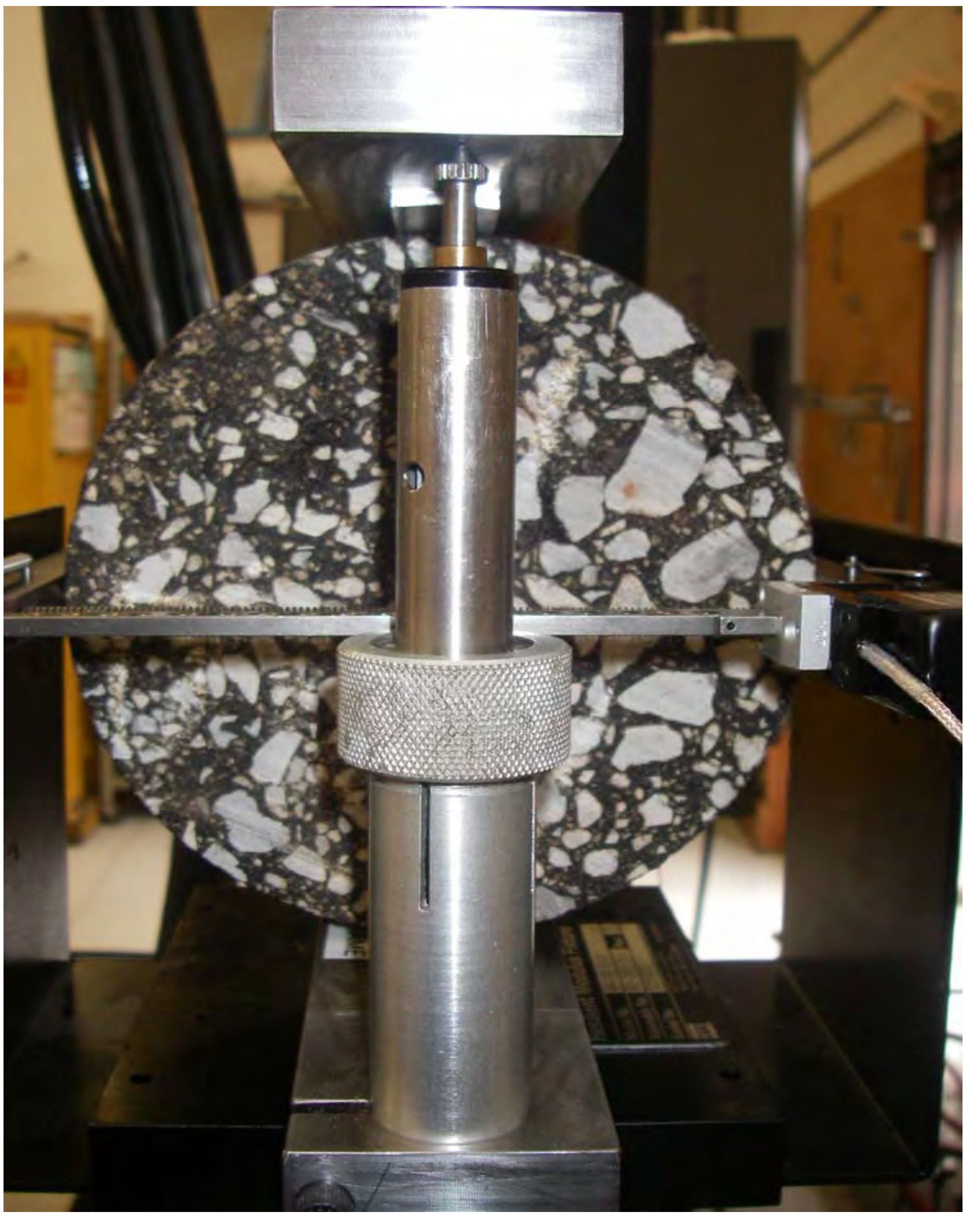

Figure 8. Specimen in the Resilient Modulus Testing Apparatus

Figure 9 shows the typical graphs generated by the program when resilient modulus testing is conducted. The graphs that are produced are for load, horizontal deformation and vertical deformation against time. The graphs in the figures are for the sample WMA_Mr4_1 tested at 25°C. The load against time graph displays the type of loading that is applied to each sample during resilient modulus testing. A load of 1 kN is applied to the sample for a period of 0.1 seconds and then the load is dropped of to 0.1 kN and the sample is kept under that loading for a period of 0.9 seconds. This cycle of loading is continued for a period of 120 loading cycles and vertical and horizontal deformation are measured through each cycle.

Table 4 shows a summary of the test results for the five samples that were tested for resilient modulus. The measurements that were made during the testing were total and instantaneous resilient modulus, as well as total and instantaneous Poisson's ratio. These measurements are taken only for the last 5 cycles during each test and then the average of these values is reported. At 5°C, the horizontal and vertical deformations were minimal and this is displayed in the fact that the Poisson's ratio at this temperature is small or negative. The resilient modulus values are used to determine the thermal and fatigue cracking potential of asphalt pavement. The smaller 100 mm (4 inch) diameter specimens could not be tested at the higher temperatures due to the fact that at those temperatures as they immediately cracked.

An average poisson ratio of 0.26 was observed for all the samples that were tested. It is commonly accepted that the poisson ratio of bituminous materials should be about 0.3. Although poisson ratio is not influential in determining the quality of the pavement it is however important in classifying the material and is also important as an input for pavement design. As the testing temperature decreased the both the instantaneous and the total resilient modulus increased and this in turn mean that the failure strain decreased, The higher resilient modulus numbers indicate an increased potential for thermal cracking, The resilient modulus values did not change significantly with the change in temperature and this indicates that Warm Asphalt technology could have reduced susceptibility to temperature induced cracking. Typical resilient modulus value for conventional asphalt (HMA) is 14,000 MPa at 0°C and from Table 4 it can be seen that at 5°C the resilient modulus value for warm mix asphalt was significantly lower. On the other hand the resilient modulus values for warm mix asphalt at 25°C were very similar to those for hot mix asphalt at the same temperature. The above trends show that warm mix asphalt would be less susceptible to cracking at lower temperatures due to the lower temperatures required for mixing.

5.3 Dynamic Modulus Testing

Dynamic modulus testing collects information related to the susceptibility of rutting of an asphalt mixture. The stiffness of a mixture under various loadings and temperatures can forecast future performance. Dynamic modulus testing is carried out at a range of temperatures. Various loadings are tested and representative of static and high speed traffic. Under static traffic and high temperatures it is anticipated that a mixture will experience the largest amount of deformation, leading to rutting over time. In cold conditions the asphalt mixture is in a stiff state which is represented by a large dynamic modulus value.

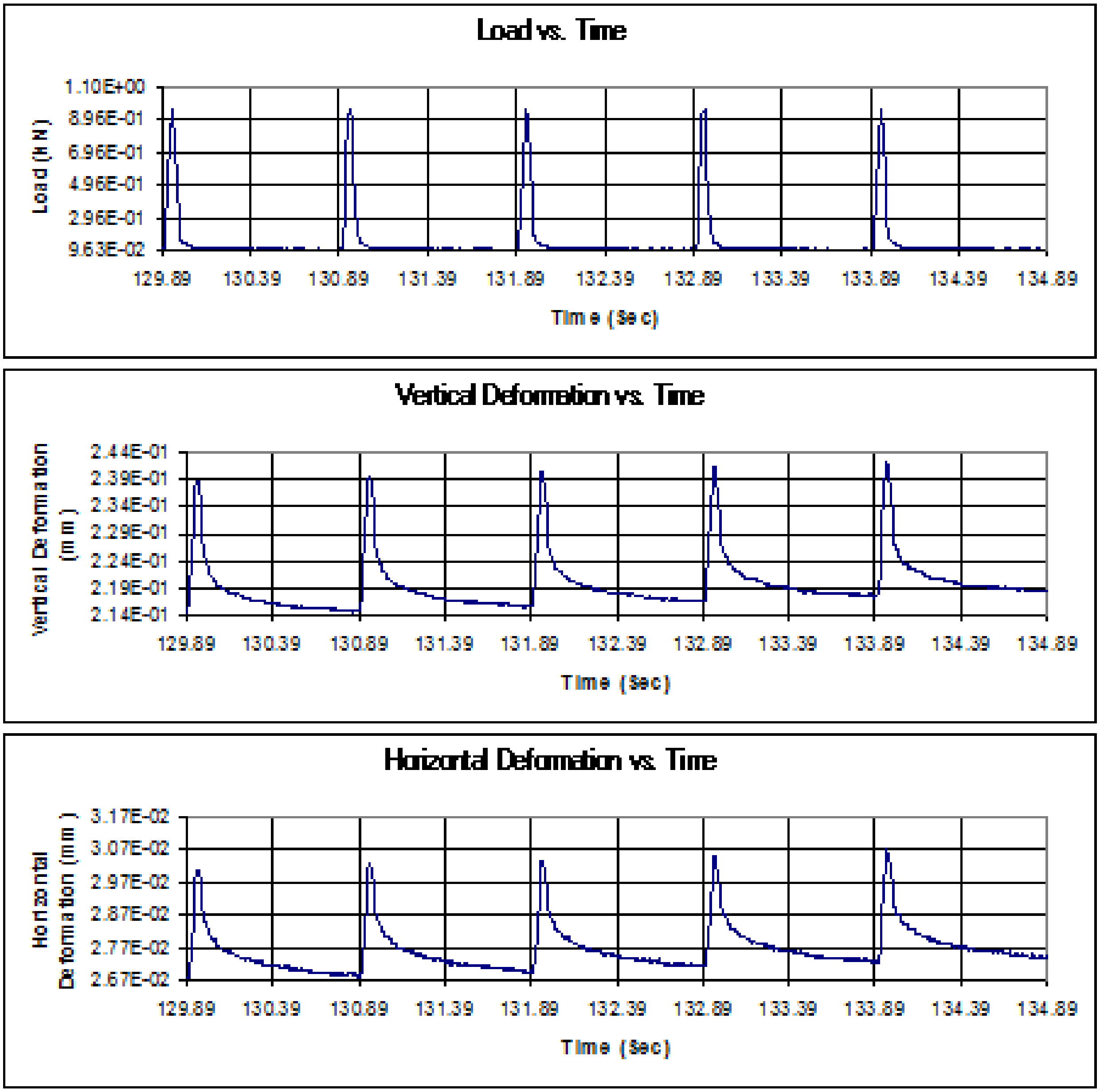

Figure 9. Graphs for Resilient Modulus Testing

Table 4. Summary of Resilient Modulus Results for WMA

Test Temp.	Test Parameter	Specimen ID					Average
		Mr4_1	Mr4_2	Mr6_1	Mr6_2	Mr6_3	
5°C	Total Resilient Modulus	6416	2535	3441	4994	4897	4456
	Instantaneous Resilient modulus	6593	2683	3527	5161	5030	4599
	Total Poisson Ratio	-0.03	-0.20	-0.14	-0.04	0.03	-0.08
	Instantaneous Poisson Ratio	-0.03	-0.21	-0.14	-0.04	0.02	-0.08
25°C	Total Resilient Modulus	3433	3451	4136	3094	3238	3470
	Instantaneous Resilient modulus	3428	3461	4115	3123	3246	3475
	Total Poisson Ratio	0.24	0.26	0.27	0.22	0.31	0.26
	Instantaneous Poisson Ratio	0.25	0.27	0.25	0.22	0.31	0.26
40°C	Total Resilient Modulus	N/A	N/A	1197	1316	1245	1253
	Instantaneous Resilient modulus	N/A	N/A	1229	1184	1228	1214
	Total Poisson Ratio	N/A	N/A	0.51	0.77	0.63	0.64
	Instantaneous Poisson Ratio	N/A	N/A	0.53	0.84	0.65	0.67

Testing was carried out in accordance with ASTM 3497 – 79. This method tests samples at three temperatures; 5, 25, and 40°C and three frequencies; 1, 4 and 16 Hz. The lowest frequency models static traffic while the higher frequency is representative of constant moving traffic. Each time the test is performed it loads the sample at all of the frequencies. Three samples were tested for dynamic modulus. Each sample was tested at each of the temperatures and the test was repeated three times at each temperature for comparison. The naming convention for the samples for dynamic modulus testing and the dimensions of the specimens are given in Table 5.

Table 5. Dynamic Modulus Specimen Dimensions

Sample ID	Height (mm)	Diameter (mm)
WMA Md_1	153	100
WMA Md_2	147	100
WMA Md_3	146	100

Figure 10 shows the graphs that are produced during dynamic modulus testing. The graphs are produced for each of the frequencies and the graphs are for load and strain against time. The graphs that are shown in Figure 10 are for sample number 1 at a frequency of 16 Hz.

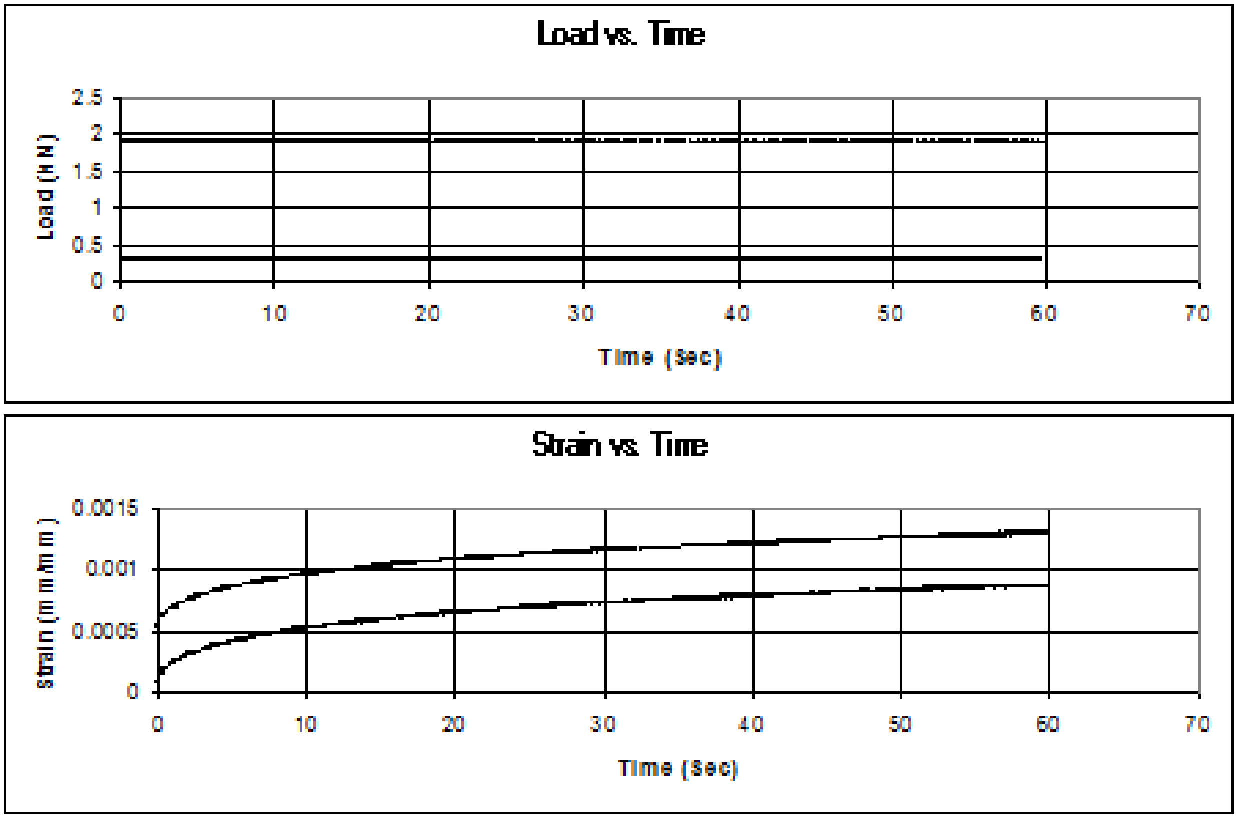

Figure 10. Dynamic Modulus Testing Results

The dynamic modulus, the phase angle, recoverable strain and load amplitude were measured during each test. Table 6 shows the average dynamic modulus values of each of the three samples tested at each of the three temperatures. The average dynamic modulus and the standard deviations of the dynamic modulus values are also presented in Table 6.

Table 6. Dynamic Modulus Values for Warm Mix Asphalt Specimens

Sample Number	Frequency (Hz)	Time (sec)	Average Dynamic Modulus (MPa)		
			5°C	25°C	40°C
1	16	0.0625	4.1076E+02	4.6881E+02	4.4594E+02
	4	0.25	3.8223E+02	3.9893E+02	3.6972E+02
	1	1	3.6601E+02	3.7667E+02	3.1171E+02
2	16	0.0625	7.4227E+02	8.5746E+02	6.5632E+02
	4	0.25	7.1313E+02	7.3992E+02	5.2047E+02
	1	1	6.8275E+02	6.7561E+02	4.2285E+02
3	16	0.0625	5.1740E+02	1.0412E+03	5.4951E+02
	4	0.25	4.9786E+02	9.1754E+02	4.3333E+02
	1	1	4.7874E+02	7.9968E+02	3.6671E+02
Average	16	0.0625	5.5681E+02	7.8914E+02	5.5059E+02
	4	0.25	5.3108E+02	6.8546E+02	4.4117E+02
	1	1	5.0917E+02	6.1732E+02	3.6709E+02
Standard Deviation	16	0.0625	169.2	292.2	105.2
	4	0.25	167.9	263.6	75.9
	1	1	160.55	217.4	55.6

Figure 11 is the graphical representation of the average dynamic modulus values of the WMA specimens. The highest dynamic modulus values were observed at 25°C and the lowest values were at 5°C.

Table 6 and Figure 11 show the dynamic modulus results from the three samples tested. The samples were tested over a range of 35˚C. Results show the lowest dynamic modulus values under static loading which is representative of the testing at the 1 Hz frequency. Dynamic modulus results increase as the loading speed increases at all temperatures. This trend is a result of the loading moving on and off the sample at a faster rate which represents high speed traffic conditions. The results of 5˚C and 40˚C show an anticipated trend as the dynamic modulus values decrease as the temperature increases. The decrease in dynamic modulus values is caused by the asphalt mixture decreasing in stiffness as temperatures increase. The 25˚C results do not fit tightly in the trend however are similar. The temperature range is small and the result of this is shown with the slight variation from the trend in the 25˚C results.

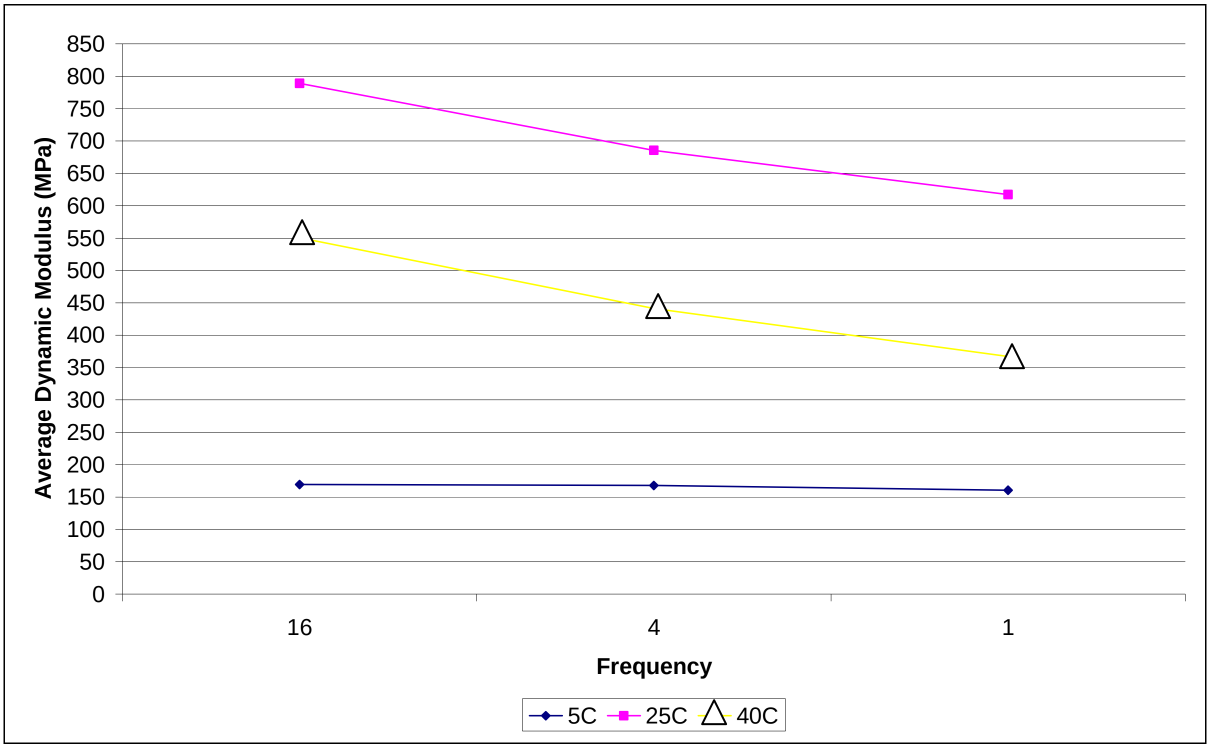

Figure 11. Graphical Representation of Average Dynamic Modulus of Warm Mix Asphalt

Dynamic modulus testing results include both dynamic modulus and phase angle data. The phase angle is a measure of the viscosity of an asphalt mixture. The difference between the peak applied load and peak strain in an asphalt mixture is represented by the phase angle. During static loading conditions an asphalt mixture has a higher tendency to deflect than during high speed loadings. The higher deflection tendency is represented by a smaller phase angle value. At cold temperatures the deflection of asphalt is reduced and the peak strain is reached sooner than in warmer conditions when the movement of the softer asphalt continues for a longer time period. Cold temperature deflections are shown in data by smaller values than deflections of warmer samples.

Table 7 shows the phase angle values of the three samples tested. The average values show larger phase angles for high speed loading and high temperature conditions. Data from loading at a frequency of 4 Hz at 25˚C did not fall into the trend. It should be noted that the results were not significantly different than those from the loading at 1 Hz. This is understandable as the loading frequencies were similar. The phase angle results of the three samples were consistent with minimal variation as shown in the standard deviation values.

Table 7. Phase Angles for Warm Mix Asphalt Specimens

Sample Number	Frequency (Hz)	Time (sec)	Phase Angle (deg)		
			5°C	25°C	40°C
1	16	0.0625	7.96	10.09	13.78
	4	0.25	8.71	9.70	13.19
	1	1	5.63	9.55	12.36
2	16	0.0625	9.86	11.43	15.61
	4	0.25	7.62	9.86	14.46
	1	1	5.64	10.58	13.50
3	16	0.0625	9.13	10.47	15.72
	4	0.25	9.16	9.34	14.17
	1	1	5.93	10.41	12.31
Average	16	0.0625	8.99	10.66	15.04
	4	0.25	8.50	9.63	13.94
	1	1	5.73	10.18	12.72
Standard Deviation	16	0.0625	0.961	0.688903	1.086793
	4	0.25	0.791	0.269135	0.665544
	1	1	0.168	0.5533	0.675711

6.0 SUMMARY

The goal of the study is to examine WMA and how it may assist as a tool for resolving longitudinal joint problems. Both the field and laboratory evaluations indicate that the WMA to date is comparable with the conventional HMA. In addition, the field results show to date that the joints are very tight and performing well. The sections will continue to be monitored over the next several years and additional field testing on the joints will be carried out to test how the joints are performing.

REFERENCES

[1] APEC Asphalt Paving Environmental Council, “Best Management Practices to Minimize Emissions During HMA Construction” EC-101, (2000).

[2] Cervarich MB. “Cooled and ready to serve?”, Roads and Bridges, 41 (9), number 9, 38-39 (2003).

[3] NIOSH, Hazard Review – Health Effects of Occupational Exposure to Asphalt. U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health, USA, December 2000. http://www.cdc.gov/niosh/pdfs/01-110.pdf (2000).

[4] Brown S. “Warm Asphalt Technology”, presentation to the Canadian Airfield Pavement Technical Group Workshop, SWIFT Conference, Calgary, September (2007)

[5] Prowell B, West R. "A Case for Reducing Production and Laydown Temperatures – Today", Hot Mix Asphalt Technology July/August (2005).

[6] Newcomb D. "Warm Mix: The Wave of the Future?", Hot Mix Asphalt Technology July/August (2005).

[7] SMOG [Smog 2005] Region of Waterloo – Clean Air Plan Paper – no regulations about paving on smog days.

[8] Florida Department of Transportation, "Florida Method of Test for Measurement of Water Permeability of Compacted Asphalt Paving Mixtures", Designation FM 5-565 (2006).

[9] Schaus LK. "Porous Asphalt Pavement Designs: Proactive Design for Cold Climate Use", MASc Thesis, University of Waterloo, Waterloo, Ontario (September 2007).

[10] American Association of State Highway and Transportation Officials (AASHTO) TP 62-03. "Determining the Dynamic Modulus of Hot Mix Asphalt Concrete Mixtures", AASHTP Provisional Standards, April 2003 Interim Edition, Washington, D.C. (2003).