INVESTIGATING THE EFFECT OF WARM MIX ADDITIVE ON THE PERFORMANCE OF ASPHALT MIXTURES

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ABSTRACT

Warm mix asphalt (WMA) is a technology that has seen widespread growth in Canada since its introduction to North America in 2002. Since this technology is relatively new, there are still concerns about how these asphalt mixtures will perform over long-term, especially regarding resistance to moisture damage. Moisture damage is the primary driver for the deterioration of asphalt in the field, and can also exacerbate existing life-cycle stresses and cause premature failure. The wide range of different techniques being used for this technology makes it difficult to make broad generalizations, as some seem to perform much better than others in a laboratory setting. With this in mind, a study comparing the results from plant produced WMA against a known hot Mix Asphalt (HMA) will provide useful information on what can be expected from the mixes currently in use. This study compared a WMA mix using a 0.3% Evotherm M1 additive and an HMA mix produced by a local provider in New Brunswick. These asphalt mixtures were prepared using the same locally sourced binder and aggregate. The WMA mix performed well compared to the control HMA mix in a Modified Lottman Test; both had tensile strength ratio (TSR) values above the minimum of 75%, and it was found that there is no difference between the WMA and HMA Tensile Strengths. Additional testing on the performance of the mixtures using the Hamburg Wheel rutting test was performed, and the mechanical response of the mixtures was characterized using the Dynamic Modulus Test. Additionally, the impact on the life cycle and a comparison using the Mechanistic-Empirical Design Method were analyzed and no difference was found in long-term performance of WMA and HMA

INTRODUCTION

Warm Mix Asphalt (WMA) refers to a larger group of techniques and processes that increase the workability of asphalt mixtures at lower temperatures than traditional hot mix asphalt (HMA) (Sargand, Nazzal, Al-Rawashdeh, & Powers, 2012). These techniques can reduce the required mixing and compaction temperatures of asphalt between 10°C to 40°C (Vaitkus, Cygas, Laurinavicius, Vorobjovas, & Perveneckas, 2016; Sebaaly, Hajj, & Piratheepan, 2015), depending on type of modification. This represents a substantial opportunity for decreasing both energy costs, lowering greenhouse gas emissions as well as reductions in harmful gases (Kim, et al., 2012; Rubio, Martínez, Baena, & Moreno, 2011), which is increasingly a priority for governments and manufacturers.

One of the drivers of moisture related damage in asphalt mixtures is the presence of water under the base course that is unable to drain and can start to strip away the asphalt coating from the aggregate which can lead to fatigue cracking or rutting (Pavement Tools Consortium, 2011). This action can take several different chemical routes (Emery & Seddik, 1997), but it leads to premature failure and wear.

WMA mixtures are especially susceptible to moisture damage, as the lower mixing temperatures may not completely dry the aggregates being used. Further, some WMA technologies depend on a water-based emulsifier to work or foaming asphalt cement, which may also contribute to stripping problems.

Because the exact mechanisms for how moisture damage occurs is imperfectly understood, several tests are used, each of which have been shown to be correlated with the potential for moisture damage. This research study examined the effect of a WMA additive in the performance of plant-produced mixtures samples of HMA and WMA collected from a local provider in New Brunswick. This paper describes the test procedures followed and findings from the comparison.

BACKGROUND

The New Brunswick Department of Transportation and Infrastructure (NBDTI) was one of the early adopters of Warm Mix Asphalt Technology in Canada. At the time, warm mix was developed to help reduce energy consumption and stack emissions during production. Warm mix has allowed for longer haul distances, lower placement temperatures and improved workability. NBDTI completed their first project of approximately 1100 tonnes of WMA in 2007 on Route 111 in Saint Martins. This project utilized an emulsion-based warm mix technology (Evotherm DAT). Two more trial projects were completed in 2008 using chemical additive (Evotherm-3G). After three successful trials, NBDTI began incorporating more WMA into the capital paving program. In 2009, there were five separate projects accounting for 55,710 tonnes WMA representing 7.2% of the paving program. This volume has been steadily increased over the years to as much as 366,000 tonnes in 2015, which represented 52.1% of the total tonnage of asphalt placed in the province. Over the last three construction seasons, NBDTI utilized WMA on approximately half of paving projects over the province.

Currently, NBDTI has eleven approved WMA technologies, and continue to evaluate new warm mix technologies and products on yearly basis. Of the approved technologies, there are six chemical or powder additives and four foaming systems. NBDTI utilizes WMA as it has seen number of benefits. Aside from benefits of being a green technology (reduction of emissions and energy consumption during production) NBDTI has seen an improvement in compaction along the longitudinal joint, resulting less longitudinal joint cracking within the first few years of a projects life cycle. Warm mix technologies have allowed NBDTI to extended the paving season in areas of the province that are relatively colder later in the paving season as well as allowing for some longer haul distances. Additionally, NBDTI feels that durability is improved with Warm Mix as there is less oxidation of the asphalt binder when compared to mixing at hot mix temperatures.

A survey of other provinces shows that this is very similar to their findings with WMA. A study done in Ontario (Esenwa, Davidson, & Kucharek, 2011) had laboratory WMA TSR of 84.5% compared to their control TSR 81.2%. Both Manitoba (Porras, 2012) and Saskatchewan (Kelln, Podborochynski, Haichert, & Berthelot, 2012) have reported tests with WMA having comparable results from indirect tension tests. In 2015, a survey on Canadian usage of WMA conducted by Varamini and Tighe found that the majority of Canadian provinces use some form of WMA on a regular basis. The respondents reported chemical additives were among the most commonly used warm mix technologies, including the type that was used for this study. Of the provinces that do require testing of WMA asphalts, the majority use a Modified Lottman Test, and have an acceptance range of 73% to 85% for these tests (Varamini & Tighe, 2015).

Evotherm M1 is a warm mix technology that also have anti-stripping properties and does not require a water emulsifier (Asphalt Innovations, 2010), a distinction that is important in some studies done to date (Cucalon, et al., 2015). Other findings in the literature (Sargand, Nazzal, Al-Rawashdeh, & Powers, 2012)) suggest that Evotherm has a positive impact on TSR tests, though some tests have shown that the anti-stripping agent must be part of the mixture to achieve the same kinds of results at the control HMA (Cucalon, et al., 2015). The Evotherm M1 and J1 technologies are the latest generation of additives also sold under the same Evotherm 3G, and both contain an anti-stripping agent (Asphalt Innovations, 2010).

MATERIALS

The materials selected for this study correspond to NBDTI mixtures Type D/ WMA-D that are Superpave mixtures with a maximum aggregate size of 12.5 mm, installed for the wearing course of Provincial Roads in New Brunswick. The additive used for the WMA was Evotherm M1 in a concentration of 0.3%. Both HMA and WMA were collected from the same plant, and were prepared with the same locally sourced PG 58-28 binder and aggregate. The compaction temperatures for WMA and HMA were 120°C and 135 °C, respectively.

Evotherm M1 has the potential to reduce the temperature by a higher range, however, in New Brunswick the dosage rate and mixing/compaction temperatures are as per supplier's recommendations. The Asphalt Concrete End Result Specifications state that the minimum temperature prior to initial compaction shall be 90°C for war mixed asphalt concrete, and that the maximum temperature of the WMA behind the screed shall be 125°C.

The samples were collected in the fall of 2015, and were tested in the NBDTI Central lab over the course of the Winter Term of 2016. Cylinders were prepared at the University of New Brunswick using a Troxler 4141 Superpave Gyratory Compactor (SGC) and sent to the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo for Dynamic Modulus and Hamburg Wheel Track Test which were completed during the summer of 2016.

TEST METHODS

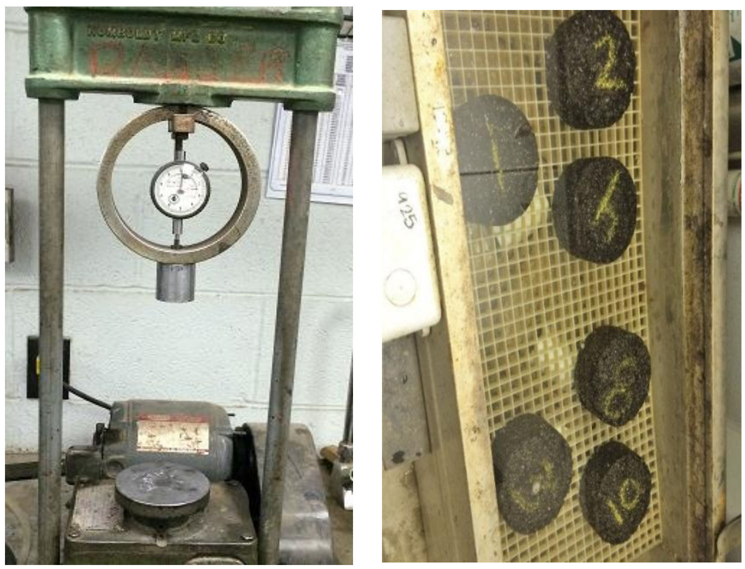
Tensile Strength Ratio

The initial density and TSR tests were performed at the NBDTI labs. WMA and HMA samples were subjected to an indirect tension test (IDT) to estimate the potential for rutting or cracking. Additionally, the sample briquettes were tested to find the theoretical maximum density (TMD) for the asphalt mixes using the ASTM D2041 process. The TMD for the asphalt samples were found to be similar to other tests done on other highways using these batches of WMA and HMA mixes. A series of Marshall (100 mm diameter) Briquettes were prepared, and trials were performed to find the compaction effort (number of Marshall hammer blows) to get a desired air void content of seven percent. Once this was established, several briquettes were prepared from each of the asphalt samples.

The IDT test performed was a Modified Lottman Test, following the ASTM D4867 standard. The briquettes were assigned to three groups: control, conditioned and freeze/thaw. The freeze cycle is 24 hours, after which both they and the conditioned briquettes are placed in a 60°C bath.

An indirect tension test takes place after the thaw cycle is complete, and the control tensile strength is compared to the test subjects. This comparison between the conditioned and control briquettes gives the TSR values. These values for the theoretical maximum density were used for all the calculations and sample measurements made going forward.

Additionally, there was an IDT performed on a group of samples to test HMA and WMA to three free-thaw cycles. Each cycle included a 60°C bath for 24 hours then, the samples were re-wrapped and placed back in the freezer. It was hoped these extra cycles would highlight any differences between the mixes.



(a) Indirect Tension Test Machine **(b)** Samples in 60 °C bath

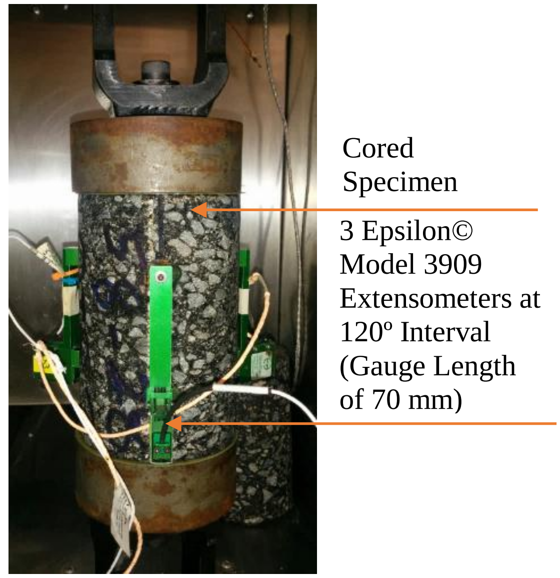
Figure 1. NBDTI TSR Equipment

Dynamic Modulus Test

A Material Testing System (MTS) at CPATT as shown in Figure 2 was used to determine dynamic modulus (|E*|) of specimens, each measuring 100 mm in diameter and 150 mm in height. Specimens were cored and cut from the middle of a SGC Compacted specimen measuring 150 mm in diameter by 180 mm in height.

The cored specimens were tested at six loading frequencies (0.1, 0.5, 1, 5, 10 and 25 Hz) and five different temperatures (-10, 4.4, 21.1, 37.8 and 54.4 degree Celsius) to obtain |E*| in accordance with AASHTO TP 62-07 "Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures" (AASHTO, 2007). Measurements obtained from this test were further combined to obtain a master curve in accordance with AASHTO PP62-09 procedure, "Standard Practice for Developing Modulus Master Curve for Hot-Mix Asphalt" (AASHTO, 2009).

(c) 810 MTS loading frame and 651 MTS environmental chamber



(d) Inside view of the environmental chamber

Figure 2. CPATT Dynamic Modulus Test Setup

Hamburg Wheel Tracking Device (HWTD)

The resistance of compacted asphalt mixtures to rutting and moisture damage was evaluated by using a Hamburg Wheel Tracking Device (HWTD) in accordance with AASHTO T324-04 "Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)" (AAHTO, 2011).

The device tracks a 705 N load hard-rubber wheel across the surface of gyratory compacted specimens submerged in a hot water bath at 50°C. During the test, the deformation of specimens under the wheel path was recorded as a function of the number of passes by using linear variable differential transducers (LVDTs).

Mechanistic-Empirical (M-E) Design Method

The AASHTOWare's M-E Software available to CPATT was used to investigate the effect of warm mix additives on the long-term performance of a pavement structure designed for New Brunswick climate and traffic conditions with WMA used as a surface course. For this purpose, a level 1 design was performed for the surface course by using dynamic modulus results and results of asphalt binder testing. All other inputs were retrieved from the Ministry of Transportation Ontario recommended inputs (MTO, 2012) and were maintained constant in all the designs for other layers.

A typical pavement structure was selected from the New Brunswick Department of Transportation and Infrastructure (NBDTI) asset management system. This structure was selected to presents pavement structures that could be routinely surface or re-resurfaced with WMA and HMA mixtures. The pavement structure comprised of a total asphalt thickness of 140 mm, underlain by 150 mm of Granular Base and 450 mm of Granular Subbase. The asphalt layer was separated into two layers with a 40 mm surface course, 100 mm binder course. The subgrade soils were clayey silt with the resilient modulus of 36 MPa. The granular base and subbase materials were comprised of crushed stones with material properties given in Table 1.

Table 1. Granular Base and Subbase Inputs

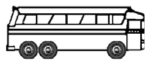
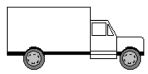
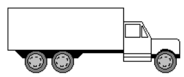
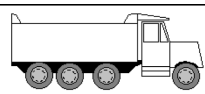
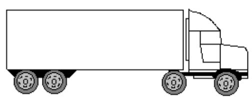
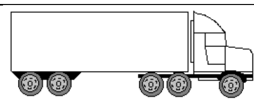
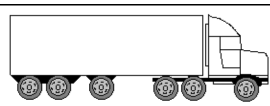
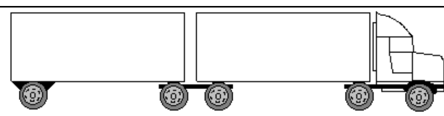
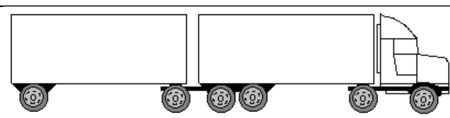
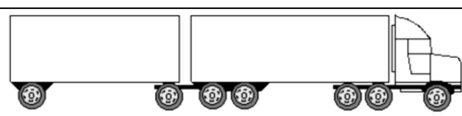
Property		**Granular Base 25-mm Type [1]**	**Granular Subbase 50-mm Type[1]**
	Sieve Size (mm)		
Gradation (% Passing)	25.0	100	75.0
	19.0	92.5	-
	9.5	61.5	-
	4.75	45.0	60.0
	1.18	27.5	-
	0.300	13.5	33.5
	0.075	5.0	4.0
Maximum dry unit weight (kgf/m^3)		2038.2	2012.4
Liquid Limit (LL)		6.0	11.0
Plasticity Index (PI)		0.0	0.0
Modulus (MPa)		250.0	150.0

Note: [1]These are types of granular materials that are commonly specified and used throughout the province of New Brunswick

Traffic Inputs

A specific traffic data (level 1) were selected for the pavement structure include 700 two-way Annual Average Daily Truck Traffic (AADTT), (2) 100 km/hr operational vehicle speed, and (3) Federal Highway Administration (FHWA) vehicle class distribution as listed Table 2. It should be noted that other vehicle classes (e.g. light passenger vehicles) were ignored in the analysis. The traffic inputs resulted in 3.91 million Equivalent Single Axle Loads (ESALs) over 20 years of design life.

Table 2. Long-Term Performance Prediction Traffic Inputs

FHWA Vehicle Class	Commercial Vehicle		Truck Flow Volume	Truck Flow Percentage
4		Two or Three Axle Buses	11	1.5
5		Two-Axle, Six-Tire, Single Unit Trucks	97	13.8
6		Three-Axle Single Unit Trucks	67	9.5
7		Four or More Axle Single Unit Trucks	6	0.9
8		Four or Less Axle Single Trailer Trucks	26	3.7
9		Five-Axle Single Trailer Trucks	305	43.6
10		Six or More Axle Single Trailer Trucks	163	23.3
11		Five or Less Axle Multi-Trailer Trucks	0	0.0
12		Six-Axle Multi-Trailer Trucks	0	0.0
13		Seven or More Axle Multi-Trailer Trucks	26	3.7

Climate Inputs

In the Pavement M-E software, climate inputs are incorporated into the performance prediction analysis through the Enhanced Integrated Climatic Model (EICM) which is a product of a computer program that calculates the effect of changes in moisture within the pavement

materials over time and depth combined with the effect of freezing and thawing on the pavement response.
Inputs such as latitude, longitude, elevation, and depth of water table for a selected weather station are required in order to generate the climatic file. For the analysis, the closest station to the site location was selected to generate the climate conditions presented in Table 3. Figure 3 shows the approximately of selected weather station to the site location.

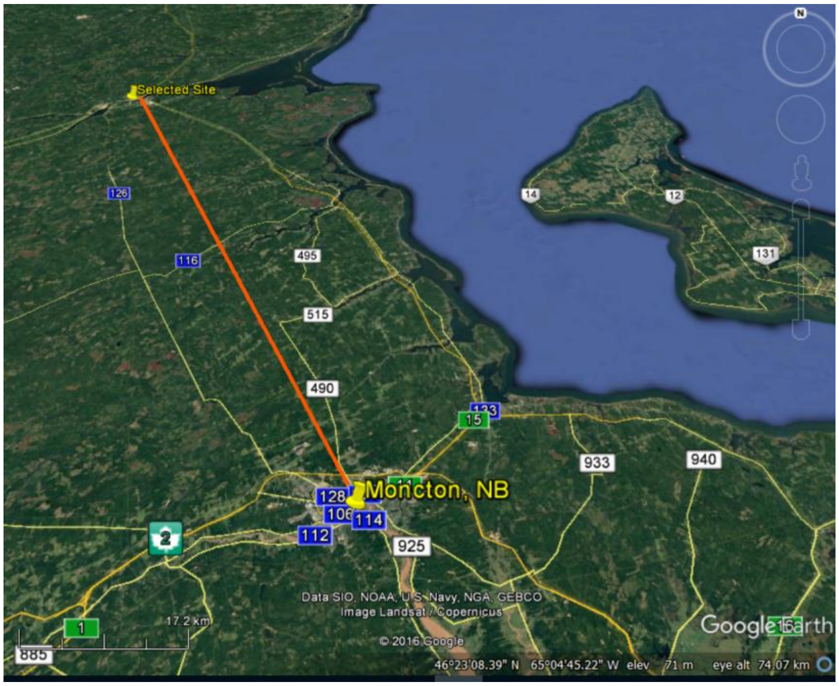


Figure 3. Approximate Location of Weather Station to Site Selected for Analysis (Google Earth, 2017)

Table 3. Long-Term Performance Prediction Annual Climate Inputs

Parameter	**Annual Statistics**
Mean annual air temperature (°C)	5.7
Mean annual precipitation (mm)	1205.2
Freezing index (°C – days)	801.2
Average Number of freeze-thaw cycles	80.1
Number of wet days	176.5

Terminal Service Levels

In the MEPDG, structural adequacy is evaluated by the ability of a design to meet sets of targeted threshold (also known as Terminal Service Levels). For this study following thresholds at 90% reliability were retrieved from the Ministry of Transportation Ontario recommended inputs (MTO, 2012).

Table 4. Warm Mix Asphalt Long-Term Performance Distress Prediction Target Values

Performance Criteria	Targeted at 90% reliability
Permanent Deformation - Total Pavement (mm)	19.00
AC Bottom-up Fatigue Cracking (%)	25.00
AC Thermal Fracture (m/km)	189.4
AC Top-down Fatigue Cracking (m/km)	378.8
Permanent Deformation – AC only (mm)	6.00

RESULT AND DISCUSSION

Moisture Induced Damage

Indirect Tensile Strength

The AASHTO T283 tests the ratio between the control and conditioned strengths. The results for the Tensile Strength Ratio TSR are shown in Table 5. It was noticed that WMA mix performed very well compared to the control HMA mix in a Modified Lottman Test, both had tensile strength ratio (TSR) values above the minimum requirement. NBDTI specifies that the average of the conditioned and Freeze-Thaw TSR values is above 80%. The strength of the samples was examined to see if there is any difference between the samples that the ratio measure may not make obvious. A summary of the results can be found in Figure 4.

It was found that that there was no statistical difference between the WMA and HMA IDT strengths. However, the average IDT strength of the conditioned WMA samples falls below 690 KPa, which Cucalon suggests as a secondary measure of moisture susceptibility for off-site plant mixed laboratory compacted specimens (Cucalon, et al., 2015).

The indirect tension tests showed that the WMA samples did not appear to be suffering from any stripping of the asphalt from the aggregate. It is worth noting that of the provinces that do not use the Modified Lottman Test, the second choice for a moisture susceptibility test is the Hamburg Wheel Test (Varamini & Tighe, 2015).

Table 5. TSR Results

Parameter	Conditioning	WMA	HMA
TSR (%)	Water only	83.7	88.5
	1 Freeze-Thaw Cycle	86.6	84.2
	3 Freeze-Thaw Cycles	88.2	71.0

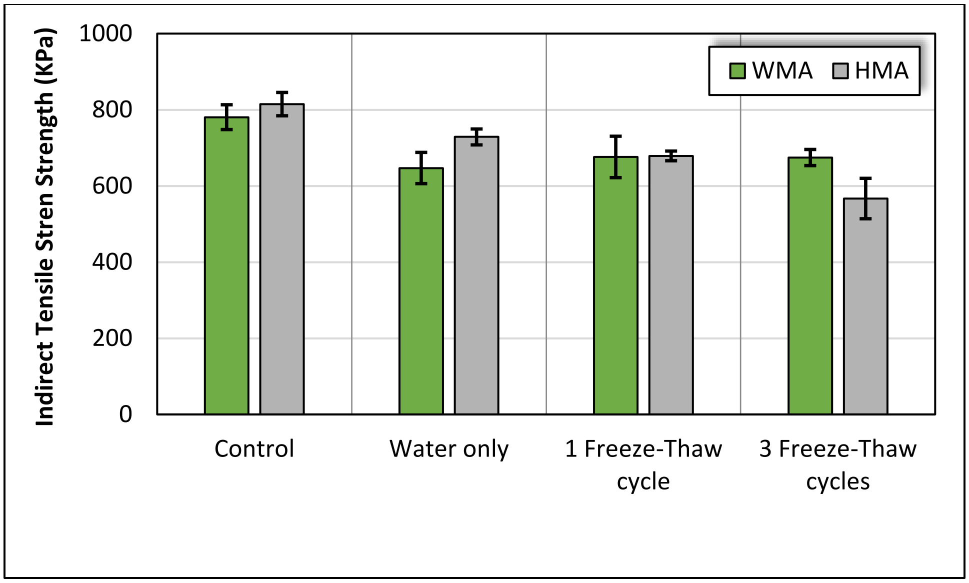


Figure 4. IDT strength comparison

The results of after cyclic freezing and thawing indicated a significant decrease in the strength of the HMA. It can be seen that the IDT strength of the WMA samples remains consistent, while a reduction of the IDT strength for the HMA is clear. When comparing the TSR results, the HMA samples lost 5% of the strength after the first freeze-thaw cycle and 20% of the strength after three freeze-thaw cycles.

Rutting

The results from the Hamburg Wheel Tracking Device were used to evaluate the moisture susceptibility of the mixtures. The moisture susceptibility is evaluated based on the total rut depth as well as the stripping inflection point, which is defined as the intersection of the slopes of stripping and rutting. HMA and WMA samples resulted in average rut depths of 3.12 and 3.32 mm respectively. This indicates that there was no difference between plant-produced HMA and WMA mixes.

Effect on Dynamic Modulus

Figure 5 illustrates |E*| measurement from different frequencies and temperatures merged into a master curve for all mixtures under study at a reference temperature of 21.1°C. Master curve results suggest that WMA and HMA have similar overall stiffness. The data from this test were also used to perform the long-term performance prediction presented in the following paragraph.

Long-Term Performance Prediction

Figure 6 presents the relative difference in predicted distresses for mixtures containing warm mix additives, as normalized by the predictions obtained for control HMA mixtures. It should be noted that the analysis was performed at 90 percent design reliability.

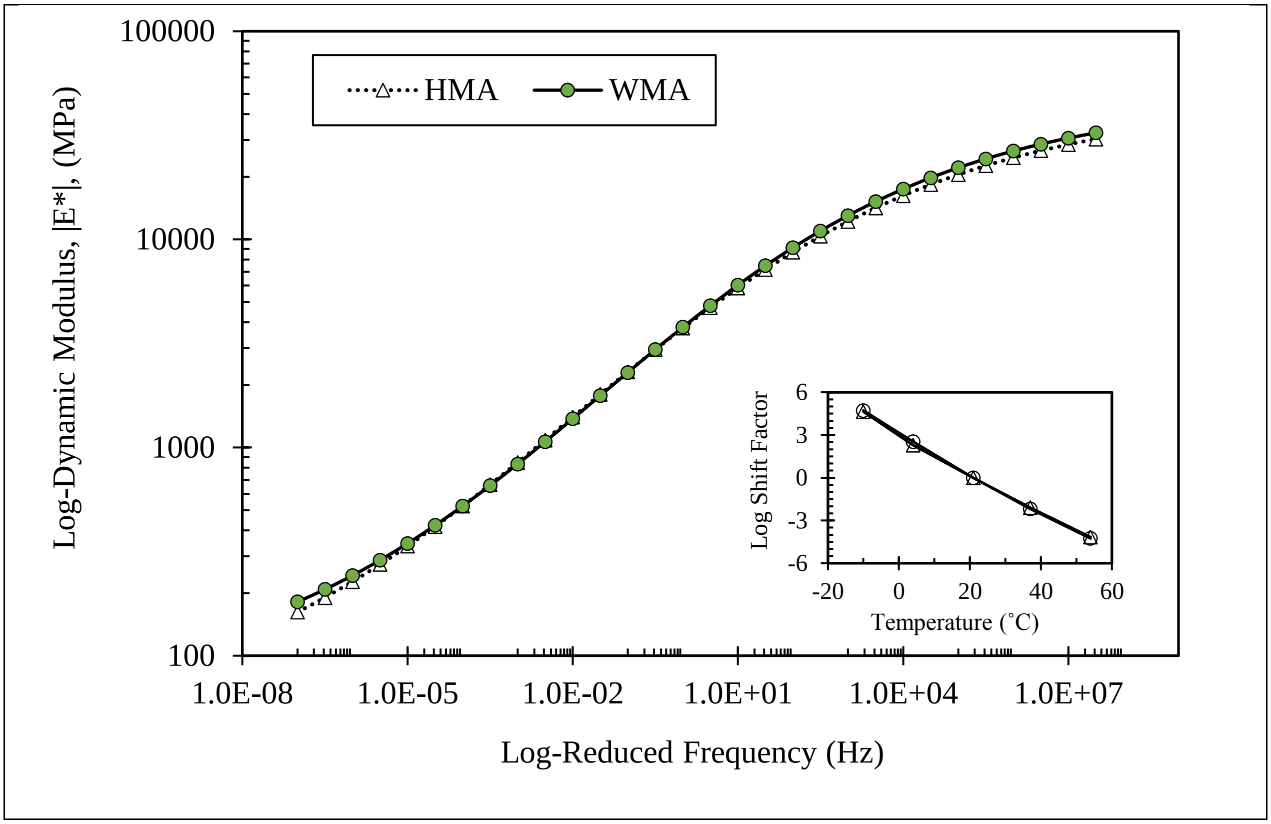


Figure 5. Master Curves for Plant-Produced HMA and WMA

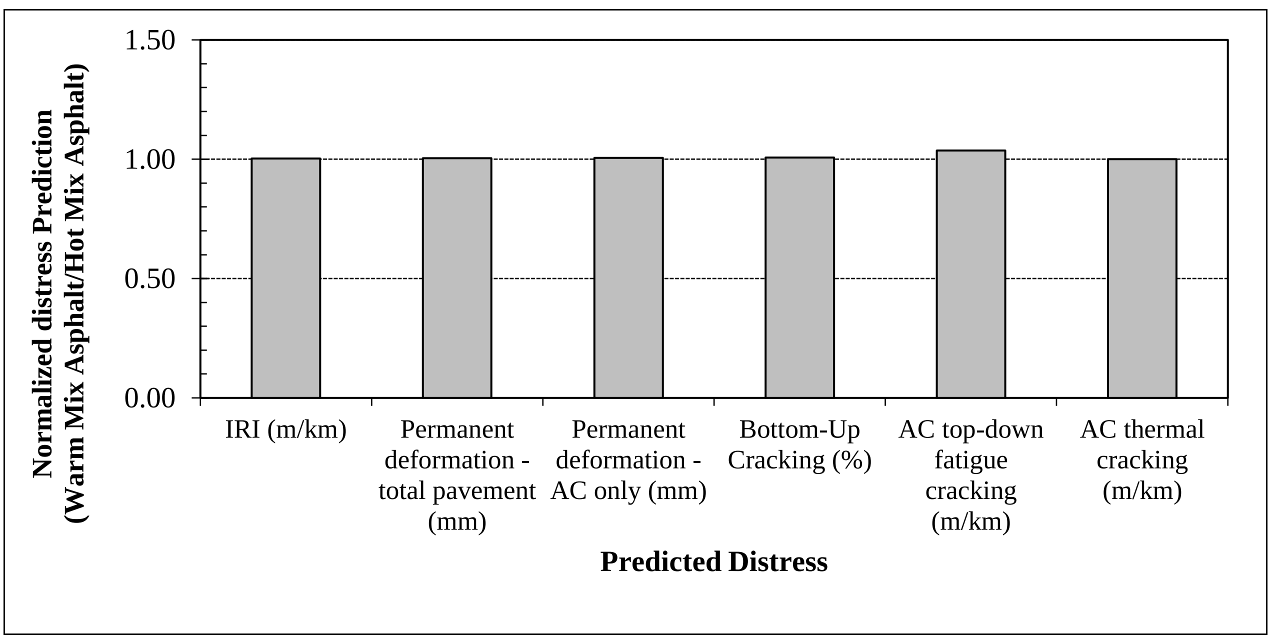


Figure 6. Effect of Warm Mix Additives on Long-Term Performance of NB Type D Asphalt Mixtures Over 20 Years of Service

CONCLUSIONS

The data thus far seems to suggest that the use of WMA should be encouraged for paving projects, provided that the WMA can continue to meet provincial requirements as outlined by the New Brunswick Department of Transportation and Infrastructure Standard Specifications. The WMA asphalt mix performs as well on an IDT as the control HMA, but with the advantage of lower production costs and fewer emissions and greenhouse gases. The literature in Canada suggests that this is well within the expected outcomes for using Evotherm as an additive for asphalt concrete. There are numerous studies that suggest many positive outcomes associated with Evotherm in a Canadian context (Kheradmand et. al, 2014).

Long-term longitudinal studies are going to be required to compare these results against a useful baseline. The laboratory tests performed can only indirectly measure potential moisture susceptibility. To fully understand how this product will work in place for New Brunswick, using on site samples from a variety of highways and aggregate sources must be done over the lifetime of existing WMA paved roads. If these longitudinal studies consistently reflect the equivalency of WMA and HMA test results seen thus far, then more uptake of this technology should be encouraged by the province for new projects.

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