

Evaluation of Warm Mix Asphalt Technology for Urban Pavement Rehabilitation Projects

Salvatory Materu, M.Sc. Candidate, University of Manitoba

Ahmed Shalaby, Ph.D., P.Eng, University of Manitoba

Ahmed Ghazy, Ph.D., P.Eng, City of Winnipeg and Department of Civil Engineering, Alexandria
University, Egypt

Blake Kibbins, P.Eng, City of Winnipeg

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Abstract

In northern climate, asphalt paving season is relatively short, and paving is often done late in the season when weather conditions are less than ideal. Warm Mix Asphalt (WMA) technology has the capability of lowering the temperature at which the asphalt is mixed and compacted by 30°C or more without compromising the performance of asphalt pavement. The reduced difference between asphalt mix and ambient temperature results to a lower cooling rate thus allowing long haul, sufficient compaction time and late season projects compared to the conventional Hot Mix Asphalt (HMA). This potential benefit means, among others, an extended paving season for the City of Winnipeg. Reduction in production temperature also generates other positive impacts both economically and environmentally.

The objective of this study is to evaluate the installation of WMA to compile experiences with this technology and evaluate their effects on construction methods and performance. The study further attempts to evaluate the effectiveness of the WMA chemical additives and its dosage rate as liquid anti-strip agents on the properties of WMA mixtures through field and laboratory testing program. In addition to the overall effectiveness of WMA, the study aimed to evaluate its economic cost relative to Hot Mix Asphalt (HMA).

Three WMA mixtures using three different chemical additive dosages (0.3, 0.5 and 0.7 percent by weight of asphalt cement) were tested. Among the different additive dosage used, the 0.5% had a better overall performance. The moisture sensitivity tests indicated the highest Tensile Strength Ratio (TSR) at this dosage, suggesting the lowest moisture damage susceptibility. The study also showed that WMA can be successfully placed using conventional HMA paving practices and procedures. The WMA price was between 2% to 11% higher than conventional HMA including the costs of additional testing as well as the WMA additives. It is expected that in future large paving contracts, the cost of WMA will decrease when the contracts do not include the additional testing and contractors realize the financial benefit of reduced energy consumption in the production of WMA.

Keywords: Warm Mix Asphalt, Chemical Additive, Pavement Performance, Moisture Susceptibility.

INTRODUCTION

Warm Mix Asphalt (WMA) technology plays a significant role towards sustainable roadways by lowering the temperature at which the asphalt is mixed and compacted while also improving the pavement performance. Asphalt mixes are generally heated to 150 °C temperature or higher, depending mainly on the type of binder used. Mixes produced with the WMA technology are being produced at temperatures of about 120°C or lower [1]. Lower temperature comes with several positive impacts such as:

- Reduced thermal cracking and enhance the overall pavement performance;
- A reduction in fuel energy consumption thus fuel cost saving;
- Less emissions including greenhouse gas that contribute to health and odor problems;
- Lower emission may allow plants to be located in areas with strict air pollution regulations thus reducing the delays associated with traffic congestion;
- Improve worker safety and health due to handling mixes at lower temperatures and reduced asphalt fumes;
- Longer haul distances due to the slow cooling rate; and,
- Extend construction season.

Different technologies were developed for WMA use, including foaming technology, organic wax technology and chemical additives technology. Such technologies produce WMA by reducing the viscosity of the asphalt binder at a given temperature. Chemical additives are more broadly used in Northern America which work as surfactants that reduce the friction at the interface between the binder and the aggregate. Evotherm is one alternative to achieve that purpose in the asphalt paving industry [2]. Evotherm can improve mixing, aggregate coating, workability, compaction and adhesion with no change in materials or job mix formula required. A third generation of Evotherm called Evotherm M1 was introduced which is a water-free additive that can reduce the mixing temperature by 33°C to 45°C [3] without compromising the asphalt performance.

Previous research has raised a concern of moisture susceptibility due to the reduction in mixing temperature. Higher moisture content in the asphalt mixture decreases the adhesion of asphalt binder to the aggregate surface, increase the moisture susceptibility of the asphalt mix which can lead to stripping and damage of the asphalt pavement. As the use of WMA technology evolves, many agencies seek better understanding of the effects of WMA dosage rate on mixture compaction, rutting resistance and moisture susceptibility. Studies have indicated that WMA chemical additives play a significant role as an anti-stripping agent and improve the resistance to moisture damages [3].

Because of the rapid and large scale implementation of WMA, the City of Winnipeg and University of Manitoba worked collaboratively to evaluate the applicability of WMA through a laboratory and field testing program. The program includes evaluating the stiffness, rutting resistance and moisture susceptibility for three WMA mixtures using three different additive dosages (0.3, 0.5 and 0.7 percent by weight asphalt cement). The selection of the materials was based on typical asphalt mixes used by the City of Winnipeg [4]. Construction used typical mixture designs and practices so that performance under typical construction conditions could be evaluated.

OBJECTIVE

The objective of this study is to evaluate the installation of WMA, compile experiences with this technology and evaluate their effects on construction methods and performance. The study further attempts to evaluate the effectiveness of the WMA additives and its dosage rate as liquid anti-strip agents on the properties of WMA mixtures through field and laboratory testing program. In addition to the overall effectiveness of WMA, the study aimed to evaluate its economic cost relative to HMA.

STATEMENT OF THE PROBLEM

The reality of being located in a northern climate means that asphalt paving season is relatively short, and paving is often done late in the season when weather conditions are less than ideal. Owners and contractors have been working towards technologies that can reduce risk associated with cool weather paving and compaction of stiff asphalt mixes. Previous studies have shown that WMA can allow paved asphalt to achieve compaction at lower mixing and compaction temperatures, while retaining better performance through its service life. This potential benefit means, among others, an extended paving season for the City of Winnipeg.

MATERIALS AND METHODOLOGY

The raw materials which were used in the preparation of WMA mixtures in this study, including asphalt cement and aggregate were characterized using routine type of tests, and the results were compared with the City of Winnipeg specification requirement to evaluate their suitability for job mix [4]. Except for the inclusion of Evotherm M1 in the WMA, the materials and mix design for the HMA and WMA were identical. Evotherm M1 was used at three dosages in the WMA (0.3%, 0.5%, and 0.7%). The physical and chemical properties of the additive are listed in Table 1 [3].

Table 1: WMA additive properties

Properties	Evotherm M1
Physical Form	Dark Amber liquid
Density at 25°C	1000.6 kg/m ³
Specific Gravity at 25°C	0.97
Conductivity at 25°C	2.2 µS/cm
Dielectric Constant at 25°C	2-10
Recommended Dosage Rate	0.25-0.75% by weight asphalt cement
Viscosity (Pa · S)	
at 27°C (80°F)	0.28 – 0.56
at 38°C (100°F)	0.15 – 0.30
at 49°C (120°F)	0.08 – 0.16

The HMA was placed in August 2018, while the WMA was installed from September to November 2018. The HMA was used as a reference and samples were collected to compare both short term and long-term performances. Placement of the HMA and WMA used the same equipment and methods [4]. The project specifications stated that the maximum mixing temperature shall be 160°C and 135°C for HMA and WMA, respectively, and the maximum temperature of the WMA behind the screed shall be less than 130°C. An infrared thermal camera was used to monitor the temperatures during construction, both before and after compaction.

FIELD CONDITIONS DURING CONSTRUCTION

Table 2 shows the field condition during paving. The ambient temperature was decreasing as construction progressed towards the fall season. In order to determine the degree of compaction, field densities for all paved sections were measured using a nuclear density meter (densometer) in accordance with ASTM Standard D2950, Standard Method of Test for Density of Bituminous Concrete in Place by Nuclear Method [5]. As required by the City of Winnipeg Specification, the measured in-place density of the completed paved sections shall be an average of 97% of the 75 Blow Marshall Density of the paving mixture, with no individual test being less than 95% [4].

Table 2: Field Conditions during Construction

Mix	Date of Construction	Ambient Temp during compaction (°C)	Ground Temp during compaction (°C)	Weather condition
HMA	August 23, 2018	28	30	Sunny
0.3% WMA	September 27, 2018	14	11	Little rain
0.5% WMA	October 4, 2018	7	8	Cloudy
0.7% WMA	November 2, 2018	0	3	Cloudy

TESTING

To evaluate the stiffness, rutting resistance and moisture susceptibility for the mixtures, loose mix samples were collected from each mixture as well as the reference HMA mix. The tests performed included the dynamic modulus test and moisture susceptibility test. All samples were compacted using a Superpave Gyrotory Compactor at mixing/compaction temperatures of 160/145°C and 130/115°C for HMA and WMA, respectively. Three replicate samples for each test were produced and tested for repeatability.

Dynamic Modulus

The dynamic modulus test was used to evaluate the stiffness of the compacted mixtures in accordance with AASHTO T342-11 procedure [6]. Cylindrical test specimens (100mm (4 in.) diameter and 150mm (6 in.) height) were prepared for the test. A sinusoidal compressive stress

was applied to the sample at given temperatures and frequencies. Specimens were tested under four temperatures (-10, 4.4, 21.1, and 37.8°C) and six frequencies (0.1, 0.5, 1, 5, 10, and 25 Hz) to determine the dynamic modulus ($|E^*|$) of specimens.



Figure 1: Gyrotory compactor (left) and Dynamic modulus testing (right)

The dynamic modulus values were further combined to obtain a master curve using AASHTO PP62-09 procedure (Standard Practice for Developing Modulus Master Curve for Hot-Mix Asphalt) at a reference temperature of 21.1°C [7].

In addition, the mixtures' performance were studied in terms of three main surface distresses using three dynamic modulus ($|E^*|$) values from each mixture: (a) thermal cracking at temperature of -10°C and high frequency of 25Hz, (b) fatigue cracking at temperature of 21.1°C and medium frequency of 10Hz, and (c) rutting at high temperature of 37.8°C and low frequency of 0.1 Hz [8].

Moisture Susceptibility

To evaluate moisture damage, AASTHO T-283 procedure was used. Six replicate specimens (100mm (4 in.) diameter and 63mm (2.5 in.) height) from each mixture were compacted to $7\% \pm 0.5$ air void content by using the Superpave Gyrotory Compactor. Three specimens were tested under dry conditions while the other three were tested after going through moisture-conditioning. The dry samples were conditioned at $25 \pm 0.5^\circ\text{C}$ ($77 \pm 1^\circ\text{F}$) for two hours before performing indirect tensile strength (IDT) test, while the moisture conditioned samples were first saturated to between 70 and 80 percent then wrapped in a plastic film and kept in a plastic bag that contained 10 ± 0.5 ml of water and sealed. The samples were then placed in the environmental chamber for a freezing cycle of 16 hours at $-18 \pm 3^\circ\text{C}$ ($0 \pm 5^\circ\text{F}$). Afterwards, the samples were removed from the plastic bag, unwrapped and then placed in a water bath at $60 \pm$

1°C (140±2°F) (thawing cycle) for 24 hours with 25mm (1 in.) of water above their surface. Finally, the samples were placed in a 25 ± 0.5°C (77±1°F) water bath for 2 hours before testing [9].

Indirect Tensile Strength

ASTM T-283 was used to determine the tensile strength ratios (TSR). The strength of the samples after freeze-thaw conditioning and dry samples were determined and the TSR were calculated as a ratio of the average tensile strength of the freeze-thaw subset to the dry subset. Figure 2 shows an example for the sample under loading at a constant rate of 50 mm/min (2 in/min). The recorded maximum load was then used to calculate the tensile strength.

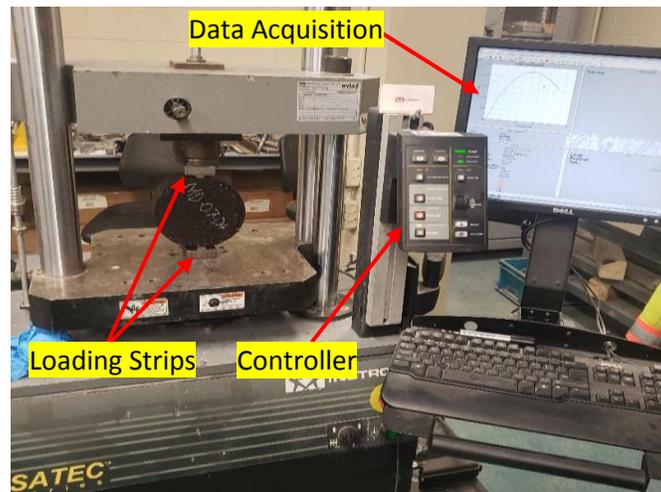


Figure 2: IDT test setup

RESULTS AND DISCUSSION

Infrared Thermal Imaging

Temperature monitoring was required to ensure that WMA mixtures were placed and compacted at lower temperature than HMA mixtures (more than 135°C) [10]. Figures 3 and 4 show examples for the thermal images of HMA and WMA sections behind the paver, respectively. The highest and lowest temperatures were 145°C and 1°C, respectively for the HMA while 109°C and -6.5°C for the WMA. The highest recorded temperature behind the paver for the WMA mixtures was 128°C. The results showed that the temperature behind the paver was below the project specified maximum temperature of 130°C.

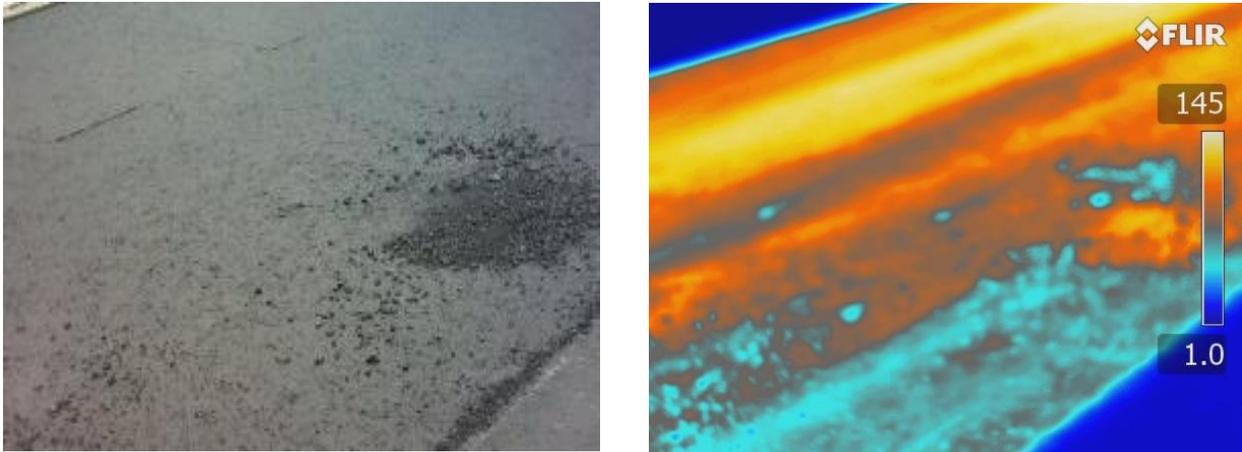


Figure 3: Paving using HMA technology (max and min temperature marked on figure)

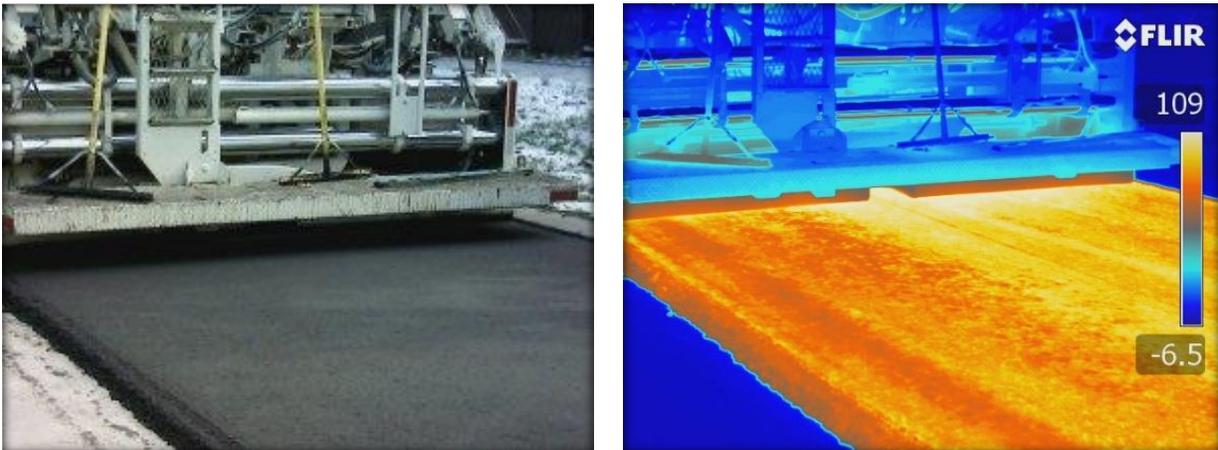


Figure 4: Paving using WMA technology (max and min temperature marked on figure)

Compaction Density

Densities of the compacted sections were determined using a nuclear density gage and the results were shown in Table 3. In general, WMA mixtures gained higher density than HMA. Also, there was a direct relationship between the additive dosages and compaction density values of the mixtures. As the chemical additive dosage increased, the degree of compaction increased even though the ambient temperature was low. The increased density may be associated with the improved compactability for the WMA mixtures due to the increased workability.

Due to the fact that the project was executed by one contractor, it was not feasible to place different dosages at the same time to compare the effect of dosage under the same weather conditions. It would require the use of two or storage banks as the additive was added to the binder by the asphalt supplier.

Table 3: Compaction Density of mixtures at different dosage

Mix	Ambient Temp during compaction (°C)	Min. Temp behind paver (°C)	Max. Temp behind paver (°C)	Max. Temp during compaction (°C)	Min. Compaction Density (%)	Max. Compaction Density (%)
HMA	28	141	150	140	97	98
0.3% WMA	14	104	125	120	97	99
0.5% WMA	7	102	128	123	98	100
0.7% WMA	0	109	127	110	98	100

Dynamic Modulus Test

The stiffness of the mixtures was compared using the dynamic modulus master curve presented in Figure 5. The master curve has the ability to characterize the performance of the mixture at different frequencies and temperature [11]. According to the master curve, WMA mixtures had slightly higher stiffness values at low and high temperatures compared to the HMA samples. However, addition of WMA additive resulted to lower stiffness values at intermediate temperatures. In general, all mixes showed very similar patterns in the mixture’s stiffness and ability to recover from induced stress.

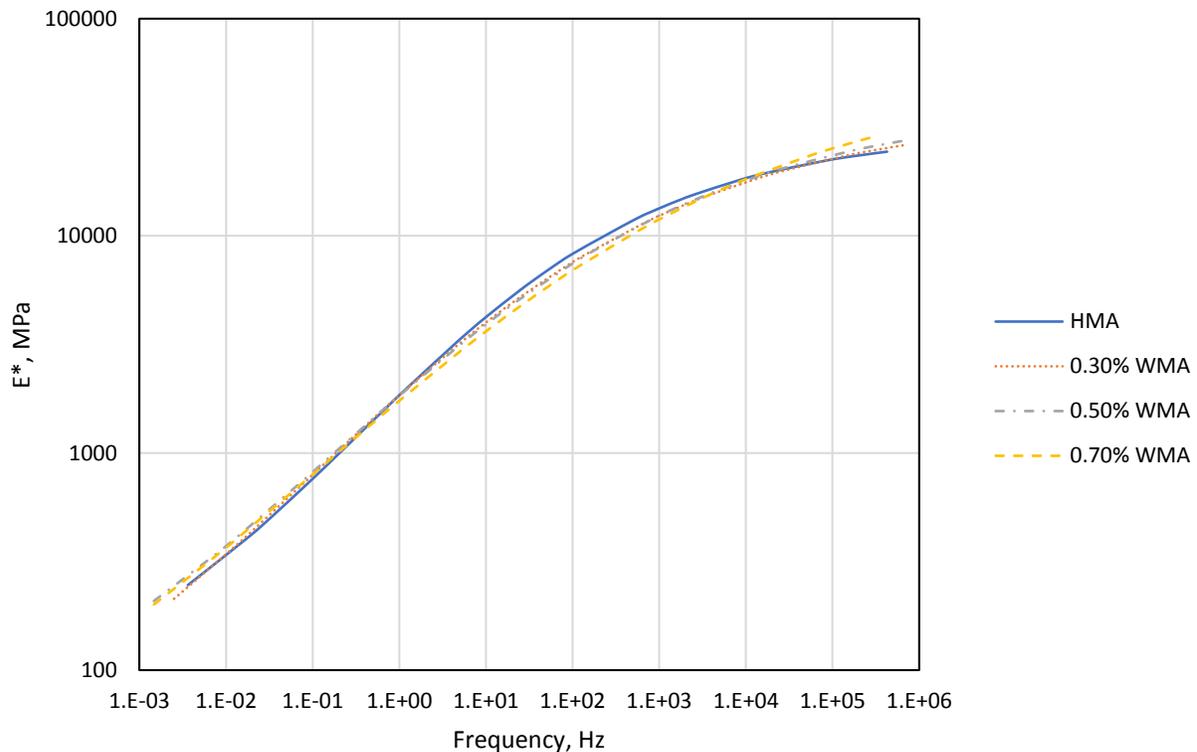


Figure 5: Dynamic Modulus Master Curve of all mixtures

Figure 6 illustrates normalized dynamic modulus ($|E^*|$) values for each warm mix with respect to the control mixture. The values greater than 1 indicates that the $|E^*|$ value of WMA is higher than that of HMA. If the ratio is less than 1, it suggests that the $|E^*|$ value of WMA is lower than that of HMA. To predict the mixtures performance to thermal cracking, fatigue cracking and rutting, three temperature degrees (frequencies) were used (-10°C (25Hz), 21.1°C (10Hz) and 37.8°C (0.1Hz)). Figure 6 shows that:

- Addition of WMA additives caused a slight increase in stiffness at cold temperatures. This suggests that the additives may not improve the resistance to thermal cracking at colder temperatures.
- At intermediate temperature of 21.1°C, addition of WMA additives led to a decrease in stiffness of the control mixture. This may suggest an improvement in resistance to fatigue cracking.
- The addition of warm mix additives showed a slight increase in high temperature stiffness. This may suggest an increase in rut resistance at high service temperature.

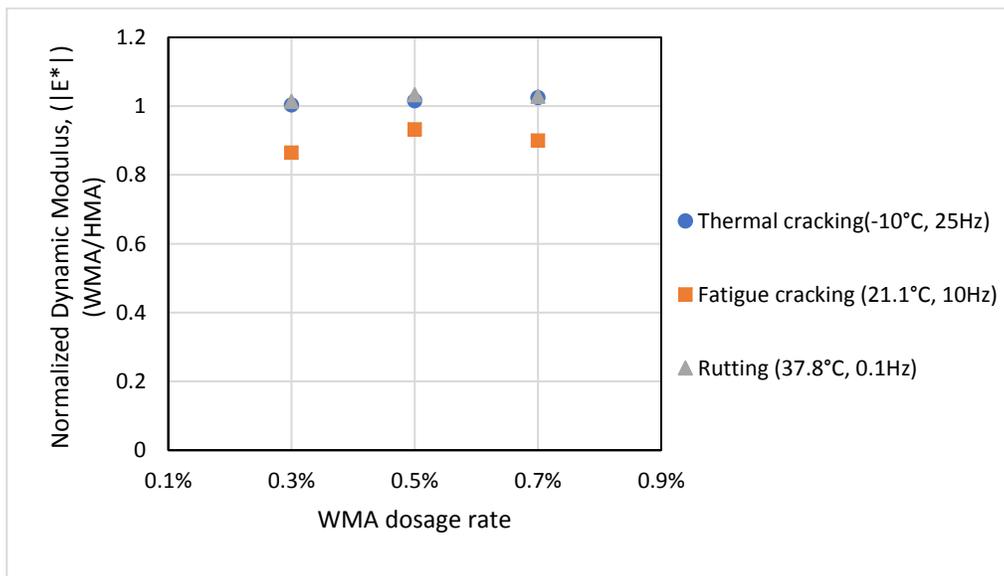


Figure 6: Normalized Dynamic Modulus results in terms of resistance to thermal cracking, fatigue cracking and rutting

Moisture Susceptibility Test

The resistance to moisture damage of the compacted mixtures were evaluated as the percentage of indirect tensile strength ratio between moisture-conditioned samples and dry samples. The highest tensile strength for the dry samples were observed for the HMA mixture as shown on Figure 7. The average tensile strength values ranged from 525 kPa for the HMA samples to 482 kPa for 0.7 percent WMA dosage. Analysis of Variance (ANOVA) with 95% confidence interval confirmed that there are statistical differences between the tensile strength values of the HMA

and WMA mixtures with a trend for all dosage rates. The results showed that when the dosage rate increased, the tensile strength of the dry samples slightly reduced.

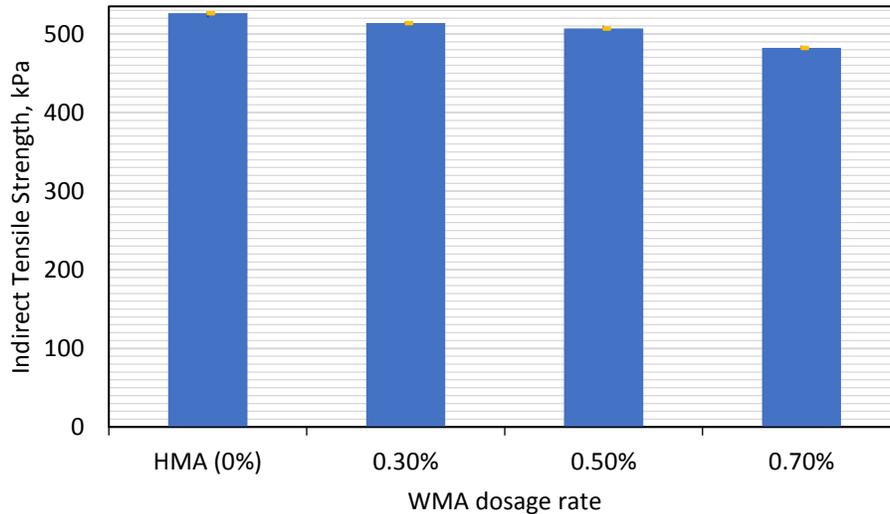


Figure 7: Indirect Tensile Strength values for dry samples

The TSR values as shown on Figure 8 have met the required 80 percent minimum value for all mixtures. There was an increase in TSR values for all WMA mixtures compared to the HMA mixtures. The ANOVA analysis suggested that there is a statistically significant difference between the TSR values for the HMA compared to the WMA but no statistical difference between the three WMA mixtures. The results showed that the 0.5% dosage has the highest average TSR value which may lead to a better resistance to moisture damage.

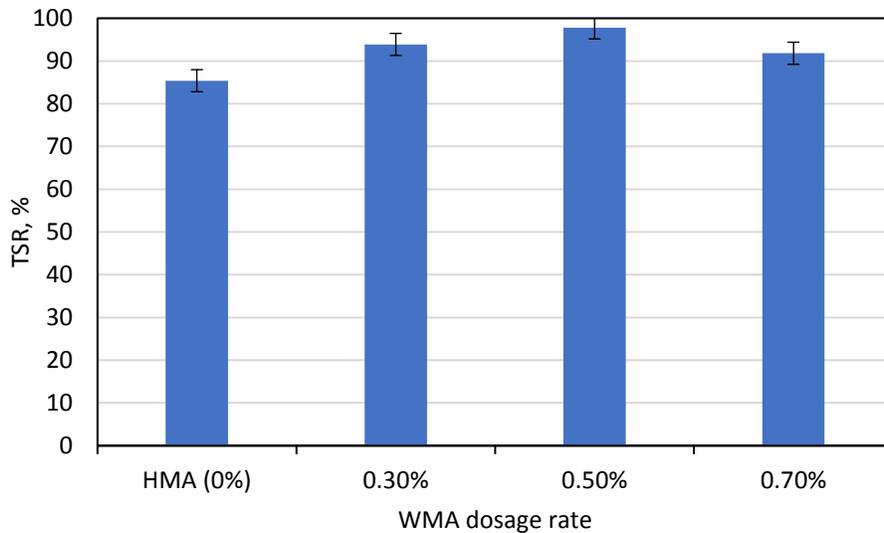


Figure 8: TSR ratios between moisture and unconditioned specimens

FINANCIAL IMPLICATIONS

To evaluate the overall effectiveness of WMA, it is important to consider its economic cost relative to HMA. The bid price for WMA was between 2% to 11% higher than conventional HMA. However, these bid prices included the costs of additional testing as well as the WMA additives. In addition, these contracts involved relatively small quantities of WMA that might not provide the benefit of economies of scale. It is expected that in future large paving contracts the cost of WMA will decrease when the contracts do not include the additional testing, and the savings from reduced energy consumption in the production of WMA are realized.

SUMMARY AND CONCLUSION

Based on the field tests and laboratory experiments, the following conclusions were derived:

- WMA mixtures were placed and compacted at lower temperature than HMA mixtures and achieved the required degree of compaction. The degree of compaction increased as the chemical additive dosage increased due to the improved workability for these mixtures.
- Among the different additive dosage used, the 0.5% had a higher overall stiffness for the WMA mixtures especially at higher temperatures.
- The results showed that the dynamic modulus master curves for the WMA and HMA were similar.
- In general, increasing the WMA additive resulted in an improvement in the TSR value and lower tensile strength values for the dry samples. This indicates that the used additive had anti-stripping properties which may increase the resistance to moisture damage.
- The normalized dynamic modulus ($|E^*|$) values showed that increasing the WMA additive may improve the fatigue cracking and rutting resistance.
- The TSR values of all mixtures met the required 80 percent minimum value and the highest TSR value was achieved at 0.5% additive.
- The WMA price was between 2% to 11% higher than conventional HMA including the costs of additional testing as well as the WMA additives. It is expected that in future large paving contracts, the cost of WMA will decrease when the contracts do not include the additional testing, and the savings from reduced energy consumption in the production of WMA are realized.

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