SURVEY ON CURRENT PRACTICES FOR EVALUATING WARM MIX ASPHALT MOISTURE SUSCEPTIBILITY

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ABSTRACT:

Warm Mix Asphalt (WMA) technology is becoming more commonly used by transportation agencies. This is due to the pressures from environmental acts and agencies to reduce Green House Gas (GHG) emissions generated by production and placement of paving mixtures. However, WMA technology has certain functional considerations, namely moisture susceptibility that need to be addressed in order to achieve performance equivalent to conventional Hot-Mix Asphalt (HMA) with the additional benefits of reduce emissions. To identify possible gaps in the WMA that need to be closed with further research, a Canada-wide survey has been prepared at the Centre for Pavement and Transportation Technology (CPATT) located at the University of Waterloo to document the state-of-the-art related to WMA technologies. This paper presents the results of this survey on the preferred practices conducted by various Canadian transportation agencies.

1. INTRODUCTION

Warm Mix Asphalt (WMA) technology is becoming more commonly used by transportation agencies. This is due to the pressures from environmental acts and agencies to reduce Green House Gas (GHG) emissions generated by production and placement of paving mixtures. WMA is defined as a group of technologies that allow for a reduction in the mixing and production temperatures of conventional Hot Mix Asphalt (HMA). WMA technologies were first employed in Europe in the late 1990s and have gained interest in North America since 2002, in response to environmental pressures related to GHG emissions. Since then, several WMA technologies have been developed with proven benefits, particularly in paving contracts in Ontario, including (Tabib et al., 2014):

- Reduced GHG emissions during asphalt production and paving operations
- Reduced fuel consumption at the asphalt plant
- Improved worker safety due to reduced asphalt fumes at paving sites
- Improved compaction and joint quality
- Reduced fuel consumption and vehicle emissions associated with user delay in construction zones due to lower compaction temperatures, and thereby less time required to re-opening lanes to traffic
- Less cracking potential due to reduced asphalt binder aging
- Potential to extend the paving season due to increased workability at lower compaction temperatures
- Facilitating longer haul distances from the production facility to the paving site
- Potential for higher reclaimed asphalt pavement (RAP) content

Despite the aforementioned environmental, economical, and safety benefits of WMA, changes in the production and placement process have raised concerns in regards to the long-term performance of WMA, particularly its moisture susceptibility.

Moisture damage in asphalt mixtures occurs due to loss of adhesion (the bonds between asphalt and aggregate) and/or cohesion (the bonds between asphalt binder molecules), which subsequently results in progressive strength reduction and decrease in stiffness of the mixture.

Several mechanisms have been cited to be contributing factors to moisture damage including detachment, displacement, spontaneous emulsification, film rupture, pore pressure, and hydraulic scouring (Solaimanian et al., 2007). However, not all these mechanisms are well understood due to the complexity of describing the level of impact of individual or combined mechanisms on the moisture susceptibility of a given mixture, as stated by Solaimanian et al. (Solaimanian, Harvey, Tahmoressi, & Tandon, 2003). Furthermore, researchers have found that moisture damage can be accelerated by mixture design or production issues, including those given in Table 1-1 (Santucci, 2003).

Table 1-1 Factors contributing to moisture-related distress (Santucci, 2003)

MIX DESIGN	• Binder and aggregate chemistry • Binder content • Air voids • Additives
PRODUCTION	• Percent aggregate coating and quality of passing the No. 200 sieve • Temperature at plant • Excess aggregate moisture content • Presence of clay
CONSTRUCTION	• Compaction—high in-place air voids • Permeability—high values • Mix segregation • Changes from mix design to field production (field variability)
CLIMATE	• High-rainfall areas • Freeze–thaw cycles • Desert issues (steam stripping)
OTHER FACTORS	• Surface drainage • Subsurface drainage • Rehab strategies—chip seals over marginal HMA materials • High truck ADTs.

From a review of the literature (FHWA, 2014) (Bonaquist, 2011) (Brits, 2004) (Hurley & Prowell, 2005a) (Prowell & Hurley, 2007) (Cervarich, 2003), the main factor that might contribute to the moisture susceptibility of WMA is the excessive aggregate moisture content due to the lowered production and compaction temperatures, and introduction of additional moisture during the production process of specific WMA technologies. This could affect the reduction of binder absorption by the aggregate, as well as binder-aggregate coating.

The AASHTO T 283 (also referred to as “modified Lottman test”) is one of the most common procedures used to evaluate moisture susceptibility of compacted asphalt mixtures, particularly Hot-Mix Asphalt (HMA). In this test, the severity of moisture sensitivity of a mixture is quantified as the percentage of tensile strength retained after conditioning which is referred to as the Tensile Strength Ratio (TSR). The tensile strength is determined by using the Indirect Tensile Strength (IDT) apparatus accordance with ASTM D6931-12, “Standard Test Method for Indirect Tensile Strength of Bituminous Mixtures” (ASTM International, 2012).

For this test, a minimum of six specimens are compacted by use of Marshall hammer or the Superpave Gyratory Compactor (SGC) to a target percentage of air voids (7 ± 0.5 percent). The compacted specimens are then separated into two subsets: conditioned and unconditioned. Conditioning of specimens includes vacuum-saturating to the saturation range of 70 to 80 percent, a freezing cycle (15 hours at -18ºC), and a thaw cycle in warm water (24 hours at 60 ºC).

The AASHTO T 283 test is a result of modifications to the original Lottman test in an attempt to improve its reliability. The AASHTO T 283 was adopted as the requirement for the Superpave HMA mixture design. Following this adoption, the AASHTO T 283 has become the most widely used procedure to evaluate moisture susceptibility. Despite its wide acceptance within the industry, several studies have reported shortcomings of the test method. One of the major shortcomings is the test's poor ability to predict field moisture susceptibility with reasonable confidence. TSR has been found to not correlate closely with measured field performance (Solaimanian et. al., 2003).

Another common complaint with regard to the test is the disagreement between the test results of specimens with 100 mm and 150 mm diameters. An extensive laboratory research program performed by Epps et al. (Epps, et al., 2000) investigated the matter. In this study, the effect of other factors on the test results were investigated including, different compaction methods (Superpave Gyratory Compactor, Marshall, Hveem), degree of saturation (50, 75, and 90 percent), and the freeze-thaw cycle. Five different types of aggregates were used with resistance to moisture damage ranging from low to excellent. Specific to each mixture, asphalt cements with performance grades of PG 58-28, 64-22, 64-28, and 70-22 were used. Results of this study have shown that 150 mm SGC specimens provided less variable results than 100 mm Marshall specimens. However, a number of transportation agencies have reported 100 mm specimens showing less variability than 150 mm SGC specimens, as part of a survey of 89 agencies compiled by AASHTO Materials Reference Laboratory (AMRL) (Azari, 2010) . Moreover, Kandhal and Rickards (Kandhal, 2002) have asserted that the IDT apparatus used for moisture damage evaluation might not accurately simulate the pumping action of traffic load. Instead, they suggested use of apparatus that enables moisture evaluation under a cyclic mode.

Poor reliability and repeatability of AASHTO T 283 is also reported by Tabib et al. (Tabib et al., 2014) on plant-produced samples collected for a study on evaluation of WMA projects across Ontario. This study concluded that TSR results were significantly variable with values from 44 to 100 percent. It is further suggested by the study that variability within TSR results might be due to a combination of factors such as production temperature variations (resulting in different levels of aging), and improper blending of WMA additives or anti-stripping agents.

To evaluate the effect of WMA additives on the moisture susceptibility of laboratory-prepared mixtures, the AASHTO T 283 testing protocol has been employed in several studies. Results obtained from these studies raised concerns about WMA mixtures as many mixtures failed the TSR requirements. However, such mixtures have not shown evidence of moisture damage in the field. The cause of the discrepancy between the laboratory and field is suggested to be due to the difference between how lab and field WMA mixtures are aged and conditioned prior to compaction, as stated by Mogawer et al. (Mogawer et al., 2011). This possible cause of discrepancy is evaluated in several studies. In brief, these studies concluded that an increase in laboratory conditioning temperature and/or time prior to compaction may provide a better correlation between the laboratory and field results.

The Ministry of Transportation of Ontario (MTO), and the Centre for Pavement and Transportation Technology (CPATT) located at the University of Waterloo (UW) are partnering as part of the Highway Infrastructure Innovation Funding Program (HIIFP) to evaluate the moisture susceptibility of WMA. The main objective of this research project is to review the variability of unconditioned dry and moisture-conditioned wet tensile strengths based on mixtures produced by using different Performance-Graded Asphalt Cement (PGAC) sources and different types of WMA technologies in combination with different types of aggregate. Through effective planning and execution, this research project is intended to suggest recommendations to improve the testing techniques in Tensile Strength Ratio (TSR) criteria outlined in AASHTO T 283 for WMA.

2. PURPOSE AND DESIGN OF THE SURVEY

A survey was distributed in January 2015 by CPATT to acquire insights into the most common types of technology and evaluation procedures Canadian agencies use for WMA. This information will be included CPATT-MTO research study. Another objective of the survey was to identify possible gaps in the WMA knowledge base that need to be closed with further research. Finally, the survey provided an opportunity for respondents to share information regarding the construction, materials, and performance of previously placed WMA pavements, as well as willingness to participate in the project.

The survey was conducted in a mail-back form with an e-mail invitation containing a brief description of the objectives and purpose of the study. The invitation was distributed to two technical Transportation Association of Canada (TAC) standing committees of the Chief Engineer's Council: (1) Pavements, and (2) Soils and Materials Standing Committees. The distribution of the survey was completed after receiving ethics clearance through a University of Waterloo Research Ethics Committee.

3. SUMMARY OF THE SURVEY FINDINGS

The following is a highly summarized overview of the survey responses in tabular and/or graphical format. For all tables, "no answer" indicates that no answer was provided by the agency. In several tables, the percentages do not add to 100 percent because agencies provided multiple answers. The list of respondents to the CPATT-WMA survey is provided in Table 3-1.

As noted in Table 3-2, the first usage of warm mix technology in Canada dates back to 2006, while majority of the agencies started using WMA in 2009. Currently, majority of the provincial agencies indicated routine use of warm mix technology in a considerable amount of tonnage, as illustrated in Figure 3-1 and **Figure 3-2** respectively. In Table 3-6, more than half of the respondents also indicated that they consider green concepts (i.e. Green House Gases reduction) in design and management decision making. Usage of WMA technology is specified as an option for most of agencies, as noted in Table 3-5.

Table 3-1 Summary of the Survey Respondents

No.	Organization	City	Province
1	Alberta Transportation	Edmonton	Alberta
2	British Columbia Ministry of Transportation and Infrastructure	Victoria	British Columbia
3	The City of Calgary	Calgary	Alberta
4	Manitoba Infrastructure and Transportation	Winnipeg	Manitoba
5	Ministry of Transportation Ontario	Downsview	Ontario
6	Nova Scotia Transportation and Infrastructure Renewal	Halifax	Nova Scotia
7	Ministry of Highway and Infrastructure, Saskatchewan	Saskatoon	Saskatchewan
8	Transports Quebec	Quebec City	Quebec
9	Halifax Regional Municipality	Halifax	Nova Scotia
10	Government of Yukon Highway and Public Works	Whitehorse	Yukon
11	New Brunswick Department of Transportation and Infrastructure	Fredericton	New Brunswick
12	University of Illinois at Urbana-Champaign & Illinois Department of Transportation	-	Illinois (United States)

Table 3-2 When did you start using WMA technology?

Year	Response
2006	8 %
2007	8 %
2008	25 %
2009	42 %
2013	8 %
No Answer	8 %

Table 3-3 How frequently do you use WMA additives?

Answer	Response
YES (routinely)	67 %
YES (rarely)	25 %
NO (never used)	-
NO (used before but not planning to use in future)	-
Other (please specify)	8%
No Answer	-

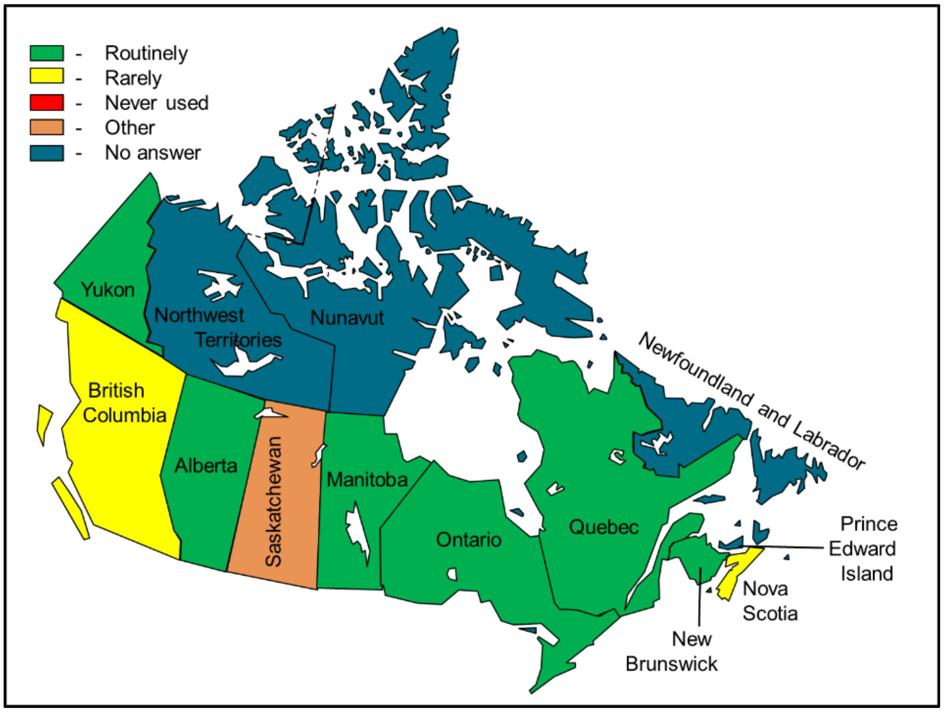

Figure 3-1 Warm Mix Asphalt usage in Canada

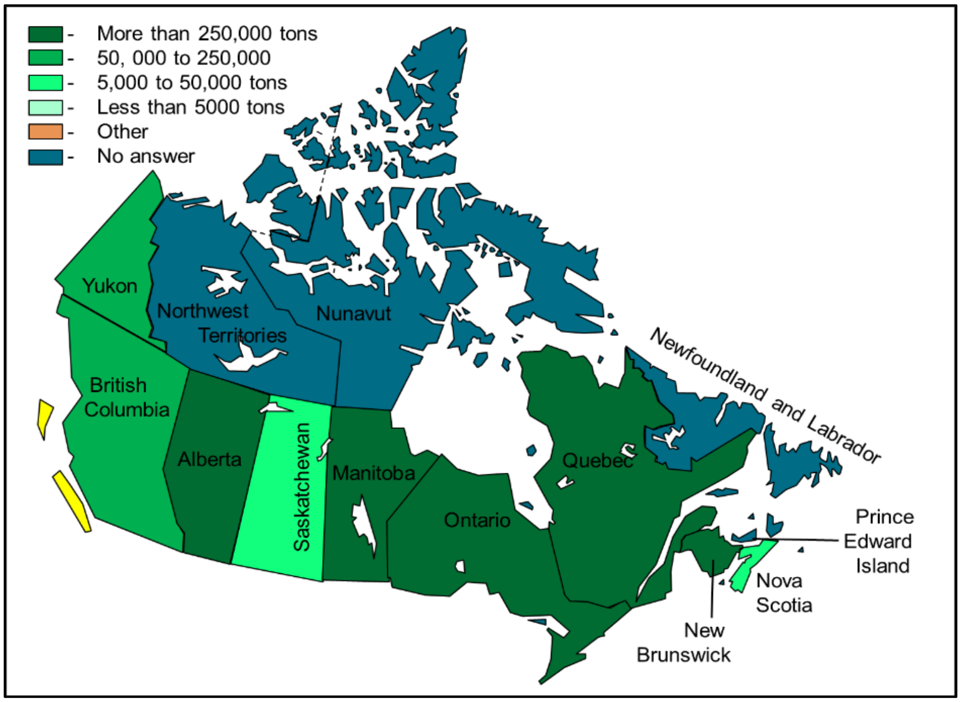

Figure 3-2 Warm Mix Asphalt tonnage placed to date in Canada

Table 3-4 Warm Mix Asphalt Placement of Selected Respondents

Organization	Province	Usage	Tonnage placed to date
The City of Calgary	Alberta	Routinely	5000 to 50,000 tons
Halifax Regional Municipality	Nova Scotia	Routinely	50,000 to 250,000 tons
University of Illinois at Urbana-Champaign & Illinois Department of Transportation	Illinois (US)	Rarely	125,000 tons on State Highway and 34,700 on Toll-way

Table 3-5 Which of the following options describe your use of WMA technology?

Answer	Response
Requirement	25%
Allow as option	75%
Allow as a separate bid item	-
No Answer	-

Table 3-6 Do you currently consider green concepts (i.e. Green House Gases, GHG, reduction) in design and management decision making?

Answer	Response
Yes	58 %
No	42 %
No answer	-

Table 3-7 provides the list of most commonly used warm mix additives and technologies used by agencies and cities across Canada. As noted in Table 3-8, almost 92% of respondents have used warm mix with dense-graded type of asphalt mixtures, which is mostly designed by Marshall method of design (Table 3-9). Superpave method is the second most common design method used for warm mix asphalt. In addition to those listed in Table 3-7, other technologies were indicated by respondents including Ecomat (Sintra-Colas product), Evotherm (M1, TE, 2000), Chemoran CWM, ALmix Foaming system, Meeker Foaming system, and some other plant-based foams with no record of tonnage or type.

Table 3-7 Which of the following WMA additives do you use most often?

Additive	Response
Accu-Shear™	-
Advera® WMA	17%
Aquablack™	-
Aspha-Min®	8%
Cecabase® RT	33%
Double Barrel Green®	42%
Evotherm® 3G.	75%
Evotherm® DAT	42%
Low Energy Asphalt (LEA)	-
Rediset®,	17%
Rediset™ WMX	8%
REVIX™	-
Sasobit®	17%
Shell Thiopave™	-
SonneWarmix™	25%
Terex®	-
TLA-X Warm Mix	0%
Ultrafoam GX™	25%
WAM Foam®	-
Other Additives	17%

Table 3-8 Mixture Type Used with Warm Mix Technology

Answer	Response
Dense-Graded	92%
Gap-Graded	8%
Open-Graded	8%
Other (please specify)	8%
None	-
No Answer	-

Table 3-9 Which of the following mixture types do use WMA additives with?

Answer	Response
Superpave	34%
Marshall	58%
Other	8%

The majority of respondents indicated mandatory use of anti-stripping agents with warm mix technology if laboratory test results indicate presence of moisture damage (Table 3-10). There are also a number of agencies that require use of anti-stripping agents when employing aggregates with a history of moisture susceptibility. Furthermore, some agencies indicated that there are warm mix additives known to have anti-stripping properties and because of this, use of anti-stripping agents may not be required. When asked if they can provide the names of anti-stripping agents that are commonly used for their projects, 67% of the agencies provide following anti-stripping agent names:

- Hydrated Lime
- Zycosoil
- Ad-Here LOF 6500 and ADHere 77-00
- Morlife 5000
- Indulin 814A
- Redicote C2914

Table 3-10 Does your agency require the use of anti-stripping agents with WMA?

Answer	Response
YES, if there is a history of moisture problems with the aggregate in the mixture	17%
YES, if laboratory test results (i.e. Tensile Strength Ratio (TSR)) indicate presence of moisture susceptibility	67%
NO	25%

As noted in Table 3-11, the majority of agencies stated that they have a set of specifications or guidelines for use of WMA. It is further indicated by respondents that evaluation of WMA moisture sensitivity is based primarily on Tensile Strength Ratio (TSR) using the AASHTO T 283, as noted in

Table **3-12**. Of the remaining, 17% of respondents preferred the Hamburg Wheel Tracking Test (AASHTO T 324), 8% the Asphalt Pavement Analyzer (APA) (AASHTO TP 63), and 8% the Immersion-Compression Test (AASHTO T 165). About 25% of respondents had no requirement for moisture sensitivity testing. Also, respondents were asked if they can provide testing criteria for WMA moisture damage (

Table **3-13**). The criteria provided by 50% of the respondents are as follow:

- AASHTO T283, require a TSR of 73% or greater with visual assessment by the Department representative
- AASHTO T283, require a TSR of 75% or greater for Superpave mixtures, and 80% or greater for Stone Mastic Asphalt (SMA) mixtures.
- AASHTO T283, require a TSR of 80% or greater with visual assessment by the Department representative
- AASHTO T283, require a TSR of 85% or greater, and 0.5-inch (12.7 mm) rut depth for given PG grade

- Lottman completed on Hot Mix Asphalt (HMA), if no additive required for HMA, no additive will be required for WMA. Typically our aggregates do not require anti-strip additives.
- AASHTO T 165, Minimum Index of Retained Stability after immersion in water at 60°C for 24 hours of 85% and 75% for different classes of pavement.

Table 3-11 Does your agency have a set of specifications or guidelines for use of WMA technologies?

Answer	Responses
NO	25%
YES	75%

Table 3-12 Do you require any test to evaluate moisture susceptibility of WMA technology?

Answer	Response
NO	25%
Modified Lottman Test (AASHTO T 283)	67%
Hamburg Wheel Tracking Test (AASHTO T324)	17%
Asphalt Pavement Analyzer (APA - AASHTO TP063)	8%
Immersion-Compression test (AASHTO T 165)	8%
No Answer	8%

Table 3-13 Willing to list your testing criteria for moisture susceptibility?

Answer	Response
No Answer	33%
Criteria Provided	50%
No Criteria	8%

As noted in Table 3-14, the laboratory and field performance of WMA has been documented by 75% of the respondents. Moreover, as noted in Table 3-15, the vast majority of agencies indicated that no premature failures or distresses had been observed for any WMA projects/trials. However, one agency observed appearance of thermal cracking in WMA pavements. Finally, three quarters of respondents are willing to participate in the research study by sharing information about mixture design, construction, materials, and/or performance monitoring.

Table 3-14 Do you have laboratory and/or field reports, laboratory specimens or cores, quality control/assurance, and technical reports on WMA available that you would like to share with us?

Answer	Response
YES	75%
No	17%
No Answer	8%

Table 3-15 For any WMA projects or trials, have you observed any of the following premature failures or distresses? (Select all applicable)

Answer	Response
No	84%
No Answer	8%
Thermal Cracking	8%

Table 3-16 Are you willing to participate in our research by sharing information about mixture design, construction, materials, and/or performance monitoring?

Answer	Response
YES, willing to participate	75%
YES, but not able to participate	17%
No Answer	8%

4. CONCLUSION AND FUTURE STEPS

This paper has presented an overview of the current Canadian state-of-the-practice warm mix asphalt based on a survey prepared by the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo. The survey results indicated that the majority of the provincial agencies use warm mix technology on a routine basis and in a considerable amount of tonnage. Usage of WMA technology is specified as an option for most of agencies, which could facilitate fair competition and purchasing of WMA technologies, and provide the asphalt industry with the incentive and opportunity to invest and build confidence in WMA.

The evaluation of moisture susceptibility of WMA is based primarily on the Tensile Strength Ratio (TSR) which is found using the AASHTO T 283. The majority of respondents indicated mandatory use of anti-stripping agents with warm mix technology if laboratory test results indicate the presence of moisture damage. There are also a number of agencies that require use of anti-stripping agents when employing aggregates with a history of moisture susceptibility. Finally, the vast majority of agencies indicated that no premature failures or distresses had been observed for any WMA projects/trials to date.

Going forward, CPATT's research team will be closely working with Ministry of Transportation Ontario (MTO) on assessing different conditioning and aging protocols and thresholds for different empirical and mechanistic standard laboratory tests used to evaluate moisture sensitivity of WMA. This would help in better determining and modeling moisture-induced damage in asphalt pavements.

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