Evaluation of the Effectiveness of Different Warm Mix Technologies to Improve Moisture Susceptibility of Asphalt Mixes

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ABSTRACT

The Ministry of Transportation of Ontario (MTO) has implemented the use of Warm Mix Asphalt (WMA) technology on Ontario's highways and roads since 2008. Many Types of WMA technologies have been successfully used to produce and place close to one million tonnes of WMA in Ontario with proven environmental, economical and safety benefits. However, reduction in the production temperature and effects of some WMA additives have raised concerns with moisture resistance of WMA mixes.

To address the aforementioned concern, MTO and the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo have partnered under MTO's Highway Infrastructure Innovation Funding Program (HIIFP) to evaluate the moisture susceptibility of WMA through a laboratory testing program. The program includes Hamburg wheel rut testing, tensile strength ratio, and stripping by static immersion tests. Mixtures for this study are produced using two Performance Graded Asphalt Cement (PGAC) sources, three Types of WMA additives, and two aggregate Types. The selection of the materials was based on typical Superpave asphalt mixes used in Ontario.

This paper presents the laboratory test results and evaluates the effects of several WMA additives on moisture resistance of typical Ontario Superpave mixes. The paper further attempts to determine any correlation between the results from the Hamburg test, TSR, and static immersion test.

INTRODUCTION

The Ministry of Transportation of Ontario (MTO) has implemented the use of Warm Mix Asphalt (WMA) technology on Ontario's highways and roads since 2008. Many Types of WMA technologies have been successfully used to produce and place close to one million tonnes of WMA in Ontario with proven environmental, economical and safety benefits. WMA technologies were first employed in Europe in late 1990s; they later gained interest in the United States in early 2000in response to environmental pressures related to greenhouse gas emissions. Given the positive feedback on usage of WMA in the U.S., Canadian agencies started allowing contractors to use WMA in lieu of conventional HMA. Since then several WMA technologies have been developed with the following proven benefits [1]:

- Reduced GHG emissions at the asphalt mixture production and during paving operations
- Reduced fuel consumption at the asphalt mixture plant
- Improved worker health and safety due to reduced asphalt fumes and lower temperature at paving sites
- Improved compaction, and joint quality
- Less potential to cracking 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, there are still potential challenges with warm mix technologies in Ontario, including [1]:

- Effectiveness of different technologies – not all are the same
- Ensuring long term performance including moisture susceptibility
- Restrictions/adjustments at the asphalt plant – production of WMA require adjustments to the burner and flights. Some plants encounter clogging of material on the conveyor belts when tried to lower the production temperature
- Combination with antistrip additive – need to ensure that the WMA additive is compatible with the antistrip additive when antistrip was needed

Types of Moisture Sensitivity Tests

Moisture susceptibility in pavement materials is a major factor that affects pavement life. Stripping which is the term used to describe the loss of adhesive bonding force between binder and aggregates is generally the result of moisture damage in asphalt mixture. Moisture damage in asphalt mixtures occurs due to loss of adhesion (the bond between asphalt and aggregate) and/or cohesion (the bond between asphalt binder molecules), which subsequently results in progressive strength reduction and decrease in stiffness of the mixture. Several mechanisms have been cited as contributing factors to moisture damage including detachment, displacement, spontaneous emulsification, film rupture, pore pressure, and hydraulic scouring [2]. However, not all of these mechanisms are well understood due to the complexity of the impact of individual or combined mechanisms on the moisture susceptibility of a given mixture, as stated by Solaimanian et al. [3].

Furthermore, researchers have found that moisture damage can be accelerated by improper mix design or production. Through the years, several testing procedures have been proposed to evaluate the moisture susceptibility of asphalt mixtures. The predominately used test to evaluate the resistance of compacted asphalt mixtures to moisture-induced damage is the AASHTO T283 (also referred to as "Modified Lottman Test"). 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. The AASHTO T283 test is a result of modifications to the original Lottman test in an attempt to improve its reliability.

The AASHTO T283 was adopted as a requirement for the Superpave HMA mix design. Following this adoption, the AASHTO T283 has become the most widely used procedure to evaluate moisture susceptibility of asphalt mixes. Despite its wide acceptance within the industry, several studies have reported shortcomings of the test method. One of the major shortcomings of this test is the lack of ability of predicting moisture susceptibility with reasonable confidence as TSR does not always correlate with the field performance. Also, it is reported that T283 does not take into consideration the in-situ repeated traffic loading. Furthermore, the TSR is sensitive to minor changes in conditioning temperatures (freeze and thaw), level of air voids, saturation level, specimen size, and aggregate orientation. Kandhal and Rickards [4] have raised that IDT apparatus used for moisture damage evaluation might not accurately simulate the pumping action of traffic load. Instead, they suggested the use of an apparatus that enables moisture evaluation under a cyclic mode.

Hamburg Wheel Tracking Device (HWTD) can also be employed to evaluate the moisture susceptibility of compacted specimens, submerged in water. This test has gained attention in recent years due to its ability to evaluate rutting and moisture susceptibility [5]. The device tracks specified number of loaded wheel passes across the surface of compacted specimens submerged in a hot water bath at 50°C. During the test, the deformation of specimens are recorded as a function of the number of passes. The moisture susceptibility is then evaluated by computing the stripping inflection point, which is defined as the intersection of the slopes of stripping and rutting.

Alternatively, there are a number of other tests that can be employed to subjectively assess quality of chemical compatibility and bonding between asphalt binder and aggregate particles in the presence of water. Examples of such tests include boil, film strip, and static/dynamic immersion tests [2]. These tests are relatively simple to run and can be carried out under a shorter period of time compared to other tests. Additionally, these tests are cost-effective as they require simpler equipment to run. However, the main disadvantage of these tests are a lack of the ability to quantify the effect of moisture damage on mechanical properties. But, mixtures failing in these tests have a potential to exhibit moisture damage problems in the field [3].

SCOPE AND OBJECTIVES

MTO and the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo have partnered under MTO's Highway Infrastructure Innovation Funding Program (HIIFP) to evaluate the moisture susceptibility of WMA through a comprehensive laboratory testing program, particularly the ability of AASHTO T 283 to detect moisture susceptibility of WMA in comparison to Hamburg and static immersion tests. Other objectives of this research includes (1) suggesting recommendations to improve laboratory conditioning protocols, and (2) evaluate any potential difference in WMA moisture susceptibility measured on laboratory mixtures compare to conventional HMA.

RESEARCH METHODOLOGY

A combination of qualitative and quantitative laboratory test methods were used to evaluate the effect of several WMA additives on moisture resistance of typical Ontario Superpave mixtures. The variables included two Types of binder, three Types of WMA additive, and two aggregate blends. The main objective of this assessment is to establish a reliable ranking system for moisture susceptibility of WMA mixtures and determine any correlation between the results from the Hamburg test, TSR, and static immersion test.

Static Immersion Test

To assess quality of chemical compatibility and bonding between binder and aggregate, static immersion test was performed at MTO's bituminous laboratory in accordance with LS-285, "Method of Test for Stripping by Static Immersion" [5].

According to this test, 100 grams of dry coarse-aggregate blend was prepared by mixing 50 grams of aggregate retained on 9.5-mm sieve size, 35 grams of retained on 6.7-mm sieve, and 15 grams of retained on 4.75-mm sieve size. The aggregate blend was placed in an oven at specified temperature prior to mixing with 4.0 ± 0.1 grams of heated asphalt binder. The loose mixture was then transferred to a 600-mL beaker to allow cooling to room temperature. After cooling, the beaker was filled with distilled water to the ¾ full mark to submerse the mixture, sealed, and placed into a water bath at 49 ± 0.5°C for 24 hours. The beaker was then removed and placed under a lamp for evaluation of the extent of retained asphalt coating on the aggregate as a percentage.

Tensile Strength Ratio (TSR)

Moisture sensitivity of compacted mixtures was quantified as the percentage of tensile strength retained after conditioning which is referred to as the Tensile Strength Ratio (TSR). The tensile strength was determined using the Indirect Tensile Strength (IDT) apparatus in accordance with ASTM D6931-12, "Standard Test Method for Indirect Tensile Strength of Bituminous Mixtures" [6]. Two moisture conditioning alternatives were considered for this study to quantify the resistance of the mixtures to moisture damage: (1) AASHTO T283 conditioning, and (2) moisture conditioning performed by Moisture Induced Stress Tester (MIST) as per ASTM D 7870-13, "Standard Practice for Moisture Conditioning Compacted Asphalt Mixture Specimens by Using Hydrostatic Pore Pressure" [7].

The strength testing was performed by applying an axial force at a rate of 50 mm/min until the maximum load was reached. The indirect tensile strength was then calculated by using Equation [1].

$$S_t = \frac{2000P}{\pi t D} \qquad \textbf{[1]}$$

where

$S_t =$	IDT strength, kPa
$P =$	maximum load, N
$t =$	sample thickness immediately before test, mm
$D =$	sample diameter, mm, and
$\pi =$	3.14

For both of the T283 and MIST conditioning alternatives, a minimum of six specimens were compacted using the CPATT Superpave gyratory compactor to a target percentage of air voids (7 ± 0.5 percent), each measuring 150 mm in diameter and 100 ± 5 mm in height. The compacted specimens were then separated into two subsets: conditioned and unconditioned. For T283, a minimum of three specimens were vacuumed to saturation range of 75 ± 3 percent, and subjected to a freeze-cycle (16 hours at -20ºC) followed by a thaw-cycle in water bath (24 hours at 60 ºC).

MIST conditioning was performed by applying 3500 cycles of 276 kPa (40 psi) pore pressure at 50°C. Pore pressure cycling was applied immediately after specimens in the chamber reached conditioning temperature of 50°C. This temperature was maintained by the equipment. After cycling, specimens were cooled to 25 ± 1°C in a water container for 2 hours prior to strength testing.

(a) Moisture Induced Stress Tester

(b) IDT testing equipment

Figure 1. MTO's MIST and Indirect Tensile Tester

Hamburg Wheel Tracking Test

The resistance of compacted asphalt mixtures to rutting and moisture damage was evaluated 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)" [8]. 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 wheelpath was recorded as a function of the number of passes by using linear variable differential transducers (LVDTs). The moisture susceptibility is then 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 as shown in Figure 2.

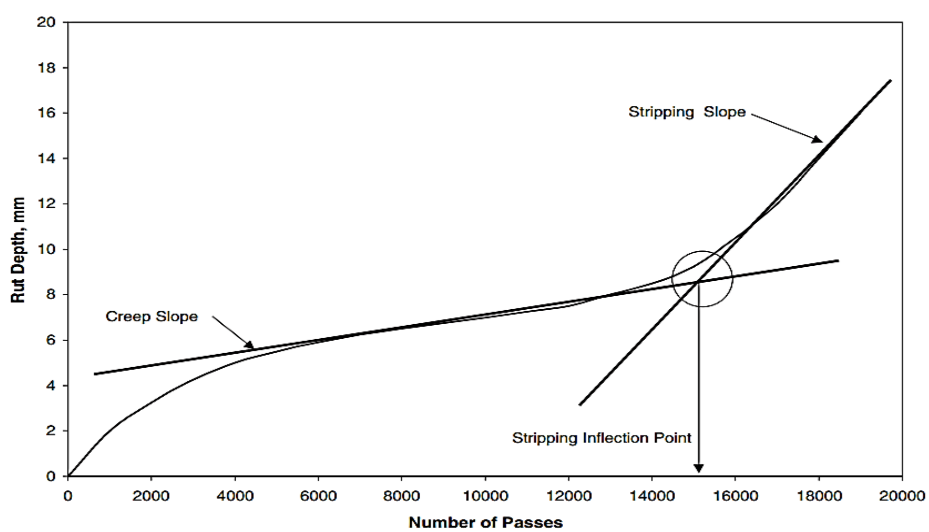


Figure 2. Typical results from Hamburg Wheel Tracking Test [9]

MATERIALS AND SAMPLE PREPARATION

Modified Binder protoTypes were produced following a consistent approach using a single-source PG 58-28 and 58-34 Polymer-modified base asphalt binders in combination with three Types of warm mix additives, as listed in Table 1. More information on additives are given in Table 2. Additive Types were selected based on the preliminary literature review, availability to the paving industry, CPATT-UW WMA survey [10], and guidance from MTO. For each additive, the supplier's recommended dosage rate (as presented in Table 2) were used to treat molten base binders with different Types of additives.

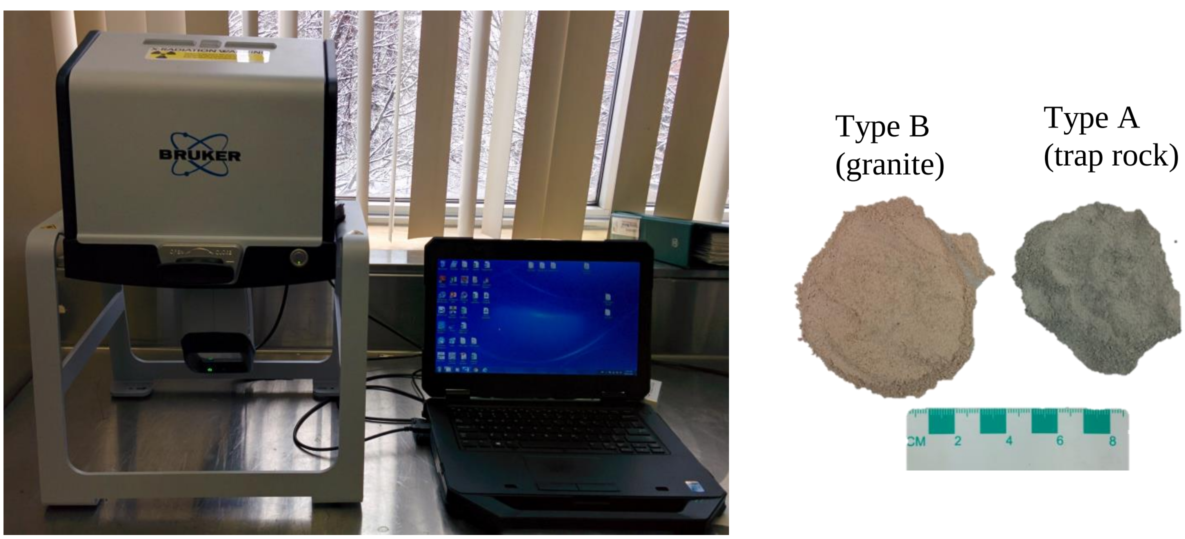
Table 1. Binder Production Material and Control Variables

Variable	Types	Description
Asphalt binder	2	Single-source virgin PG 58-28 and 58-34 polymer modified
Warm Mix additive	3	Evotherm® 3G, Rediset® LQ, and SonneWarmix™
Anti-stripping agent	1	PaveBond (Only used for a few mixtures – 0.5 percent)

Table 2. Warm Mix Additive Information

WMA Additive	Type	Colour	Addition rate (% by binder weight)	Physical State at 25ºC
Evotherm 3G	Chemical (Fatty amine derivative)	Amber Dark	0.3	Liquid
Rediset LQ	Chemical (Surfactant blend)	Brown	0.5	Liquid
SonneWarmix	Wax/Organic	Brown	1.0	Solid

Two aggregate sources were used in this study: trap rock diabase, referred to as aggregate A, and granite, referred to as aggregate B. Aggregate Types and sources were selected based on the MTO's past experience and historical records on their composition and level of resistance to moisture damage without use of anti-stripping agent: Type A with acceptable moisture performance and Type B with relatively weaker resistance to moisture damage. Both aggregate Types are listed in the MTO's Designated Sources for Material (DSM) for use in surface friction courses. More information on aggregate mineralogy and physical properties are listed in Table 3. Composition of each aggregate Type was confirmed by using an X-ray fluorescence (XRF) analyzer at MTO's bituminous laboratory shown in Figure 3 (a). For this test, 50-grams of material retained on different sieve sizes were batched and crushed by using two Types of crushers to achieve a fine powder passing 75-µm sieve size for XRF analysis, as shown in Figure 3 (b). Given in Table 3, XRF analysis verified that Type B aggregate contained relatively higher percent of silicon dioxide (SiO_2) compared to Type A, which was expected to cause the Type B aggregate source to be more susceptible to moisture damage.



(a) X-ray fluorescence (XRF) analyzer

(b) fine powder of passing 75-µm sieve size used for XRF analysis

Figure 3. MTO's X-ray fluorescent (XRF) analyzer and sample size used for the analysis

Table 3. Aggregate Physical Properties

Laboratory Test and Number[2]	Coarse (12.5 mm)			Washed Fines		Unwashed Fines	
	OPSS[1] Requirement	Type A[4]	Type B[4]	Type A	Type B	Type A	Type B
Wash Pass 75-µm Sieve (% maximum) LS-601	1	0.2	0.2				
Absorption by mass (% maximum) LS-604	1	0.50	0.55				
Flat and Elongated Particles (% maximum) LS-608	15	4.5	4.4				
Unconfined Freeze Thaw Loss (%maximum) LS-614	6	3.6	2.2				
Micro-Deval Abrasion Loss (% maximum) LS-618	10	4.3	7.2				
Micro-Deval Abrasion Loss (% maximum) LS-619	15			7.3	5.8	8.5	5.7
Silicon dioxide Content by XRF[3], passed 75-µm (% of weight)	-	42.5	57.0				
Plastic Fines, LS-631	Non-Plastic (NP)			NP			

Notes: [1]OPSS is Ontario Provincial Standard Specification, [2]LS is MTO's Laboratory Standards, [3]XRF is X-ray fluorescence,[4]Type A is trap rock diabase and Type B is pink granite

Each aggregate blend consisted of premium 12.5 mm coarse aggregate, and crusher fines (washed, and unwashed) to meet physical requirements of premium Superpave 12.5 mm mixture as per Ontario Provincial Standard Specification, as given in Table 4. Asphalt mixtures were produced in the CPATT's laboratory at the University of Waterloo. All mixtures were short-term aged prior to testing using a forced draft oven: HMA mixtures (control) for 4 hours at 135ºC as per AASHTO R30 and WMA mixtures for 2 hours at field compaction temperatures as per AASHTO R35.

Table 4. Asphalt Mix Properties

Property		OPSS Requirement	Type A Blend	Type B Blend
	Sieve Size (mm)			
Gradation (% Passing)	16.0	-	99.0	99.9
	12.5	90 – 100	96.7	94.8
	9.5	45 – 90	83.6	79.6
	6.7	-	65.3	64.6
	4.75	45 – 55	55.0	55.0
	2.36	28 – 58	45.3	42.8
	1.18	-	30.6	32.6
	0.600	-	19.8	23.8
	0.300	-	12.2	13.2
	0.150	-	7.2	5.9
	0.075	2 – 10	4.0	3.0
N_{des} (%G_{mm})		96.0	96.0	96.0
N_{ini} (%G_{mm})		≤ 89.0	88.8	89
N_{max} (%G_{mm})		≤ 98.0	97.2	97
Air Voids (%) at N_{des}		4.0	4.0	4.0
Voids in Mineral Aggregate, VMA (% minimum)		14.0	14.7	14.3
Voids Filled with Asphalt, VFA (%)		65 – 75	73.2	72.2
Dust Proportion, DP		0.6 – 1.2	1.0	0.7
Asphalt Film Thickness (μm)		-	8.7	9.0
Asphalt Cement Content (%)		-	4.7	5.0

Notes: OPSS is Ontario Provincial Standard Specification, Type A is trap rock diabase and Type B is pink granite

RESULTS AND DISCUSSIONS

Effect of Warm Mix additives on Asphalt Binder Grade

The asphalt binders were performance graded in accordance with AASHTO M320 [10], as illustrated in Figure 4. It can be seen that the PG grades were not adversely affected by warm mix additives.

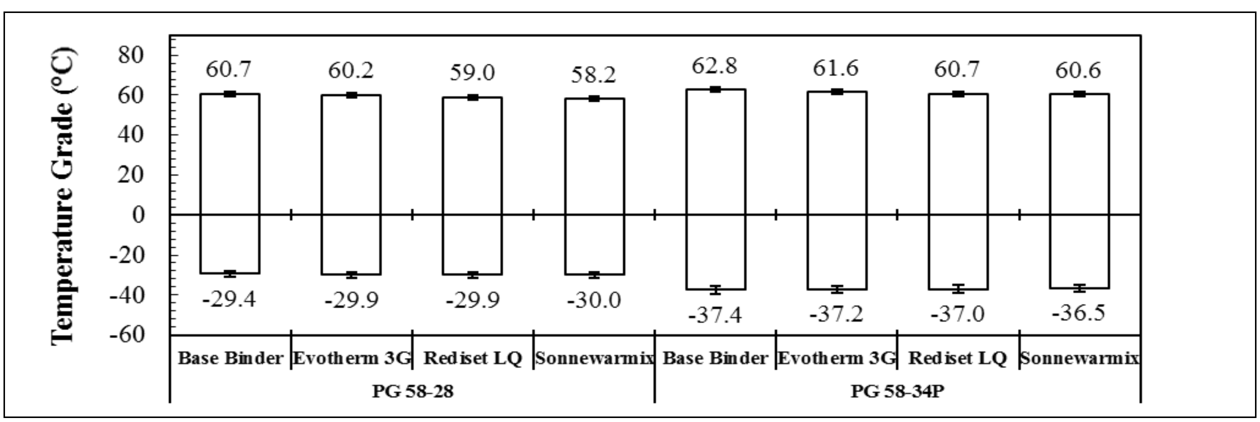
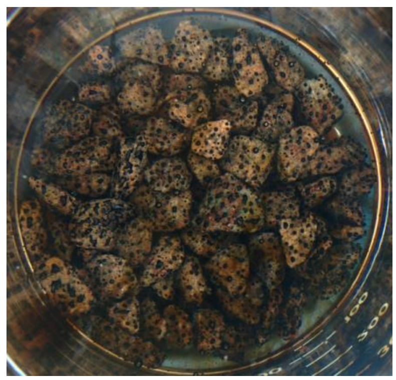


Figure 4. Continuous Performance Grade (PG) of asphalt binders treated with warm mix additives

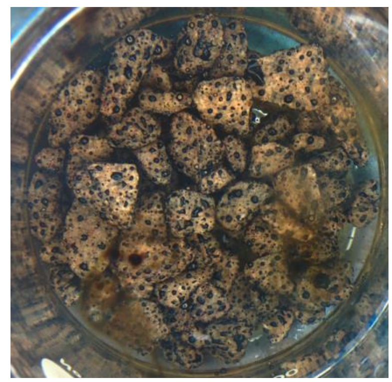
Static Immersion Test

To assess quality of chemical compatibility and bonding between modified binders and aggregates, static immersion testing was performed. For this test, it was observed that all combinations with Type A aggregate resulted in average percent retained coating of more than 95 percent similar to Figure 5 (a). However, combination of Type B aggregate and PG 58-28 base binder resulted in severe stripping as shown in Figure 5 (b). Similar severe stripping was also observed when SonneWarmix additive was used with Type B aggregate and PG 58-28, as shown in Figure 5 (c). This suggests requirement of anti-striping agent when SonneWarmix is used with an aggregate source with known history of moisture susceptibility. This recommendation was further validated by adding an anti-stripping additive, as shown in Figure 5 (d). Moreover, results obtained from static immersion test imply that Evotherm and Rediset may not require anti-stripping additive for mixes using granite aggregate (Figure 5 (e) and (f)).

(a) PG58-28 + trap rock diabase Type A
(>95% retained coating)



(b) Base PG58-28 + granite Type B
(10% retained coating)



(c) PG58-28 + SonneWarm + granite Type B
(10% retained coating)

(d) PG58-28 + SonneWarm + PaveBond+ granite Type B
(87% retained coating)

(e) PG58-28 + Rediset + granite Type B
(>95% retained coating)

(f) PG58-28 + Evotherm + granite Type B
(>95% retained coating

Figure 5. Static immersion test (LS-285) visual ratings

Tensile Strength Ratio (TSR)

The resistance of compacted mixtures to moisture damage as the percentage of indirect tensile strength ratio was evaluated by employing two moisture conditioning protocols: (1) vacuum saturation followed by one freeze-thaw cycle as per AASHTO T283 procedure, and (2) moisture conditioning performed by MIST. Figure 6 and Figure 7 present the IDT strength test results for T283 and MIST conditioned specimens containing Type A aggregate and different additive Types. IDT strength of mixtures containing Type B are shown in Figure 8 and Figure 10. In all figures, error bars represent one standard deviation from the average value of three replicates tested, with TSR results shown above the bars of each conditioning protocol.

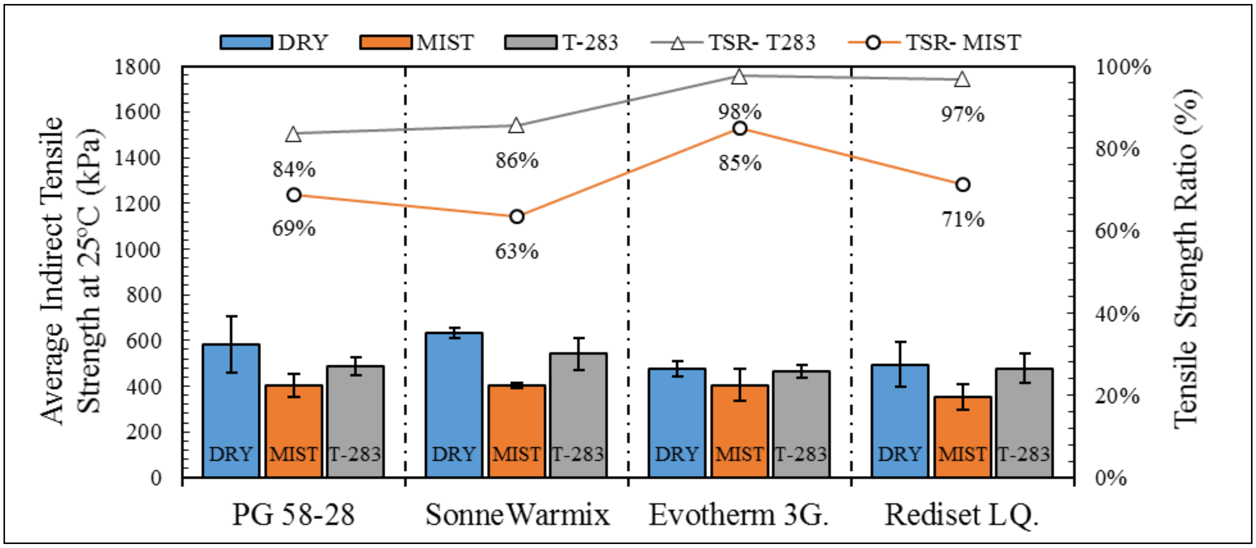


Figure 6. Effect of Warm Mix Additives on Indirect Tensile Strength of mixtures containing Type A aggregate (trap rock diabase) and PG 58-28 base binder

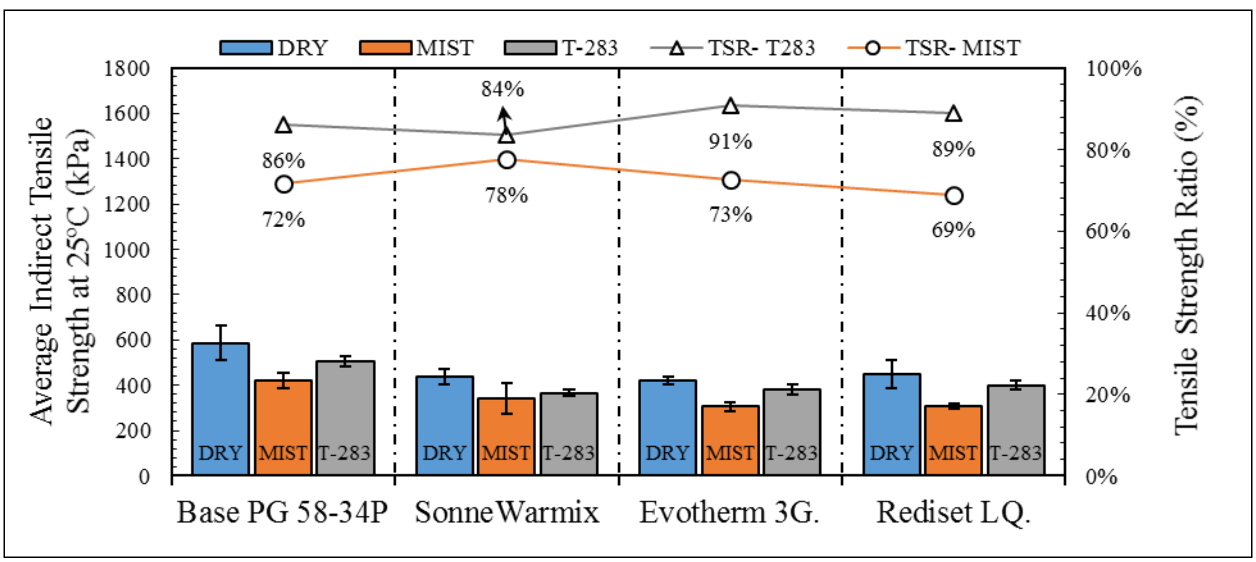


Figure 7. Effect of Warm Mix Additives on Indirect Tensile Strength of mixtures containing Type A aggregate (trap rock diabase) and PG 58-34P base binder

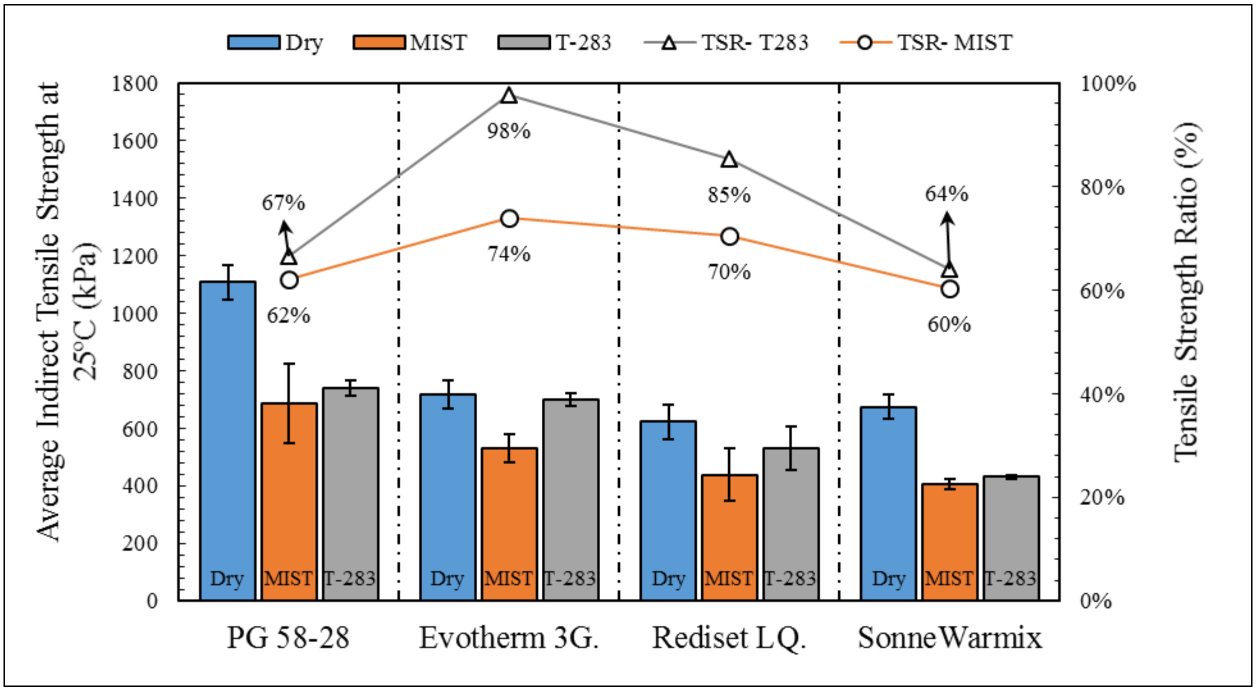


Figure 8. Effect of Warm Mix Additives on Indirect Tensile Strength of mixtures containing Type B aggregate (granite) and PG 58-28 base binder

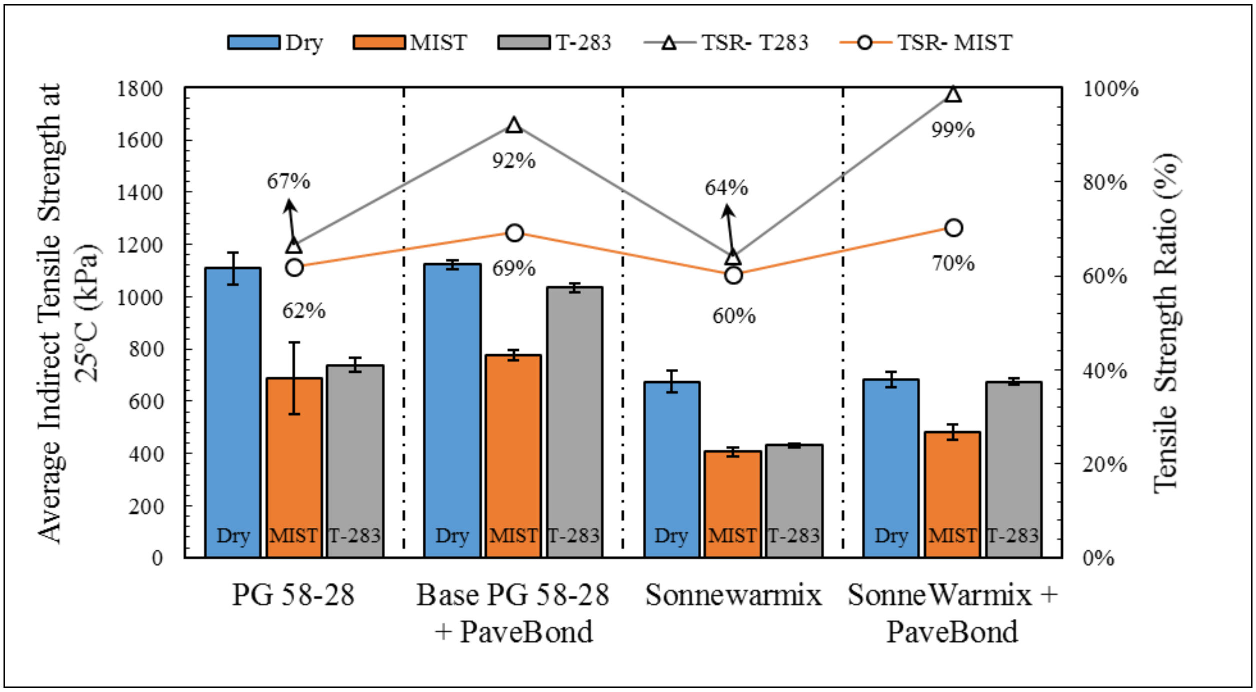


Figure 9. Effect of Liquid Anti-Stripping Agent on Indirect Tensile Strength of mixtures containing Type B aggregate (granite) and PG 58-28 base binder

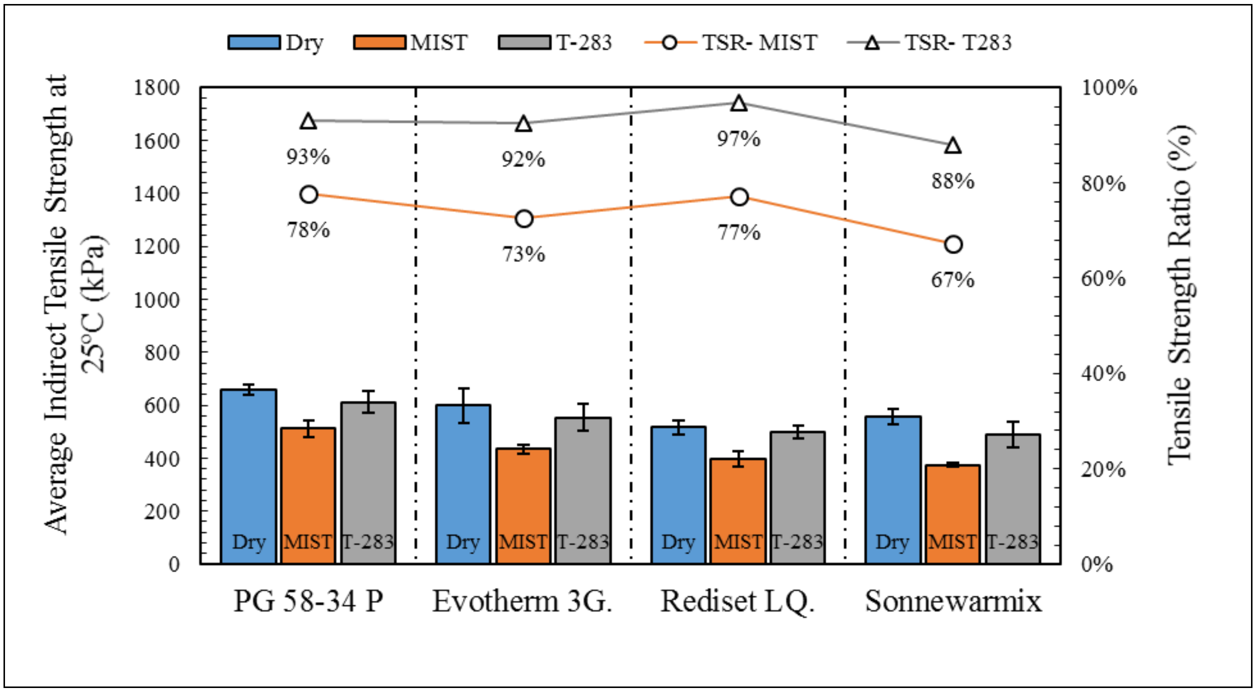


Figure 10. Effect of Warm Mix Additives on Indirect Tensile Strength of mixtures containing Type B aggregate (granite) and PG 58-34P base binder

In General, for all mixtures, the addition of WMA resulted in lower tensile strength of dry mixtures, except when SonneWarmix additive was used in mixture containing PG 58-28 base binder with Type A aggregate. Addition of warm mix additives improved TSR value, mostly due to a drop in dry tensile strength, except when SonneWarmix was used. However, usage of anti-stripping agent and modified binder (PG 58-34P) improved TSR values.

According to TSR values obtained from T283 conditioning protocol, Evotherm 3G provided higher level of resistance to moisture damage compared to Rediset and SonneWarmix, expect when Evotherm was used in combination with PG 58-34P and Type B aggregate. Furthermore, it was observed that TSR values of all mixtures are more than threshold of 80% specified by MTO, except when SonneWarmix was used with PG 58-28 and Type B aggregate. Conventional HMA containing PG 58-28 and Type B aggregate also exhibited TSR value of less than 80%, however, the TSR exceeded the threshold after addition of PaveBond liquid anti-stripping agent, as depicted in Figure 9. Similar observation was made for static immersion test. It was also observed that mixtures containing Type B aggregate resulted in higher dry tensile strength compared to those containing Type A aggregate.

It was observed that MIST conditioning protocol resulted in lower TSR values for all mixtures compare to T283. This difference was evaluated by a statistical pairwise comparison known as “Tukey” method at 95% confidence interval. The analysis was performed by Minitab© statistical software and results of this method is presented in Table 5 in terms of connecting letters report. Tukey’s results indicate that MIST protocol significantly produced the most severe moisture damage compared to T283 protocol.

Table 5. Tukey statistical analysis results at 95% confidence interval for different moisture conditioning protocols

	Number of specimens	Average Indirect Tensile Strength at 25ºC (kPa)	Grouping Letter[2]
Unconditioned (dry)	48	602	A
T283 ("modified Lottman")	48	512	B
MIST[1]	48	420	C

Note: [1]MIST = Moisture Induced Stress Tester, and [2]protocols that do not share a letter are significantly different

Results of static immersion test were found to be correlating well with TSR values obtained from different conditioning protocols, as well as Hamburg rutting test. The TSR results obtained from T283 and percent retained coating obtained from static immersion testing represented in Figure 11, which shows a good correlation (R^2 value of 0.67). A reasonable correlation was also observed between TSR results obtained from MIST conditioning and retained coating obtained from static immersion testing (Figure 12).

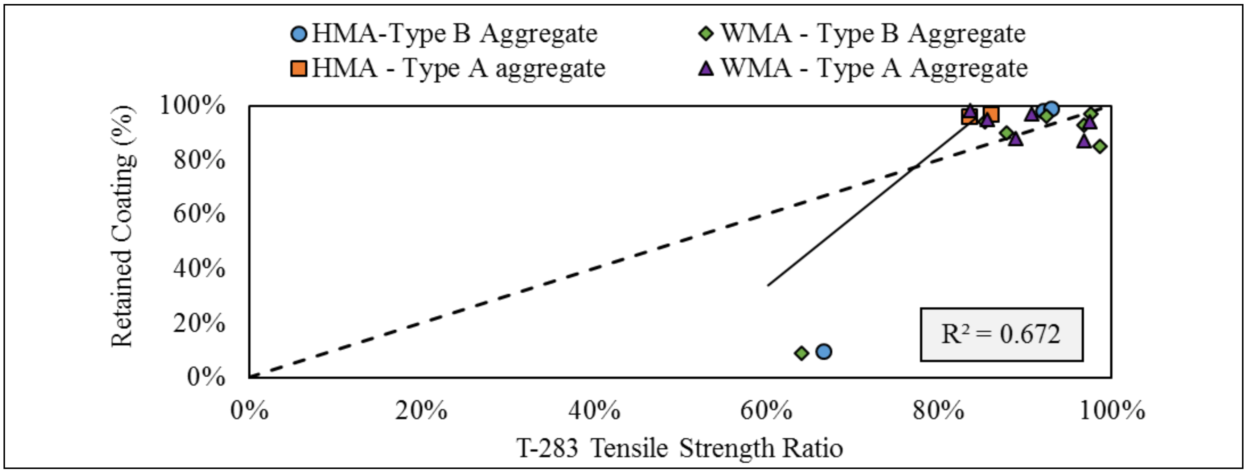


Figure 11. Relationships between T283 conditioned TSR results and retained coating obtained from static immersion test

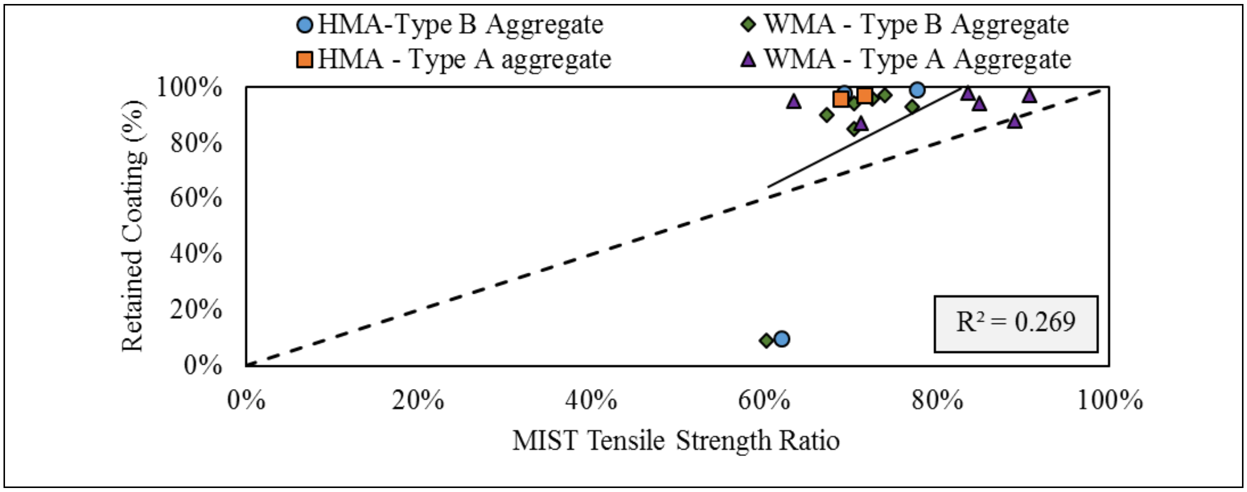


Figure 12. Relationships between MIST conditioned TSR results and retained coating obtained from static immersion test

Hamburg Rutting Test

The resistance of compacted asphalt mixtures to rutting and moisture damage was evaluated by tracking a 705 N (158 lb) load hard-rubber wheel across the surface of gyratory compacted specimens submerged in a hot water bath at 50°C. Test results of Hamburg rutting test are presented graphically in Figures 11 to 14.

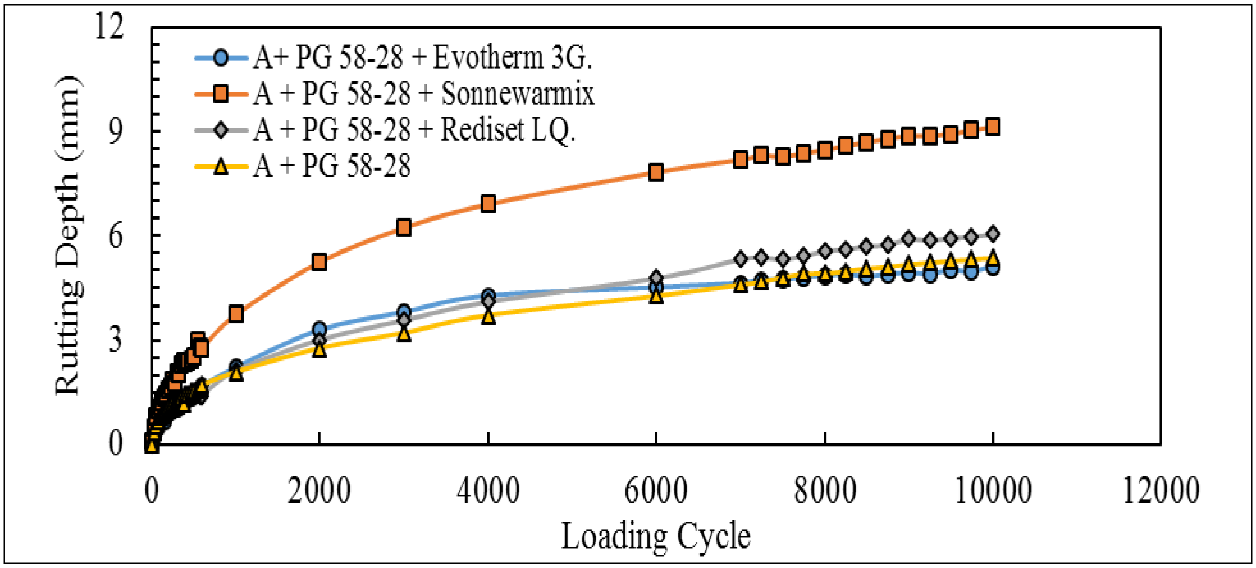


Figure 13. Hamburg rutting results for mixtures containing Type A aggregate (trap rock diabase) with PG 58-28

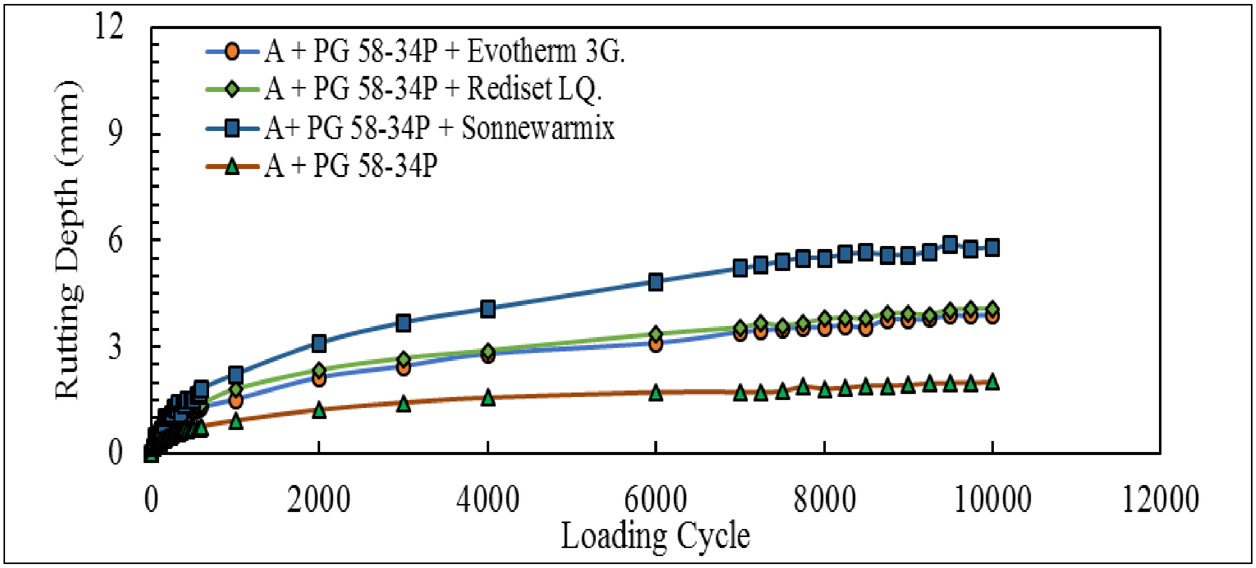


Figure 14. Hamburg rutting results for mixtures containing Type A aggregate (trap rock diabase) with PG 58-34P

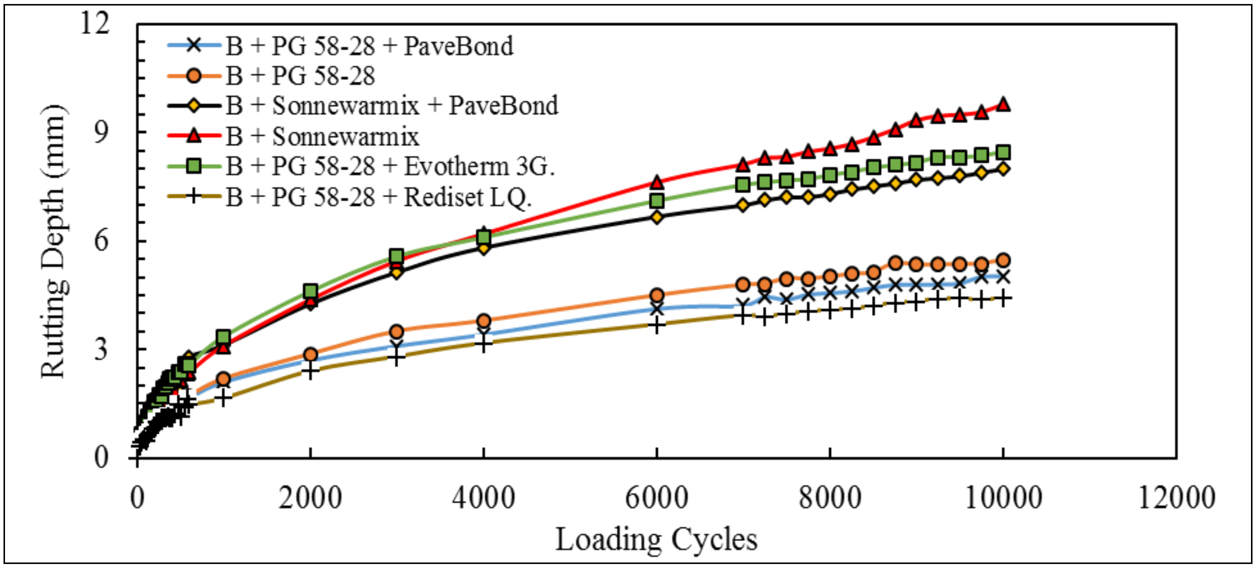


Figure 15. Hamburg rutting results for mixtures containing Type B aggregate (pink granite) with PG 58-28

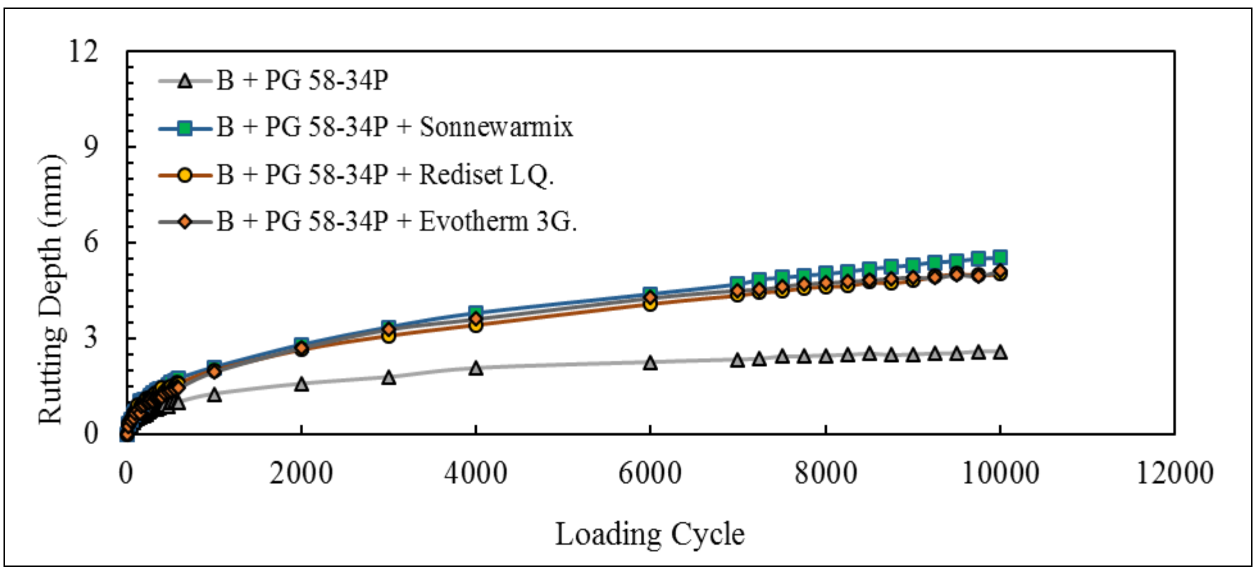


Figure 16. Hamburg rutting results for mixtures containing Type B aggregate (pink granite) with PG 58-34P

None of the mixtures exhibited stripping inflection point. This suggests that all mixtures have an acceptable level of resistance to moisture damage. This finding confirms that premium surface course mixtures typically designed in Ontario provide an adequate level of rutting resistance. Recent research studies suggest [5] that higher number of loading cycles should be considered in order to evaluate the moisture susceptibility.

It should be noted that two mixtures exhibited severe visual stripping in the wheelpath after completion of the Hamburg test: (1) conventional HMA containing PG 58-28 and Type B aggregate, and (2) WMA mixture containing SonneWarmix with PG 58-28 and Type B aggregate. This observation was well correlated with static immersion observation. These mixtures did not exhibit such visual stripping after treated by PaveBond anti-stripping agent. This improvement can be observed in rutting results illustrated in Figure 15.

Other general trends observed from the Hamburg rutting results are as follows:

1. Addition of warm mix additives in general resulted in decreased level of resistance to rutting, except for when Evotherm 3G was used with Type A aggregate and PG 58-28. Also, addition of Rediset to the combination of Type B aggregate and PG 58-28 improved the rutting resistance.
2. It was observed that mixtures containing SonneWarmix provided the least level of resistance to rutting. This could be related to the melting point of this additive which causes asphalt mixture to behave relatively softer at the test temperature and lower the resistance to rutting. Further investigation is required.
3. For all mixtures, use of warm mix additives in combination with polymer modified asphalt binder (PG 58-34P) resulted in increased level of resistance to rutting.

DISCUSSIONS AND CONCLUSIONS

In this paper, a combination of qualitative and quantitative laboratory test methods were used to evaluate the effect of several WMA additives on moisture resistance of typical Ontario premium surface course Superpave mixtures containing two Types of binder (PG 58-28 and PG 58-34P), three Types of WMA additives (SonneWarmix, Rediset LQ, and Evotherm 3G), and two aggregate blends (trap rock diabase and granite). The main objective of this study was to evaluate moisture susceptibility of WMA mixtures and determine any correlation between the results from the Hamburg, TSR, and static immersion tests. Following conclusions can be drawn:

1. Statistical analysis of TSR values suggest that MIST conditioning protocol is capable of discriminating different mixtures in terms of resistance to moisture damage better than T283 in shorter testing period.
2. Results of static immersion test were found to be correlating well with TSR values obtained from different conditioning protocols, as well as Hamburg rutting test. The TSR results obtained from T283 and percent retained coating obtained from static immersion testing show a correlation. A reasonable correlation was also observed between TSR results obtained from MIST conditioning and retained coating obtained from static immersion testing.
3. Hamburg rutting test showed that addition of warm mix additives in general resulted in decreased level of resistance to rutting with some exceptions.
4. WMA additives used in this study were found to be effective in improving moisture susceptibility; except for SonneWarmix.

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