Determination of Critical Stripping Temperatures for Typical Asphalt Concrete Mixtures Used in Nova Scotia

Brandon Feener, P.Eng., Materials Engineer, Wood Environment & Infrastructure Solutions

Chris Barnes, Ph.D., P.Eng., Associate Materials Engineer, Wood Environment & Infrastructure Solutions

Adam Marlin, P.Eng., Pavement Management Engineer, Nova Scotia Transportation and Active Transit

Paper prepared for Testing and Modeling of Roadway/Embankment Materials and Geotechnical Engineering session

of the 2021 TAC Conference and Exhibition

Abstract:

The Hamburg Wheel Tracking Test (HWTT) per AASHTO T324 has been widely used to evaluate rutting resistance and moisture susceptibility of asphalt mixtures and is tested at various temperatures by different agencies. Research has shown that there is a Critical Stripping Temperature (CST) above which visco-plastic rutting and moisture damage occur during HWTT, while tests below the CST only exhibit visco-plastic rutting. The objective of the current study was to determine the CST needed for representative asphalt concrete mixtures used in Nova Scotia which use PG 58S-28 and PG 58H-28 binders. Optimized asphalt concrete mix designs were completed for three local aggregate sources which have historically exhibited low, medium, and high levels of moisture susceptibility without using anti-stripping additives. HWTT testing was completed at four different water bath temperatures for each aggregate source and PGAB combination to determine the CST. The creep and stripping slopes were analyzed for each test based on AASHTO T324 to determine the Stripping Inflection Point (SIP) of the mixture. The SIP indicates how quickly the material begins to experience significant moisture-induced damage. While this approach has been adopted by several transportation agencies, AASHTO T324 does not provide a specific method of analysis, so the results tend to be subjective and variable with poor repeatability. A novel method which separates visco-plastic and moisture damage effects in HWTT results was also used to analyze the HWT test results, yielding the Visco-plastic Ratio (VR) which characterizes the mixture's rutting resistance under dry conditions and the Moisture Ratio (MR) defined as the percentage of total rutting that results from moisture-induced deformation at a total rut depth of 12.5 mm. A strong correlation was observed between MR and the existence of significant moisture damage as defined via the AASHTO T324 method as exceedance of a maximum rutting depth of 12.5 mm and a minimum SIP of 15,000 passes as used by Maine DOT. It was found that an MR of 30% appears to provide a reliable threshold for verifying moisture susceptibility of asphalt mixtures. This systematic approach could replace the more complex and subjective AASHTO method to objectively and reliably detect and quantify moisture-induced damage in susceptible asphalt concrete mixtures. The CST for local asphalt mixtures using PG 58S-28 and PG 58H-28 binders were found to be 46°C and 50°C, respectively.

Introduction

The Hamburg Wheel Tracking Test (HWTT) is a laboratory procedure that uses repetitive loading of a steel wheel applied over the surface of asphalt concrete test specimens at a constant test temperature and measures the rut depth induced in an asphalt mixture with increasing load cycles [Yin, 2014]. The HWTT per AASHTO T324 has been widely used to evaluate rutting resistance and moisture susceptibility of asphalt mixtures tested under water at a constant temperature. Failure caused by moisture damage in the HWTT is a function of the presence of water, the wheel load, the chemistry, and the test temperature.

The approach described in AASHTO T324 for evaluating moisture damage is a maximum rutting threshold and the Stripping Inflection Point (SIP). The SIP is the intersection between the slope of the creep phase through the visco-plastic inflection point and the slope of the stripping phase as shown in Figure 1. The SIP offers an indication of how quickly the material begins to experience significant moisture-induced damage, while the strip slope indicates how quickly the material deteriorates once significant moisture damage has occurred. Asphalt mixtures with higher SIP values and lower rut depths are considered to have good performance in the HWTT [Yin, 2014]. Although these parameters have been widely adopted by several transportation agencies, the accuracy and variability in characterizing mixture properties from these parameters have been questioned [Yin, 2014].

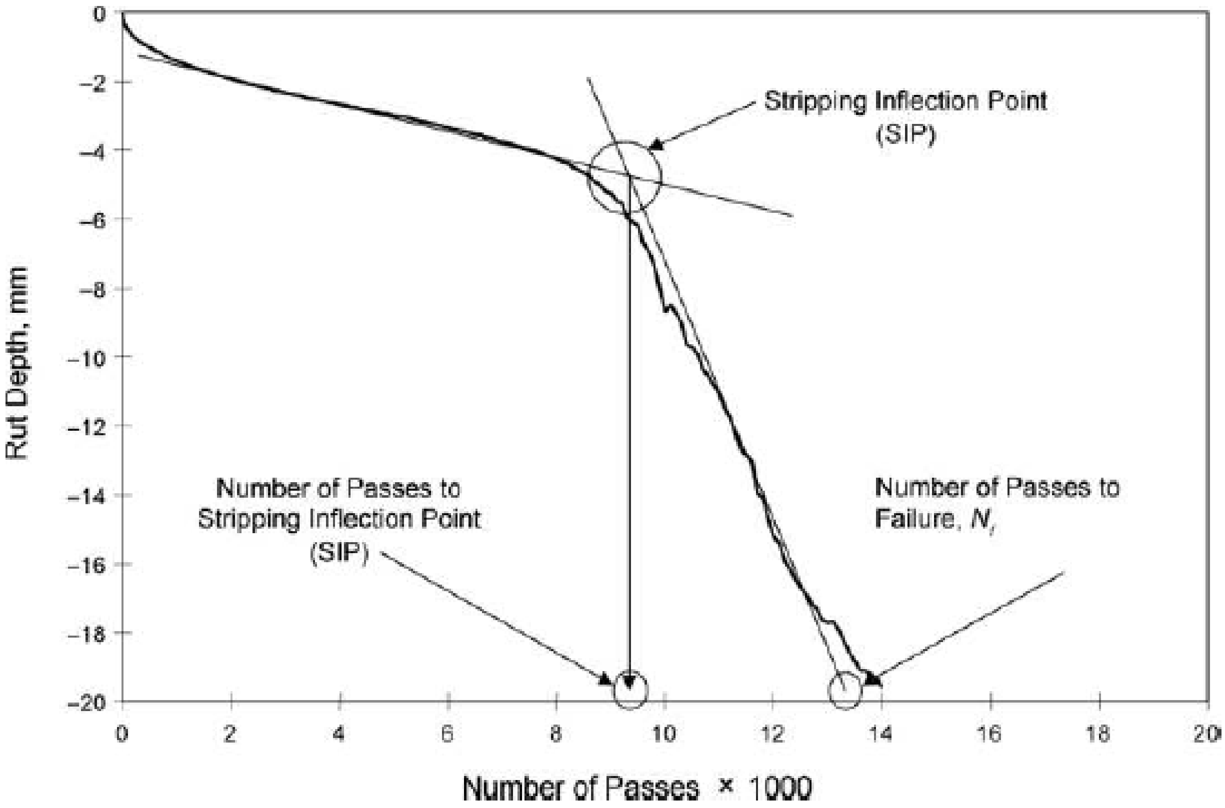

Figure 1: AASHTO T324 HWTT Analysis (from AASHTO T324)

In recent years, novel methods for HWTT analysis have been developed to separately evaluate moisture susceptibility and rutting resistance, with significantly improved accuracy [Yin, 2014]. NCHRP Project 9-49 determined that the inflection point of the HWTT curve is an indicator of the onset of stripping and defines the point at which rutting ceases to be a function of visco-plastic rutting [Yin, 2014]. Based on preceding research completed at the Texas Transportation Institute (TTI), Bahia and Lv introduced a HWTT analysis to separate the deformation due to visco-plastic flow from the deformation induced by moisture in the wet HWTT as shown in Figure 2 [Bahia and Lv, 2019]. Bahia and Lv's research concluded that variability caused by post-compaction consolidation is dependent on the actual void content of the specimens within the first 1,000-wheel passes during HWTT tests. Subtracting rutting measurements during this initial 1,000 passes improves consistency in the remaining data and subsequent analysis [Bahia and Lv, 2019]. By eliminating the post-compaction stage, a visco-plastic model, in the form of a power-law function, can be fit to the HWTT data and used to identify and separate moisture damage effects from the visco-plastic response. The results of Bahia and Lv's analysis include a visco-plastic ratio (VR) which characterizes the mixtures rutting resistance under dry conditions and a moisture ratio (MR) which determines the percentage of the moisture-induced deformation in the final rutting depth [Bahia and Lv, 2019]. Parameters α and VR are the scaling coefficient and exponent defining the rate of change of the power function rutting model, respectively. Minimizing both α and VR minimizes the amount of visco-plastic rutting that occurs. Compared with the current AASHTO T324 HWTT parameters, the new parameters were calculated from the HWTT results by using nonlinear regression and avoiding subjective data interpretation when two straight lines were fit to the creep phase and the stripping phase. More importantly, the new parameters allowed mixture moisture susceptibility and rutting resistance in the HWTT to be evaluated separately [Yin, 2014].

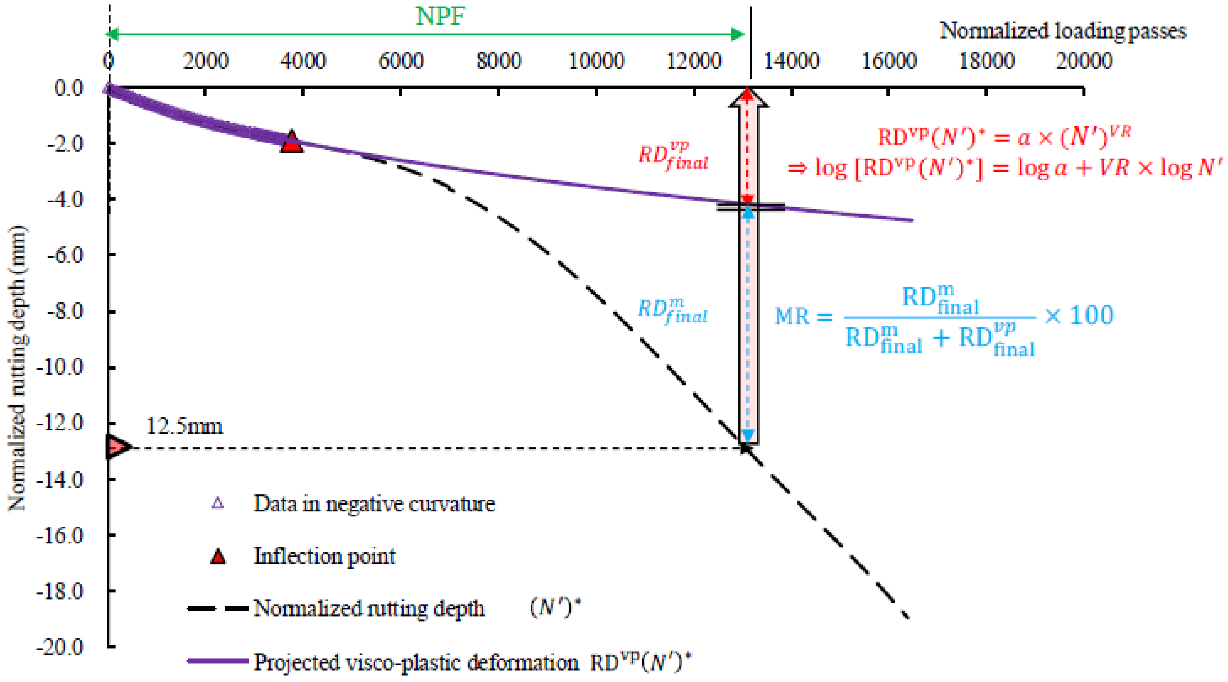

Figure 2: Bahia and Lv HWTT Analysis (from Bahia and Lv, 2019)

The most used testing temperature in the HWTT by both state and federal agencies is 50°C. However, several state agencies have specified HWTT water bath temperatures based on asphalt binder grades. Research has shown that there is a Critical Stripping Temperature (CST) above which visco-plastic rutting and moisture damage occur during HWTT, while tests below the CST only exhibit visco-plastic rutting [Romero, 2008]. Investigation of the CST has been completed by Utah and Colorado DOT's based on local asphalt binders and aggregates to establish HWTT testing temperatures. Each State agency independently evaluated the effect of test temperature on HWTT results and their relation to potential mixture performance. Table 1 summarizes the HWTT temperatures currently being used by Utah and Colorado DOT's.

Table 1: HWTT Temperatures for Utah and Colorado DOT's

PGAB Grade	Utah, °C	Colorado, °C
PG 58-XX	46	45
PG 64-XX	50	50
PG 70-XX	54	55

The findings from Utah and Colorado suggest that a CST exists for each mix, at which point energy, in the form of heat, is sufficient to reduce the stiffness of the binder, leading to de-bonding and stripping [Romero, 2008].

The main objective of the current study was to determine the CST needed for local PG 58S-28 and PG 58H-28 asphalt binders exhibiting different ranges of creep compliance (J_{nr}) when graded according to the current Nova Scotia Transportation and Active Transit (NSTAT) PGAB Specification based on AASHTO M332. Additionally, the study investigated the novel HWTT analysis introduced by Bahia and Lv to determine if it offers a simpler and more reliable indicator and predictive measure for moisture susceptibility in asphalt mixtures compared to AASHTO T324, which has received criticism by many agencies due to its lack of reliability.

Testing Program

The study involved retrieving and testing three local aggregate sources and two asphalt binder grades. The aggregate sources were selected to best replicate asphalt mixtures that were understood to typically exhibit low, medium and high levels of moisture susceptibility when anti-stripping additives are not included. The asphalt binder grades analysed in the study were PG 58S-28 ($J_{nr} < 4.50\ kPa^{-1}$) and PG 58H-28 ($J_{nr} < 2.00\ kPa^{-1}$ and $R > 30\%$). In total, six optimized mix designs with a 12.5 nominal maximum aggregate size were developed for the three aggregate sources and two asphalt binders following the Asphalt Institute's MS-2 Methodology for selecting a Design Aggregate Structure (DAS). These designs did not include anti-stripping admixtures or Reclaimed Asphalt Pavement (RAP). The six optimized mix designs were used for all HWTT asphalt testing in this study.

The HWTT testing for this study was completed using a Model LDT-AMP 78-PV3UP10 manufactured by Controls Group (Pavelab). This model is a double wheel system allowing simultaneous testing between replicate samples. The individual wheels of the HWTT device have a nominal load of 700 N with a variable wheel speed of 26 cycles/min. Specimens are tested up to a maximum of 20,000-wheel passes or until a maximum rut depth of 20 mm is achieved. HWTT specimens were prepared using a Pine AFGB1 Superpave Gyratory Compactor (SGC) following AASHTO T324 test standards. The specimens were compacted to a height of 62 mm and a diameter of 150 mm with an air void content of 7 ± 0.5%.

Following sample preparation, the HWTT specimens were trimmed and loaded into the HWTT. The mixtures using PG 58S-28 binder were tested at HWTT water bath temperatures of 42°C, 46°C and 50°C and the mixtures using PG 58H-28 binder were tested at HWTT water bath temperatures of 46°C, 50°C and 54°C. The HWTT results were evaluated to determine the CST at which significant moisture damage in the specimens resulted a total rut depth exceeding 12.5 mm and/ or a Stripping Inflection Point (SIP) less than 15,000 passes.

HWTT Temperature Correlation and Applied Temperature Correction

During testing it was identified that the HWTT water bath temperature sensor, which is fully submerged in the water bath, had developed significant amounts of corrosion which changed its capacitance and caused inaccurate test temperatures to be recorded. AASHTO T324 requires water bath temperature verification within ±1.0°C of the temperature readout from the HWTT. The temperatures recorded by the HWTT water bath sensor were compared to measurements made using a calibrated Hoskins resistive temperature sensor with a high precision Fluke multi-meter and a calibrated mercury thermometer. The calibrated mercury thermometer confirmed the accuracy of the Hoskins resistive temperature sensor, exhibiting a coefficient of determination, $R^2 = 0.9999$. Significant differences were observed between the HWTT water bath temperature sensor and the Hoskins resistive temperature sensor and the mercury thermometer. Linear correlations between the HWTT temperature sensor output and the Hoskins resistive temperature sensor and the mercury thermometer were developed so that corrections could be determined and applied to the temperatures measured by the HWTT. It was determined that on average the water bath temperature sensor read 2.2°C higher than the calibrated resistive temperature sensor and the calibrated mercury thermometer over a temperature range of 10 - 60°C. Table 2 lists the intended HWTT test temperatures, the measured test temperatures from the HWTT, and the actual test temperatures determined via the linear correlation to the Hoskins resistive temperature sensor.

Based on research conducted by Utah and Colorado DOT's, it was expected that the CST for the PG 58S-28 and PG 58H-28 would be approximately 46°C and 50°C, respectively. Therefore, additional HWTT samples for each mixture were generated and tested at 46°C for the PG 58S-28 and 50°C for the PG 58H-28, using the temperature correction as the target set-point temperature for the HWTT.

Table 2: HWTT Test Temperature Correlation

Intended HWTT Test Temperature, °C	HWTT Temperature Probe Reading, °C	Corrected Temperature via Fluke Multi-meter Linear Equation, °C (y = 0.9548x)
42	42	40.1
46	46	43.9
50	50	47.7
54	54	51.6

Since completing this study, a replacement temperature sensor has been installed in the HWTT device, however the temperature discrepancy persisted, and incorrect temperatures were still being displayed in the Pavelab software. Following further consultation, the manufacturer provided a software procedure to complete a temperature calibration. The procedure provided the necessary instructions to modify the software parameters. Execution of the temperature calibration resulted in the HWTT bath temperatures directly correlating with the high precision Fluke multi-meter and the calibrated mercury thermometer.

Modified AASHTO T324 Analysis

Many state transportation agencies, including Maine and Texas, specify a maximum HWTT rut depth of 12.5 mm at 18,000 or 20,000 passes. Other state agencies such as Utah and Colorado specify a maximum rut depth of 10 mm at 20,000 passes and 4 mm at 10,000 passes, respectively. In addition, some agencies specify a minimum number of passes to reach SIP as an additional failure criterion. Specifically, Maine DOT requires a minimum SIP of 15,000 passes to achieve an acceptable test result. Maine DOT also considers a SIP to be valid when the ratio of strip slope to creep slope is greater than 3.0 and when the stripping slope exceeds 0.63 mm/ 1000 passes. When these conditions are not satisfied, the SIP is reported as "N/A" or, in the case of this study, "No SIP". These conditions establish a threshold that considers the significance of the moisture damage accumulation rate that is dependant upon the rate of visco-plastic rutting for the material but does not consider very low rates of moisture induced rutting to be of significance. AASHTO T324 does not provide guidance for these issues, which would improve consistency and repeatability of inter-laboratory testing and specifications among different agencies.

HWTT and CST Analysis

This study followed Maine DOT's HWTT specifications to determine the CST for the PG 58S-28 and PG 58H-28 binders. It was determined that 50% of the HWTT tests completed for this study contained invalid SIPs as per Maine DOT specifications and were therefore reported as "No SIP".

This analysis validates the importance of implementing criteria to invalidate SIP determinations where minimal stripping exists and to reduce the potential for falsely rejecting HWTT results.

Table 3 provides an overview of the HWTT test results following Maine DOT specifications, including validity of SIP values, and highlights the number of passes to the SIP and maximum rut depth for each asphalt mixture and test temperature. The average number of passes to the SIP and the average maximum rut depth of both wheels were used to determine the pass/ failure criteria. The average values highlighted in green signify a passing test result, while the average values highlighted in red represent failures based on a minimum of 15,000 passes to the SIP and a maximum rut depth of 12.5 mm. The CST for the different asphalt binder grades were determined based on the average of both wheels failing the minimum number of passes to the SIP or reaching the maximum rut depth.

Table 3: HWTT Test Results (Maine DOT Specifications)

Asphalt Binder Grade	**Aggregate Source**	**HWTT Temperature, °C**	**Average SIP Number of Passes (Minimum = 15,000)**	**Average Maximum Rut Depth, mm (Maximum = 12.5)**
PG 58H-28	A	43.9	No SIP	6.1
		47.7	No SIP	7.6
		50.0	11,906	17.6
		51.6	14,953	17.1
	B	43.9	No SIP	6.4
		47.7	No SIP	7.6
		50.0	12,603	17.1
		51.6	6,460	18.8
	C	43.9	No SIP	4.2
		47.7	17,394	7.7
		50.0	15,547	13.2
		51.6	13,652	19.2
PG 58S-28	A	40.1	No SIP	8.5
		43.9	No SIP	9.1
		46.0	10,866	17.4
		47.7	No SIP	16.7

Asphalt Binder Grade	Aggregate Source	HWTT Temperature, °C	Average SIP Number of Passes (Minimum = 15,000)	Average Maximum Rut Depth, mm (Maximum = 12.5)
PG 58S-28	B	40.1	No SIP	8.2
		43.9	14,229	17.5
		46.0	8,484	17.4
		47.7	7,740	18.1
	C	40.1	No SIP	2.4
		43.9	17,279	7.1
		46.0	13,837	20.1
		47.7	13,022	17.7

It is evident that the amount of rutting and moisture susceptibility experienced during HWTT testing for different mixtures is highly dependent on the water bath temperature. As expected, all mixtures exhibited better resistance to rutting and stripping at low temperatures than at higher temperatures. According to Utah DOT the transition from better performance with little to no stripping to poor performance with significant stripping is attributed to a critical temperature that causes the asphalt concrete material to change, and the dominant source of deformation to change. Below this critical temperature, the material deforms mainly based on its structural stability from the aggregate structure but shows little to no stripping. Above this temperature, changes in the cohesive and adhesive bond strength of the material occur and the predominant source of deformation occurs from moisture damage as asphalt is stripped from the aggregate [Romero, 2008].

From the analysis shown in Table 3, it can be concluded that the CST for the PG 58H-28 binder is 50°C and the CST for the PG 58S-28 binder is 46°C with nearly all of the tests meeting the rutting and SIP criteria at lower temperatures. These results also concur with Utah's findings, as all the tests completed above the CST for each binder grade were either below the minimum number of passes to the SIP or they exceeded the maximum rut depth of 12.5 mm. In comparison, all the tests completed below the CST exceeded the maximum number of passes to the SIP and were below the maximum rut depth of 12.5 mm, apart from aggregate source B PG 58S-28 at 43.9°C.

Stripping is considered a catastrophic failure for an asphalt mixture which results from the material undergoing compositional changes [Romero, 2008]. According to Utah DOT, the rut depth has no physical meaning after stripping since it represents the behaviour of a different material than the one originally prepared and the rutting behaviour should only be evaluated for a mixture that does not strip, while a mixture that strips simply fails and should be rejected [Romero, 2008]. As previously mentioned, there appears to be inconsistencies within various State agencies when implementing the AASHTO T324 methodology, specifically relating to defining the stripping inflection point and its validity, which could result in false-positive or false-negative results. Maine DOT's additional SIP conditions applied to AASHTO T324 aim to resolve these issues and would promote consistency and accuracy throughout the industry. However, these additional constraints add complexity to the analysis. The simpler HWTT analysis introduced by Bahia and Lv separates the visco-plastic rutting response (VR) from moisture effects (MR).

As shown in Figure 3, a plot of the HWTT results from the Bahia and Lv analysis were compared to the results based on AASHTO T324 via Maine DOT specifications. The average SIP and average maximum rutting depth were plotted versus MR and the left and right vertical axes were normalized to show 15,000 passes and 12.5 mm rutting at the same horizontal location. From Figure 3, the top left and bottom left quadrants represent acceptable HWTT tests for the number of passes to SIP and the maximum rut depth, respectively. The top right and bottom right quadrants represent HWTT test failures for maximum rut depth and number of passes to SIP, respectively. All tests with a SIP greater than 15,000 passes have less than 12.5 mm of rutting and all tests with a SIP less than 15,000 have a maximum rut depth greater than 12.5 mm. The only exception is the aggregate source C mixture with PG 58H-28 at 50°C which had a SIP greater than 15,000 passes and a rut depth greater than 12.5 mm. The analysis shows that there is a significant correlation between MR and AASHTO T324 results using Maine DOT's pass/ failure criteria. Specifically, at low MR values (i.e. MR < 30%) the HWTT tests are acceptable via Maine DOT specifications and at high MR values (i.e. MR>30%) the HWTT tests fail Maine DOT specifications. The simplicity of the Bahia and Lv method avoids the complicated analyses associated with AASHTO T324 and additional constraints applied to obtain valid tests and valid SIP values for consistent results, while the MR appears to consistently characterize moisture-induced damage.

As shown in Figure 3 the trend of the total rut depth versus MR appears to generally follow an S-shaped sigmoidal function where the effects of increasing moisture damage at levels up to MR = 20% result in small near-linear increases in total rut depth. However, increases in MR levels from 20% to 30% appear to rapidly increase the rate of rutting, which then decreases when MR increases from 30% to 40%. It is apparent that the highest rate of acceleration in total rutting occurs at a critical MR value equal to 30%, which also appears to be equivalent to the Maine DOT pass/ fail criteria for the AASHTO T324 analysis where SIP = 15,000 passes and total rut depth = 12.5 mm.

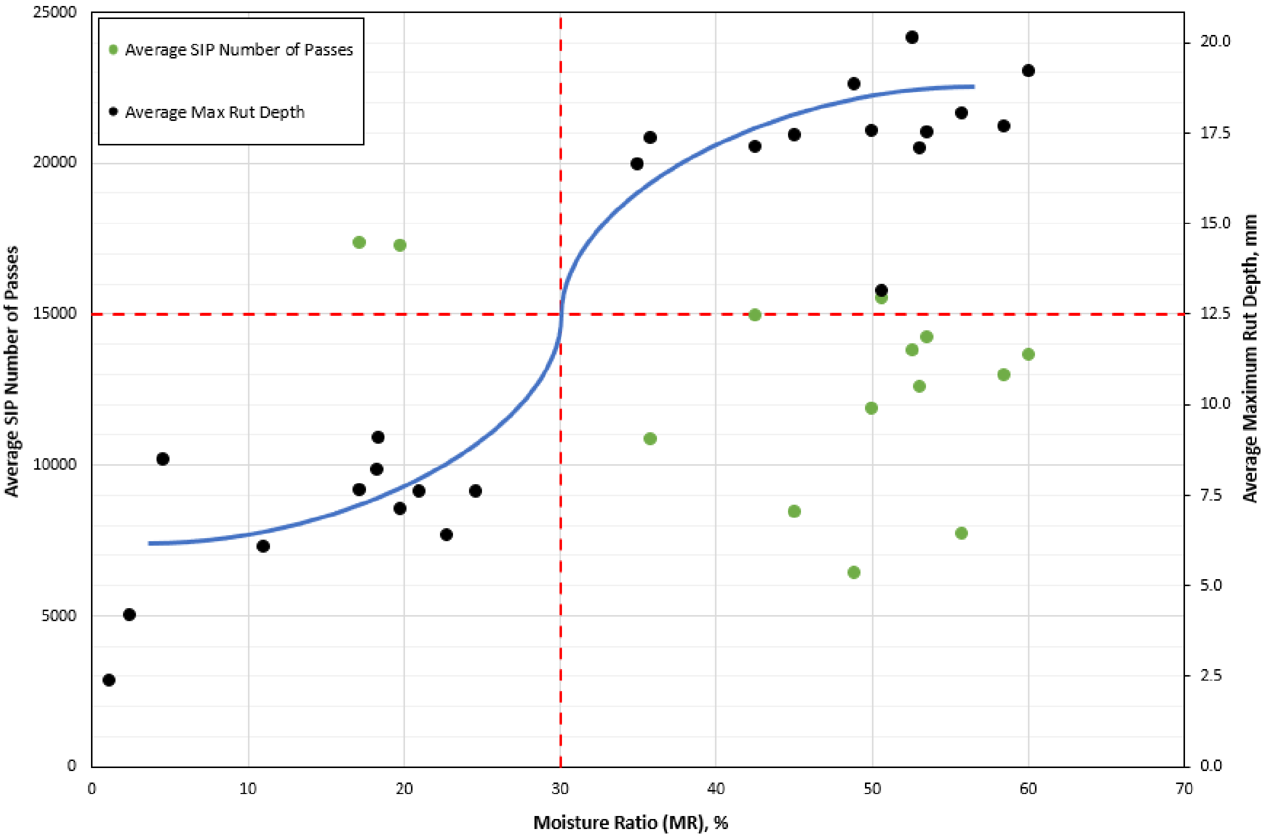

Figure 3: Bahia-Lv and AASHTO T324 Correlation

In addition, there is a perfect correlation between the average MR passes/ failures and the results shown in Figure 3 from AASHTO T324 incorporating Maine DOT specifications. Table 4 summarizes the MR values for each asphalt mixture and test temperature using a maximum MR of 30% as the failure criterion. The average MR values highlighted in green signify a pass and the average values highlighted in red represent failures.

All PG 58H-28 mixtures failed at the HWTD test temperature of 50°C and all PG 58S-28 failed at the HWTD test temperature of 46°C, except for the aggregate source C mixture which failed at 43.9°C. The strong correlation between the Bahia and Lv method results and AASHTO T324 results based on the Maine DOT specifications suggests that the simpler and less subjective Bahia-Lv analysis could be used as an indicator and predictive measure for moisture susceptibility in asphalt mixtures. It is expected that the Bahia and Lv method could be implemented as a reliable alternative testing method to the traditional Modified Lottman test (AASHTO T283), which has received criticism by many agencies due to its lack of reliability.

Table 4: HWTT Moisture Ratio (MR) Results

Asphalt Binder Grade	**Aggregate Source**	**HWTT Temperature, °C**	**Average Moisture Ratio (MR), %**
PG 58H-28	A	43.9	10.9
		47.7	20.9
		50.0	50.0
		51.6	42.5
	B	43.9	23.0
		47.7	25.4
		50.0	53.0
		51.6	48.8
	C	43.9	2.4
		47.7	17.1
		50.0	50.6
		51.6	60.0
PG 58S-28	A	40.1	4.5
		43.9	18.3
		46.0	35.8
		47.7	34.2
	B	40.1	18.2
		43.9	53.5
		46.0	45.0
		47.7	55.7
	C	40.1	1.1
		43.9	19.8
		46.0	52.5
		47.7	58.4

NSTAT has adopted a baseline pavement design high temperature of 58°C which corresponds to the maximum value occurring within the Province (Barnes et al., 2018). Adopting the maximum design temperature as the baseline condition eliminates the requirement for cooler high temperature binder grades, providing uniformity to the market and reducing costs to the Department. However, this uniformity should also be reflected in the properties and performance requirements of the binder and asphalt concrete mixtures used for various environments throughout the Province. For HWTT tests it is imperative that minimum testing temperatures for the PG 58x-28 base grade are specified by various traffic levels for each specific project design requirement to achieve this consistency, not the characteristics of the particular binder selected for the project.

Recommendations and Conclusions

The objective of this study was to determine HWTT test temperatures needed to evaluate moisture resistance of hot mix asphalt mixtures incorporating local AASHTO M332 PG 58S-28 and PG 58H-28 asphalt binder grades used in Nova Scotia. HWTT tests conducted over a range of temperatures for the expected CST for each of the two binders selected for this study were evaluated using two independent approaches. One following AASHTO T324 including additional test criteria specified by Maine DOT and the other following a novel approach reported by Bahia and Lv, which separates and quantifies the influences of visco-plastic rutting and moisture damage. The following conclusions and recommendations were observed from this study:

- The CST for the different asphalt binder grades was determined based on the Maine DOT specifications where the average rutting of both HWTT wheels were evaluated for failure based on the number of passes to the SIP being less than 15,000 or exceeding the maximum rut depth of 12.5 mm. Based on the results from this analysis, it was determined that the CST for the PG 58S-28 and PG 58H-28 were 46°C and 50°C, respectively. All asphalt mixtures failed HWTT testing at these temperatures using AASHTO T324 via Maine DOT specifications.

- The Bahia and Lv analysis was used to evaluate the MR of the asphalt mixtures as a measure of the percentage of moisture-induced deformation in the final rutting depth. The analysis revealed a strong correlation between the MR and the AASHTO T324 via Maine DOT specifications. Equivalency of the MR from the Bahia and Lv method to the Maine DOT failure criteria was demonstrated at MR = 30%, which yielded the same CST values for the two binder grades. These combined analyses confirmed that all asphalt mixtures for NSTAT contracts using PG 58S-28 and PG 58H-28 should be tested in the HWTT at test temperatures of 46°C and 50°C, respectively.

- There are many specified conditions that are required to be met for a HWTT test to be considered valid using Maine DOT specifications. These specifications are based on extensive HWTT testing and analysis from asphalt binders and aggregate sources used in Maine. While the results of the testing described in this report are valid for the two binders and three aggregate sources that were tested, additional data from ongoing projects would be beneficial to confirm that this approach and ensure test requirements are applicable to all binders and aggregate sources in Nova Scotia. It is possible that the HWTT specifications set by Maine DOT may not directly apply and would require modification for other local asphalt concrete mixtures. In contrast, the only pertinent criteria for the Bahia and Lv model would be to establish a maximum MR value. Although the Bahia and Lv method is relatively new to the industry, this study has demonstrated the accuracy and reliability of the Bahia and Lv model for predicting moisture susceptibility. In addition, the Bahia and Lv model would require less development and analysis, and eventually, could be used to replace traditional methods for detecting and predicting moisture-induced damage via AASHTO T283.

- The CST to be used during HWTT testing should be selected based on the pavement design high grade temperature selected for each project, not the particular asphalt binder selected for the mixture. If for example, a baseline grade of PG 58S-28 was specified, but the design traffic dictated a Heavy "H" traffic level, then the HWTT test temperature should be increased to the PG 58H-28 temperature of 50°C, rather than 46°C required for standard traffic levels.

- HWTT testing should be completed using PG 58S-28 and PG 58H-28 binders from a secondary binder source. Additional HWTT tests above and below the CST would confirm the applicability of the CST selected in this study. A similar investigation was completed by Utah DOT, who observed variations in CST values for different binder sources, which ultimately influenced the HWTT test temperatures chosen by their agency. Further research using PG 58V-28 binder sources should be conducted to determine the CST for the various traffic designations as per AASHTO M332.

- Anti-stripping agents and RAP materials are common in asphalt mixtures produced in Nova Scotia, therefore future research should be considered to determine the overall effects on rutting resistance and moisture damage. Research has shown that anti-stripping agents improve moisture susceptibility, while improvements in rutting resistance are insignificant. RAP materials tend to increase mixture stiffness improving rutting resistance. However, moisture damage typically increases due to poor bonding between aggregates and overaged binder.

- Begin developing correlations between the proposed HWTT parameters developed in this study with actual field pavement performance. NSTAT to monitor pavement sections using ARAN vehicle to determine rutting rates under various traffic levels for materials exhibiting a range of visco-plastic rutting parameters. Consideration should be given to implementing a balanced-mix design approach would enhance predictive measures and provide opportunity to balance cracking resistance versus visco-plastic rutting resistance while determining moisture or cracking susceptible mixtures prior to asphalt production.

References

AASHTO M 332 – Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test.

AASHTO T350 – Standard Method of Test for Multiple Stress Creep Recovery (MSCR) Test of Asphalt Binder.

AASHTO T324 Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures

Asphalt Institute. (2014). Asphalt Mix Design Methods MS-2 (7th Edition). USA.

Bahia, H.U. and Lv, Q. (2019). "Separating Effects of Loading from Moisture in Wet Hamburg Wheel-Track Test". *Journal of the Association of Asphalt Paving Technologists.* Vol. 88. pp751-781.

Barnes, C.L. et al. (2018). "Review of Current Asphalt Cement Performance Grade Temperature Requirements in the Maritime Provinces". *Transportation Association of Canada (TAC) and ITS Canada 2019 Joint Conference and Exhibition.*

Colorado Department of Transportation (2015). "Hamburg Wheel-Track Testing of Compacted Bituminous Mixtures"*.* CP-L 5112-14. Section 7.1. pp3.

DeCarlo, C. et al. (2020). "Comparative Evaluation of Moisture Susceptibility Test Methods for Routine Usage in Asphalt Mixture Design". *Journal of Testing and Evaluation.* Vol. 48 (1). 20180908.10.1520/JTE20180908.

Maine Department of Transportation (2019). "HMA Hamburg Wheel Tracker Specification". Special Provision Division 400 Section 401 – Hot Mix Asphalt Pavement.

Maine Department of Transportation (2019). "HMA Hamburg Wheel Tracker Testing". MaineDOT Policy.

Nova Scotia Transportation and Active Transit (2020). "Superpave Asphalt Concrete End Product Specification (EPS)". Division 4 – Pavements.

Nova Scotia Transportation and Active Transit (2020). "TM-20 Procedure for Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures"*.* Test Methods Manual.

Romero, P. et al. (2008). "Analysis of the Hamburg Wheel Tracking Device to Predict Behavior of Asphalt Mixtures at Different Test Temperatures". *Utah Department of Transportation.* https://digitallibrary.utah.gov/awweb/awarchive?item=12889

Utah Department of Transportation (2011). "Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)". Part 8 -Materials Manual. Section 990.04.03. pp3.

Yin, Fan et al. (2014). "Novel Method for Moisture Susceptibility and Rutting Evaluation Using Hamburg Wheel Track Testing*". National Academies of Sciences, Engineering, and Medicine.* NCHRP Project 9-49.