EVALUATION OF ASPHALT BINDER CHARACTERISTICS OF TYPICAL ONTARIO SUPERPAVE® CRM AND RAP-HMA MIXTURES

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Abstract

Utilization of Reclaimed Asphalt Pavement (RAP) and Crumb Rubber Modifiers (CRM) in Hot Mix Asphalt (HMA) offers transportation agencies the opportunity of enhancing the functional properties of the mixture and reducing construction costs, thus creating an engineered value-added application. Consequently, these resources are reused as opposed to being disposed in a landfill. However, a successful utilization entails evaluating engineering properties of the asphalt binder and the mechanistic properties of hot mix asphalt concrete produced using varying amounts of RAP and CRM compositions. This paper presents the results of a study to characterize and evaluate the performance of asphalt binders extracted from an array of laboratory and plant-prepared Ontario Superpave HMA mixtures containing up to 40% RAP in combination with varying CRM compositions. Such binders were characterized in accordance with the Superpave performance-based specification.

1. INTRODUCTION

1.1 Background and Problem Statement

Asphalt recycling technology remains an important topic in the pavement industry. The increasing demand for recycled asphalt pavements in Ontario is largely due to the increasing cost of asphalt binders, scarcity of high quality virgin aggregates and an increasing environmental awareness. Utilization of Reclaimed Asphalt Pavement (RAP) and Crumb Rubber Modifier (CRM) in Hot Mix Asphalt (HMA) offers transportation agencies the opportunity of enhancing the functional properties of the mixture and reducing construction costs, thus creating an engineered value-added application of these resources as opposed to a disposal mechanism.

The addition of RAP stiffens the HMA mixture, but at higher blends (for example, greater than 25 percent) mixture performance significantly changes due to the increased stiffness of the aged RAP binder, and degree to which blending occurs with virgin binder.

Ontario's challenges with high RAP mixes include factors such as effects on moisture susceptibility, mix stiffening, binder grade adjustments or also known as "binder bumping", loss of desired binder performance grade, mix volumetric, the inability to meet consensus properties, reduced field workability and issues with compactability [1]. These reasons, in addition to current specification requirements further limit the use of RAP in HMA to 20% amongst contractors in Ontario [2].

The concept of incorporating crumb rubber into asphalt mixes is aimed at enhancing performance properties of virgin asphalt binders. Roberts's notes that CRM [3]:

- Lowers the viscosity at the construction temperature to facilitate pumping, mixing and compaction of HMA,
- Increases the viscosity at high service temperatures to reduce rutting and shoving,
- Increases relaxation properties at low service temperatures to reduce thermal cracking, and
- Increases adhesion between asphalt binder and aggregates in the presence of moisture to reduce or prevent stripping.

Although parts of the United States indicate that mix modification improves rutting, fatigue and thermal cracking resistance performance including reduced noise levels of rubberized pavement sections [4]. This degree of improvement has been variable. The most effective incorporation method and initial poor performance has limited the placement of asphalt mixes containing CRM in Canada. Interest toward sustainability in Ontario's pavement industry presents an opportunity to consider higher RAP percentages and utilization of the wet process CRM in HMA mixtures. Extensive and thorough research is critical to fully characterize and understand the behavioural responses of an asphalt binder and its corresponding influence on the performance of typical Ontario Superpave HMA mixtures under different environmental and loading conditions. By using RAP and CRM in HMA mixtures, it is possible to offset the shortfalls of RAP with respect to the effects of binder aging thus increasing the mixture's resistance to fatigue cracking and thermal cracking, improve susceptibility to moisture damage, as well as rutting resistance.

1.2 Scope and Objectives

The objective of this research is to explore the feasibility of designing and constructing typical Ontario Superpave asphalt mixtures incorporating high RAP or in combination with CRM without compromising performance levels. This paper presents results of the rheological properties of virgin and recovered binders from RAP and RAP-CRM HMA mixtures. Additionally, results of rutting and thermal cracking performance of such mixtures are also evaluated in this paper. It is expected that these performance findings would advance the knowledge and practice mixtures containing RAP and CRM in Ontario.

2. ASPHALT BINDER RHEOLOGY

Asphalt binder, the principal binding agent of asphalt-aggregate mixtures is a viscoelastic material. At elevated temperatures, it is a viscous liquid and at freezing or cold temperatures it is an elastic-solid [5]. This behaviour is critical to the mechanical properties of asphalt-aggregate mixtures especially in terms of rutting, thermal and fatigue cracking pavement distresses. To better match the behavior of asphalt binder to HMA pavement distresses, an asphalt-grading system called Performance Grading (PG) is included in the Superpave mixture design, in which the binder grade is specified by two numbers, for example "PG 58-28". The first number, 58, represents an average 7-day maximum pavement service temperature (in degrees Celsius, ºC) at which the binder is intended to perform adequately to resist rutting. The second number, minus 28ºC, represents the minimum pavement temperature at which the binder is intended to resist thermal cracking [3 - 6].

The binder grading is performed by measuring rheological parameters including the total resistance to deformation (G*), relative non-elasticity of the binder (sin δ), flexural creep stiffness (S), and rate of stress relaxation (m-value). A combination of the G* and sin δ is used to capture the contribution of asphalt binder in rutting susceptibility of mixtures. Increasing the G*/sin δ parameter makes the binder stiffer and more elastic, and thus more resistant to rutting. On the other hand, parameters S and m-value are related to the binder's properties to thermal cracking resistance. Binders with relatively lower values of creep stiffness will exhibit fewer amounts of thermal cracks in cold weather. Likewise, higher value of m-value shows the ability of binder to absorb stress in the event of temperature drop, and exhibit lesser cracking tendency

[7]. G* and δ values of virgin and recovered binders from RAP mixtures in particular are also necessary to attain proper blending charts [8 - 11].

3. EXPERIMENTAL DESIGN RESEARCH METHODOLOGY

3.1 Experimental Mix Description

An array of typical Ontario surface course HMA mixtures were evaluated in this study. All mixtures were designed to meet the Superpave mixture design specification, and consists of six laboratory-prepared and two plant-produced mixes covering two binder performance grades with Nominal Maximum Aggregate Size (NMAS) of 9.5 and 12.5 mm. These include: six dense-graded laboratory-prepared HMA mixtures with RAP contents varying between 0, 20 and 40%; and two plant-prepared HMA: a dense-graded terminal blend CRM mix with 20% RAP and a dense-graded mix with 20% RAP. It is important to note that terminal blend refers to the type of wet-process wherein the CRM is blended at the asphalt binder manufacturing plant whereas field blending is done at the HMA mixing plant. All plant-prepared HMA mixtures in this study were taken during construction of different trial sections on Highways 7 and 115 in Ontario. The compositions and volumetric properties of the HMA mixtures prepared in this study are presented in Table 1.

Table 1: Composition and Volumetric Properties of Evaluated HMA Test Matrix

Mix ID	Laboratory-prepared						Plant-produced	
	L1	L2	L3	L4	L5	L6	P1	[e]P2
PGAC[a]	58-28			52-40			58-28	58-28[b]
RAP Content (%)	0	20	40	0	20	40	20	
Virgin AC (%)	5.2	4.3	3.3	5.2	4.3	3.1	4.1	6
AC from RAP (%)	-	0.9	1.8	-	0.9	1.8	0.98	
Total AC (%)	5.2	5.2	5.1	5.2	5.2	4.9	5.1	7
Dust Proportion	0.7	1.2	1.1	0.7	1.2	1.1	0.9	0.7
% VMA[c]	14.8	15.5	14.3	14.8	14.3	14.2	15.2	19.9
% VFA[d]	73.1	74.2	72.1	72.9	72.1	71.5	74	80

Note: [a]PGAC = Performance Graded Asphalt Cement, [b]RFB = Rubber Field Blend; [c]VMA = Voids in Mineral Aggregates; [d]VFA = Voids Filled with Asphalt. [e]P2 contains 20% CRM.

3.2 Binder Characterization

The Virgin and recovered asphalt binder were characterized in this study. Extraction of the RAP and RAP-CRM binders were completed with the solvent Normal propyl bromide (nPB) while recovery consisted of heating the mixture and distilling the solvent using a Rotovap. The rheological parameters of virgin and recovered binders were measured by using a Dynamic Shear Rheometer (DSR) as per AASHTO T315 [12]. Short-term aging of the binders was accomplished in a Rolling Thin-Film Oven (RTFO) as per AASHTO T 240 [13] while a pressure aging vessel (PAV) in accordance with AASHTO T315 was used for tests on residue to simulate the long-term aging of the binder. AASHTO T 313 [14]. The true grade of the recovered binders was determined as per AASHTO R-29 [15]. This allowed for characterization of the binders high, intermediate, and low-temperatures. Additionally, a Rotational Viscometer (RV) was used to measure viscosity of the binder in accordance with AASHTO T 316 test method [16].

3.3 Mixture Characterization

The rutting potential of the asphalt mixtures under investigation were evaluated in accordance with AASHTO T324-04 'Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)" [17]; while resistance to thermal cracking was evaluated in accordance with AASHTO TP 10-93, "Standard Test Method for Thermal Stress Restrained Specimen Tensile Strength" [18].

4. TEST RESULTS AND DISCUSSION

By employing test methods described in section 3.2, the continuous high and low temperature grades of recovered binders were estimated and are shown in Figure 1and Figure 2 respectively.

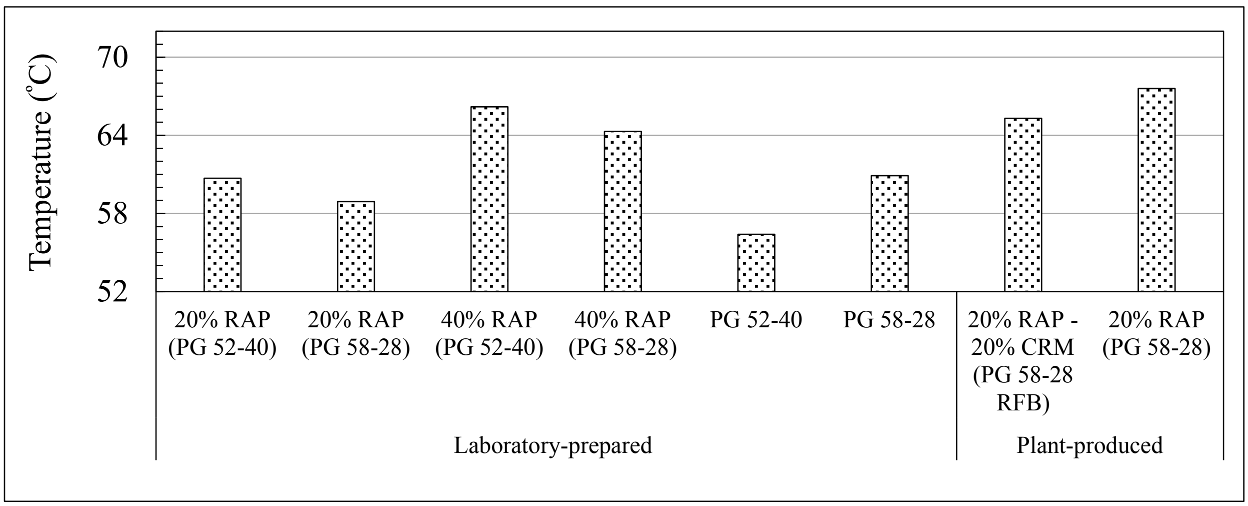

Figure 1: Continuous High Temperature Grade for Virgin and Recovered Binders

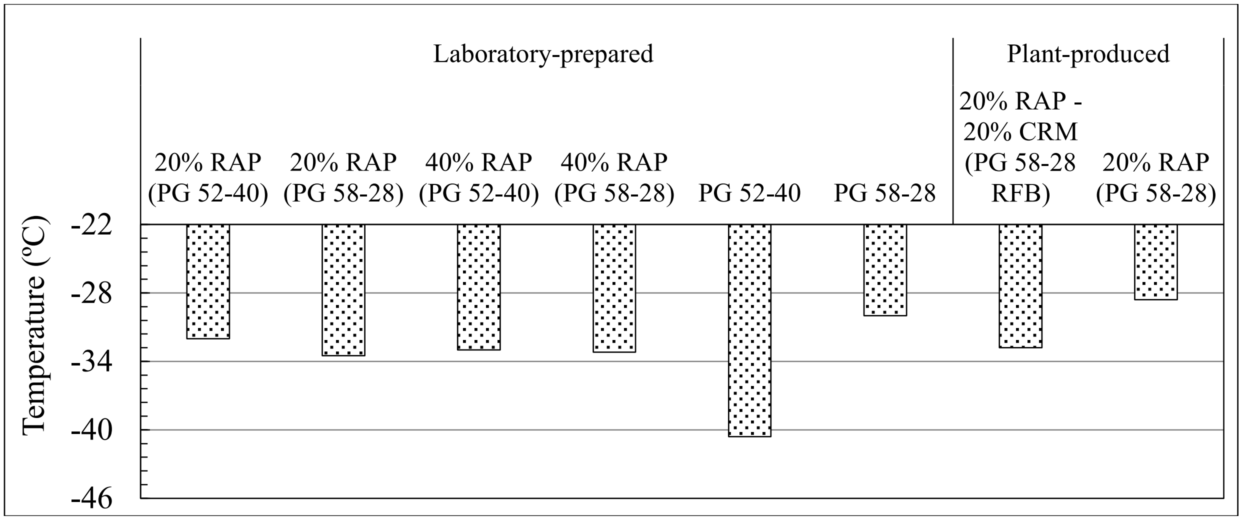

Figure 2: Continuous Low Temperature Grade for Virgin and Recovered Binders

In general, for both laboratory and plant mixtures, the addition of RAP resulted in an increase in the continuous high temperature grades. This potentially implies favorable enhancement of rutting resistance. The exception to this trend, is noted with the 20%RAP (PG 58-28) laboratory prepared mixture which resulted in a slight decrease in continuous high temperature grade. However, such decrease was observed to be marginal.

The addition of 40% RAP resulted in a grade adjustment of the PG 52-40 base binder to PG 64-28. The same PG was obtained with the PG 58-28 base binder and 40% RAP content. It should be noted that same continuous low temperature was observe for both mixtures. Although the addition of 20% RAP was observed to result in marginal decrease in the continuous low temperature grade of plant-produced 20% (PG 58-28) mixture, while an increase was observed for the laboratory-prepared 20% RAP 58-28. However, this increase did not result in an adjustment to the low temperature grade.

Table 2: Grade Selection for Ontario [9]

	PGAC Zones		
	Zone 1	Zone 2	Zone 3
New Hot Mix or up to 20% RAP	52 - 34	58 - 34	58 - 28
21 to 40% RAP	52 - 40	52 - 40	52 - 34

Table 2 shows the PGAC designations for Ontario under normal traffic conditions. When traffic is slow moving or static the high temperature grades are adjusted, Table 2 suggests that a grade change is not required for mixes with up to 20% RAP, but one grade lower PG is recommended for mixes with 21 to 40% RAP. The aforementioned implies that when adding RAP and changing the grade, it is expected that the recycled mixture has at least the same grade required for a new hot mix. It can be seen in Figure 1 and Figure 2 that the target lower temperature was not met for the mixtures with PG 52-40 which is a polymer modified binder. Those mixtures in this study appear to be affected by the RAP addition. However, the PG 52-40 binders should be tested to verify this funding. The mixtures with the PG 58-28 did appear to be affected in the low temperature range, regardless of the addition of up to 40% RAP.

It was observed that combination of 20% RAP and CRM did soften the base PG 58-28 base binder. This suggests that a combination of RAP and CRM might improve the mixture's resistance to thermal cracking is observed at lower temperatures. The combination of RAP and CRM was also observed to stiffen the base PG 58-28, suggesting more resistance to rutting.

In order to verify these observed trends, resistance of mixtures to permanent deformation and thermal cracking were measured by using a Hamburg Wheel Tracking Device (HWTD) and a Thermal Stress Restrained Specimen Test (TSRST) respectively. The results of these tests are further explained in the sections below.

4.2 Permanent Deformation Characterization

The resistance of compacted asphalt mixtures to rutting was evaluated by using a Hamburg Wheel Tracking Device (HWTD) in accordance with AASHTO T324-04 "Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)" [17]. As shown in Figure 3, the device tracks a 158 lb (705 N) load steel/rubber wheel across the surface of Superpave® gyratory compacted HMA specimens submerged in a hot water bath at 50°C for 10,000 cycles (20,000 passes). Results of the rutting performance of mixtures are shown in Figure 4.

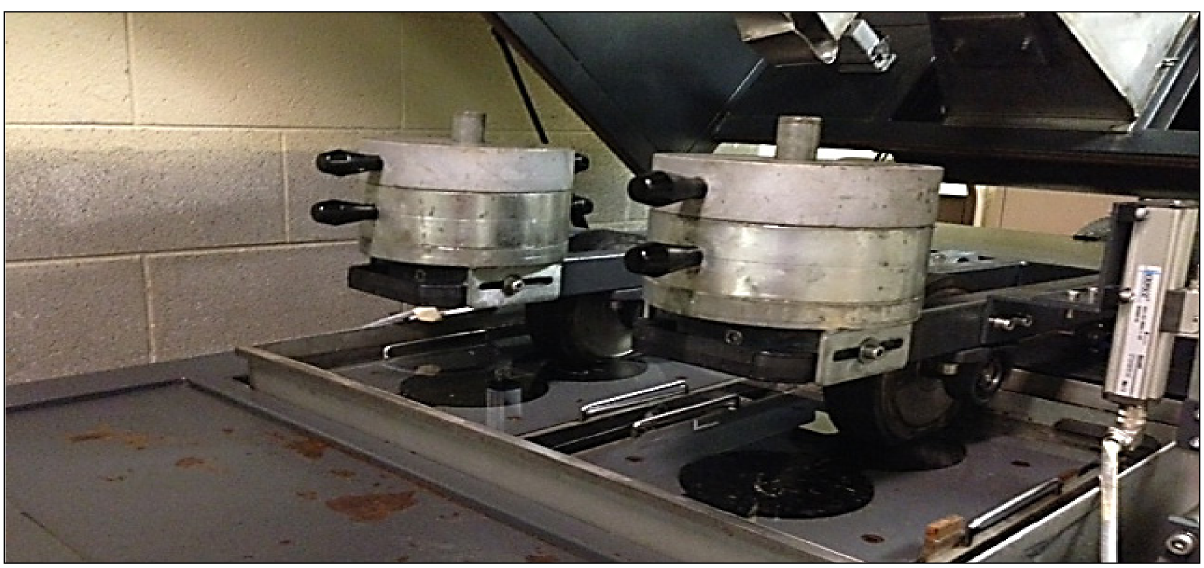

Figure 3: CPATT's Hamburg Wheel Tracking Device (HWTD) Setup

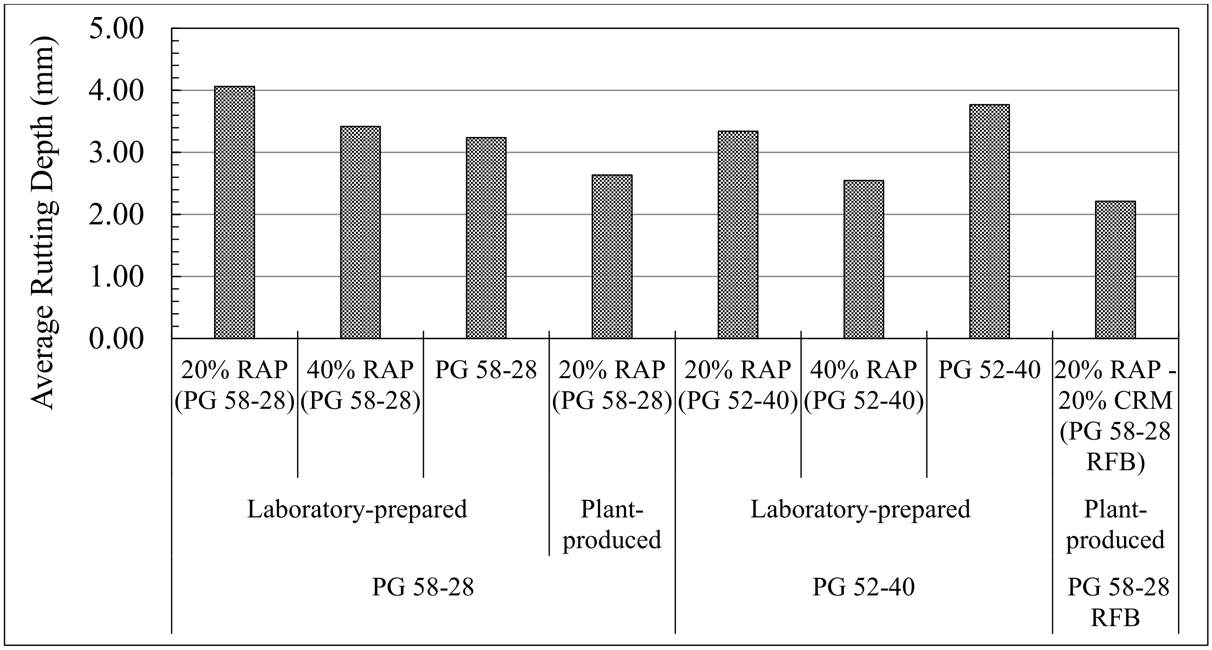

Figure 4: Average Rutting Results

The addition of RAP resulted in less rutting for laboratory-prepared mixtures containing base asphalt binder of PG 52-40, while the mixture with 40% RAP resulted in a lower amount of rutting compared to the 20% RAP mixture. In contrast, the addition of 20% RAP resulted in a slight increase in the amount of rutting for the laboratory-prepared mixture containing base asphalt binder of PG 58-28. However, the increase was slightly improved by the addition of 40% RAP for the PG 58-28 mixture. The addition of 20% RAP to the plant-produced mixture containing base asphalt binder of PG 58-28 resulted in slightly better rutting resistance. It was also observed that combination of RAP and CRM resulted in better rutting resistance.

4.3. Thermal Cracking Characterization

A Thermal Stress Restrained Specimen Test (TSRST) was used to evaluate the resistance of compacted mixtures to thermal cracking in accordance with the AASHTO TP 10-93, Standard Test Method for Thermal Stress Restrained Specimen Tensile Strength [18]. For this test, an initial tensile load is applied to a compacted beam specimen measuring 250 mm x 50 mm x 50 mm, whilst being simultaneously subjected to a constant cooling rate of -10ºC hourly, while being restrained from contracting. The specimen setup is shown in Figure 5. The beam fails as the stress generated exceeds the tensile strength and the failure temperature and fracture stress are measured. The failure temperature represents the temperature at which the asphalt pavement will develop a transverse thermal crack and the fracture stress controls the spacing between those cracks. A higher fracture stress results in wider spacing between cracks in the field [10]. A typical stress temperature curve is shown in Figure 6.

Figure 5: CPATT's Thermal Stress Restrained Specimen Test (TSRST) Setup

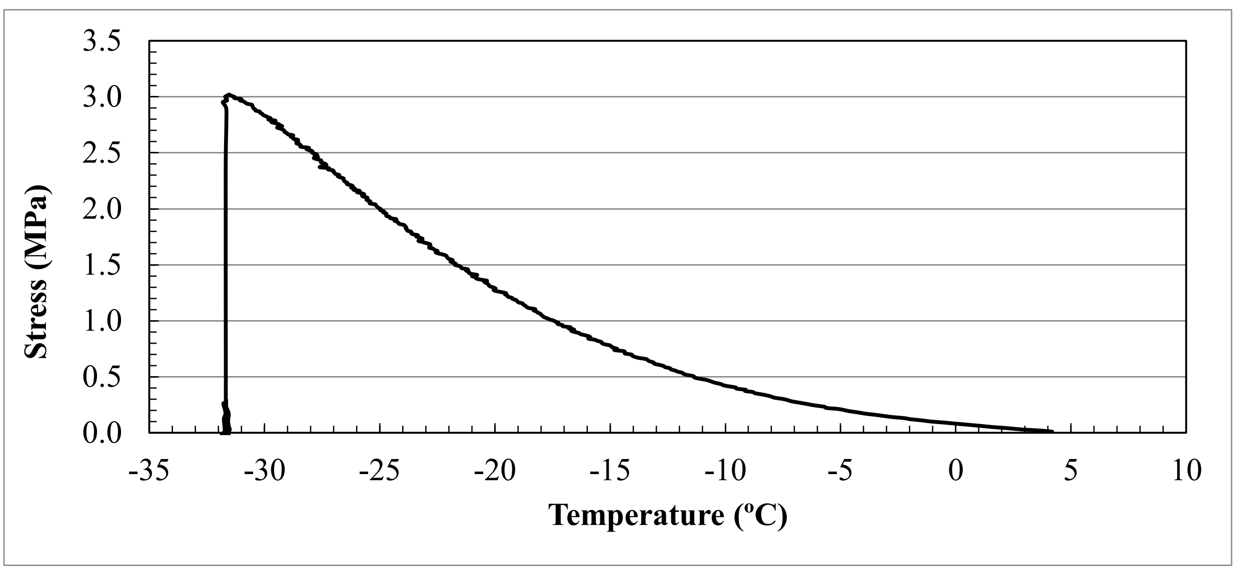

Figure 6: Typical Force-Temperature Fracture Curve for Asphalt Mixes

The failure temperature results obtained from TSRST and binder's recovered continuous low temperature are compared in Figure 7.

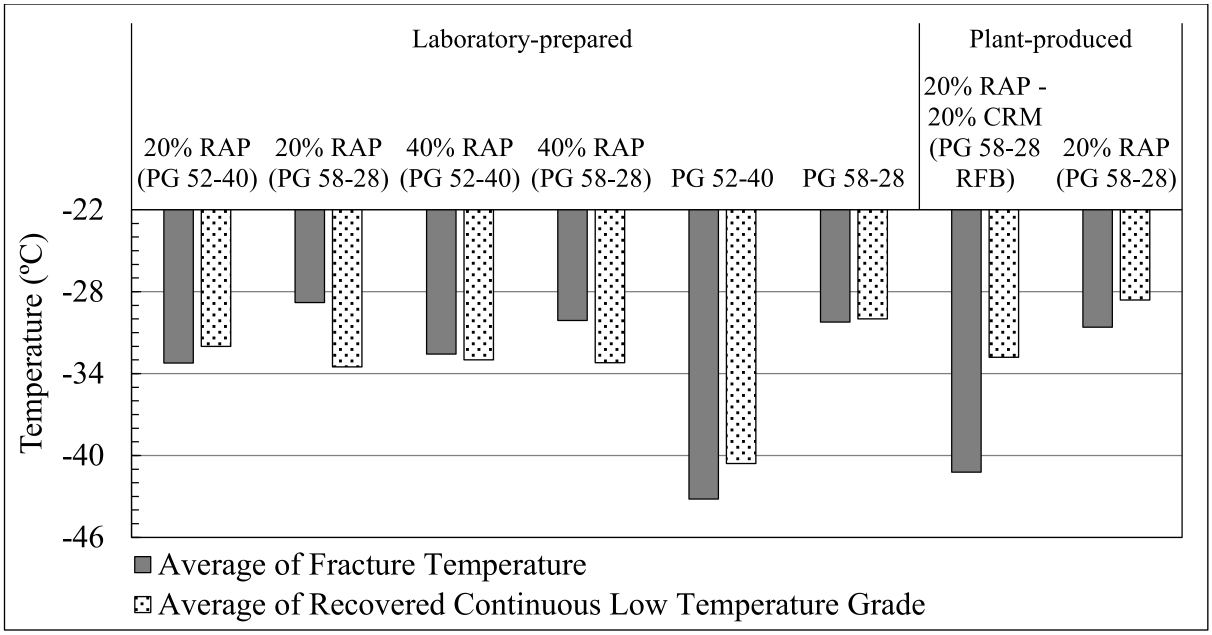

Figure 7: TSRST and Binder's Recovered Continuous Low Temperature

As shown in Figure 7, for the RAP added mixtures, in general the failure temperature matches the low PG temperatures obtained from the recovered binder. The TSRST results are consistent with the BBR outcomes. It can also be observed from Figure 7 that the results are very close for all the PG 52-40 mixtures. However, for the PG 58-28 mixtures; the Bending Beam Rheometer method tends to overestimate the low temperature cracking resistance for the laboratory-prepared mixtures.

An increased resistance to low temperature cracking was observed with the addition of 20% CRM, bumping the grade from -28 to -40, suggesting that the rubber counteracts the brittleness and enhance the flexibility of the asphalt binder under low temperature conditions.

5. CONCLUSIONS AND NEXT STEPS

The primary objective of this study was to evaluate the adequacy of Superpave Performance Grading (PG) parameters in predicting rutting and thermal cracking of typical Ontario asphalt mixtures with RAP content up to 40%. Following conclusions can be drawn from this study:

- In general, the Superpave rutting parameter of $G^*/\sin(\delta)$ was found to be inadequate in capturing contribution of asphalt binder in rutting susceptibility of mixtures as observed by the Hamburg Wheel Tracking Device (HWTD). On other hand, the thermal cracking parameters measured by the Bending Beam Rheometer method tends to provide a much better correlation with the Thermal Stress Restrained Specimen Test (TSRST) method.

- It was observed that the MTO's target lower temperature (Table 2) was not met for the mixtures with PG 52-40 which is a polymer modified binder. Those mixtures seem to be more affected by the RAP addition. The mixtures with PG 58-28 had no effect on the target low temperatures, regardless of the addition of up to 40% RAP.

Results of this study strongly suggests the usage of RAP in combination with CRM as an extraordinary resistance to low temperature cracking and rutting was observed with the addition of 20% CRM to mixture containing 20% RAP and PG 58-28 asphalt binder.

Recognizing the inadequacy of Superpave G*/sin(δ) rutting parameter in predicting the rutting performance of some mixtures containing RAP, one of the next steps in this study will involve evaluating alternative test methods in capturing contribution of asphalt binder in rutting resistance. One of these test methods is known as the Multiple Stress Creep Recovery (MSCR) test, which can be performed in accordance with AASHTO TP 70-12, "The Multiple Stress Creep Recovery (MSCR) Test for Asphalt Binder Using a Dynamic Shear Rheometer (DSR)" [19]. Other steps will include evaluation of the elastic properties and fatigue life of the respective HMA mixtures by employing the dynamic modulus and flexural fatigue testing protocols respectively. Overall, these observations suggest that typical Ontario Superpave HMA mixtures incorporating CRM, and RAP exhibit the potential to resist low-temperature cracking and the combined effects of rutting stripping and moisture damage if properly designed, mixed and compacted. Findings from plant-produced HMA are to be correlated with field investigations for validation.

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