RUBBERIZED ASPHALT MIXTURES WITH RAP: A CASE FOR USE IN ONTARIO

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ABSTRACT

In 2011, the Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo, the Ontario Tire Stewardship (OTS), and the Ministry of Transportation of Ontario (MTO) partnered to conduct several demonstration studies on the use of Rubberrized Asphalt with the intent to better understand and resolve the technical challenges associated with such mixtures as well as to advance the pavement industry to a more sustainable and economically viable direction.

To evaluate field performance, placement of rubberized roads in Ontario, Canada was conducted. This paper reviews past experiences and reports on the laboratory performance of characterized HMA mixtures incorporating 0.5 to 1% Crumb Rubber Modifiers (CRM) and 15 to 20% Reclaimed Asphalt Pavement (RAP) by total weight of the mixture. Overall observations suggests that combining RAP with CRM in typical Ontario HMA compensates for RAP shortfalls such as its effects on binder aging and mix stiffness thus improving the mixture’s durability, susceptibility to the combined effects of rutting, stripping and moisture damage, including its overall resistance to fatigue and thermal cracking if properly designed, mixed and compacted. Findings further indicate the potential to incorporate higher RAP contents (i.e. > 25%) into Ontario rubberized pavements.

Keywords: Crumb Rubber Modifier (CRM), Reclaimed Asphalt Pavement (RAP), and Sustainable Pavement.
1. INTRODUCTION

1.1. Background and Problem Statement

Rubber Modified Asphalt (RMA) is the mixture obtained from mixing asphalt rubber-binder (AR) with graded aggregates. The province of Ontario in Canada first experimented with this technology in 1980. This attempt which included the use of both wet and dry process rubberized Hot Mix Asphalt (HMA) mixtures were noted to have performed poorly (1). The wet process involves blending fine crumb rubber powders with virgin asphalt binder to form AR prior to the HMA mixing operation. The dry process utilizes crumb rubber particles that are coarser than those in the wet process and are considered part of the aggregate gradation. The wet process is further categorized into terminal and field-blend AR. A moist process similar to the dry process, but utilizes crumb rubber particles smaller than 0.6 mm in size may also be utilized.

Terminal-blend AR involves blending about 5 to 12% CRM particle sizes less than 0.6 mm mesh into the asphalt cement (AC) with or without a polymer. The complete digestion of the fine rubber component results in a binder of lesser viscosity thus making it most suitable for only dense-graded mixtures (2). Field-blend AR incorporates about 18 to 20% CRM particle sizes less than 0.2 mm mesh directly into the AC before it is mixed with the aggregates (3). Note that 5 to 12% CRM by total weight of binder constitutes about 0.5% CRM by weight of the mix, and 18 to 20% CRM by total weight of binder is about 1% CRM by weight of the mix. Also, 18 to 22% CRM by weight of the total asphalt binder represents high rubber content (4). The rubber crumbs utilized in either dry or wet process is a product of ambient or cryogenic grinding of scrap rubber tires.

Further experimentation with the rubberized pavement technology in Ontario continued between 1991 and 1997 recording some technical successes, but with pavement raveling, cracking, roller pick and insufficient asphalt cement noted as issues of concern at the time (1, 5-8). In all of these trials, pavement sections constructed using the dry process performed worse than sections with the wet-process or conventional HMA. However, the wet process mix was associated with an additional initial cost 40% greater than the moist process mix (6). This higher initial costs consists of factors involved with purchasing, renting, contracting and modifying the blending units required to blend the rubber crumbs with virgin binders. Consequently, the placement of rubberized pavements in Ontario became unattractive.

The objectives of these experimentations at the time were to determine the environmental acceptability and economic feasibility of recycling scrap rubber tires into asphalt pavements following the February 12, 1990 Hagersville tire fire in Ontario (1). These resolutions were in part considered following the successes with RMA pavements by U.S states such as Arizona, California, Florida and Texas. Laboratory and field trials had shown that rubber mix modification improved rutting, fatigue and thermal cracking resistance including noise levels of rubberized pavement sections (9-11). Other benefits of RMA are that the RMA retains more heat, and during the winter which assists with de-icing. RMA pavements also has better ice and friction performance during the cold months (12). This can reduce the use of salts and chemicals for de-icing purposes in the winter.

The degree of improvement, incorporation methods, and cost effectiveness associated with rubberized asphalt concrete mixtures in the U.S is not firmly established in Ontario. However, the general conclusion from the assessment of rubberized pavement sections in Ontario is that the dry process is feasible while the wet process could be engineered for better or comparable performance with conventional pavements following the development of mix designs and good construction procedures.
This paper describes the full-scale placement/trials of rubberized pavements in Ontario based on findings from laboratory performance characterization of rubberized HMA mixtures incorporating Reclaimed Asphalt Pavement (RAP). The inclusion of RAP in the evaluated mixtures is aimed at providing agencies with data which evaluates RAP in conventional Ontario mixes. The governing RAP specification for Ontario, OPSS 1150, permits the use of up to 20% for surface layers, and up to 30% for binder layers (13). The authors believe that surface course RAP can be increased to 30 or 40%, and that combining RAP with CRM is capable of compensating for RAP shortfalls such as its effects on binder aging and mix stiffness thus improving the mixture’s durability, susceptibility to the combined effects of rutting, stripping and moisture damage, including its overall resistance to fatigue and thermal cracking.

2. SCOPE AND OBJECTIVES

This study is part of Ontario’s renewed interest in RMA pavements. CPAIT in collaboration with the OTS and the MTO partnered to conduct several demonstration projects with RMA. The research explores the feasibility of designing and constructing typical Ontario Superpave (SP) HMA mixtures incorporating CRM and RAP without compromising pavement performance. The intent is to understand and resolve the key technical challenges associated with such mixtures as well as to advance the pavement industry to a more sustainable and economically viable direction.

3. METHODOLOGY

This study has mainly been conducted through laboratory characterization of the binder and performance testing of HMA mixtures obtained from the 2011 Ontario rubber demonstration projects. TABLE 1 summarizes the volumetric properties and compositions of each mix.

### TABLE 1 Mix Description

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>PGAC Mix Type</th>
<th>NMAS (mm)</th>
<th>RAP Content (%)</th>
<th>Virgin AC (%)</th>
<th>RAP AC (%)</th>
<th>Total AC (%)</th>
<th>DP</th>
<th>VMA (%)</th>
<th>VFA (%)</th>
<th>TSR (%)</th>
<th>G&lt;sub&gt;mm&lt;/sub&gt;</th>
<th>Compaction Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H7-C</td>
<td>DGAC</td>
<td>12.5</td>
<td>15</td>
<td>4.3</td>
<td>0.94</td>
<td>5.2</td>
<td>0.8</td>
<td>15</td>
<td>73.0</td>
<td>84.7</td>
<td>2.629</td>
<td>138</td>
</tr>
<tr>
<td>H35-C</td>
<td>DGAC</td>
<td>12.5</td>
<td>20</td>
<td>4.1</td>
<td>0.94</td>
<td>5.2</td>
<td>0.8</td>
<td>15</td>
<td>73.0</td>
<td>84.7</td>
<td>2.629</td>
<td>138</td>
</tr>
<tr>
<td>H7-RTB</td>
<td>DGAC</td>
<td>12.5</td>
<td>20</td>
<td>4.1</td>
<td>0.94</td>
<td>5.2</td>
<td>0.8</td>
<td>15</td>
<td>73.0</td>
<td>84.7</td>
<td>2.629</td>
<td>138</td>
</tr>
<tr>
<td>H7-RFB</td>
<td>DGAC</td>
<td>12.5</td>
<td>20</td>
<td>4.1</td>
<td>0.94</td>
<td>5.2</td>
<td>0.8</td>
<td>15</td>
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<tr>
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<td>12.5</td>
<td>20</td>
<td>4.1</td>
<td>0.94</td>
<td>5.2</td>
<td>0.8</td>
<td>15</td>
<td>73.0</td>
<td>84.7</td>
<td>2.629</td>
<td>138</td>
</tr>
</tbody>
</table>

Note: Nominal Maximum Aggregate Size (NMAS); PGAC = Performance Graded Asphalt Cement; C = Conventional Mix; DGAC = Dense-graded Asphalt Concrete Mixtures; RFB = Wet-process rubber field-blend; RTB = Wet-process Rubber Terminal-blend; VMA = Voids in Mineral Aggregates, VFA = Voids Filled with Asphalt; H = Highway No.; TSR = Tensile Strength Ratio; G<sub>mm</sub> = Maximum Relative Density; DP = Dust Proportion.
respective mixtures were met. All values for Tensile Strength Ratio (TSR) met or exceeded the minimum 80% requirement as seen in TABLE 1. Note that this is an indication that the mixtures should be highly resistant to moisture damage and effects of stripping.

3.1. Binder and Mix Performance Characterization

The high and low-temperature grades of the aged-original, and recovered blended binder from each recycled HMA mixture were determined as per required specifications (14-18). Extraction was completed with the solvent Normal propyl bromide (nPB) while recovery consisted of heating the mixture and distilling the solvent using a Rotovap. 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) were measured to complete the grading process. A ratio of the G* and sin δ, (G*/sin δ) captures the contribution of asphalt binder in rutting susceptibility of mixtures. An increase in this 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 resistance to thermal cracking. Binders with relatively lower values of creep stiffness will exhibit fewer amounts of thermal cracks in cold weather. Likewise, a higher m-value shows the ability of binder to absorb stress in the event of temperature drop, and exhibit lesser cracking tendency (19-20).

Mechanistic and stiffness assessment on the experimental matrix were evaluated in accordance with specified AASHTO standards (21-23). These tests include:

- Thermal Cracking – Material Testing System (MTS) 810 and 651 Environmental Chamber
- Rutting, Stripping and Moisture Damage – Hamburg Wheel Tracking Device (HWTD)
- Stiffness – Dynamic Modulus Test MTS 810 and 651 Environmental Chamber

The HWTD tracks a steel wheel of 705 N load across the surface of a pair of HMA specimens submerged in a water bath at 50°C for 10,000 cycles or until a rut depth of 20 mm is reached. This paper compared rutting performance between mixtures to the National Center for Asphalt Technology (NCAT) suggested rut-depth criteria of less than 10 mm after 10,000 cycles for conventional dense-grade HMA mixes (24). The post-compaction consolidation at 1,000 load cycles and creep slope were also evaluated and compared since rutting occurs due to consolidation and plastic flow. Note that creep slope is preferred for evaluating rutting potential over rut-depth since the number of load cycles at which moisture damage begins to affect rut depth varies between HMA mixtures (25). A mixture’s potential for and severity of damage due to moisture is evaluated from the stripping slope obtained at the number of passes where the creep slope intercepts the stripping slope. It is important to note that a mixture where in the Stripping Inflection Point (SIP) occurs at a load cycle less than 10,000 is susceptible to moisture damage.

In the thermal cracking test, a rectangular beam specimen is conditioned at 5°C for a period of 6 hours. Thereafter, it is subjected to an initial tensile load to restrain it from contracting whilst being simultaneously subjected to a constant cooling rate of -10°C hourly. The beam fails as the stress generated exceeds the tensile strength and the failure temperature and fracture stresses 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. Higher fracture stress results in wider spacing between cracks in the field (26).

Stiffness characterization test is critical because of its sensitivity to the changes in HMA mixture volumetric and binder stiffness. An increase in stiffness of the asphalt mix is depicted by an increase in stiffness values which is a reflection of a decrease in strain corresponding to an applied load. Similarly, a decrease in stiffness results indicates an increase in strain and is interpreted as decrease in the stiffness of the asphalt mix (27). Stiffness and low-temperature fracture characterizations were completed in triplicates while rutting tests was conducted in pairs for each
mix, all within the recommended 7±1% air void specification. Note that air void specification for rutting test on laboratory compacted samples is 7±2%.

4. TEST RESULTS, ANALYSIS AND DISCUSSION

4.1. Binder and Thermal Crack Characterization

The high and low grades of the aged-original binders were 59-29 for PG 58-28, 65-35 for PG 64-34 and 67-35 for PG 64-34P respectively. The recovered binder characteristics were determined as highlighted in FIGURE 1.

FIGURE 1 Recovered Binder Grades and Mix Fracture Temperature

FIGURE 1 also compares the low temperature grade of the recovered binders with the mean fracture temperatures from testing triplicates of each recycled mix. It is observed that adding RAP, or combining RAP and CRM increased the high grades. The higher end PG potentially implies favorable enhancement of rutting resistance. The fracture temperature of the evaluated mixtures are observed to have exceeded those of the respective recovered and aged-original binders. A significant increase is also noted with the terminal and field-blend Rubberized-RAP mixtures. This observed increment is good indication of the potential to resist transverse thermal cracks. It also suggests that the rubber counteracts the brittleness and enhances the flexibility of the asphalt binder under low temperature conditions. Comparing mean fracture stresses for the mixtures as shown in FIGURE 2 indicates that mixtures incorporating RAP and CRM are less susceptible to fracture at low temperatures. Field-blend mixtures reported the least fracture stresses in comparison to mixtures with only RAP. However this difference is not significant when compared with the terminal-blend mix. A single factor analysis of variance (ANOVA) with a probability of 95% confirms that there are no significant statistical differences between and within the rubberized-RAP mixtures with $F_{\text{statistics}}$
(0.87) < $F_{\text{critical}}$ (4.06). The analysis between RAP and CRM-RAP mixtures of PG 58-28 reported $F_{\text{statistics}}$ (7.09) > $F_{\text{critical}}$ (3.48) to affirm the influence of the rubber crumbs and change in binder grade of the blend. Analysis between mixtures of PG 64-34 and PG 64-34P indicated $F_{\text{statistics}}$ (5.97) < $F_{\text{critical}}$ (7.71). Regardless of these variations, triplicate tests showed good repeatability for fracture temperature. Therefore, the reported fracture stress values are not significantly high to suggest that the mixtures will be prone to transverse thermal cracking at low temperatures. To verify these deductions, t-tests were performed for different coupled asphalt mixtures; the results are shown in TABLE 2.

With exceptions to comparisons made between H7-RTB and H35-C, and H115-C and H115-RFB; all other cases indicated $t_{\text{statistic}}$ to be less than $t_{\text{critical}}$. Based on a confidence of 95%, it is concluded that differences between the fracture stress results are not statistically significant. Scenarios with statistically significant fracture stresses could be attributed to the difference in mix type, binder grades, RAP content, CRM component and method of incorporation.

![Fracture Stress](image)

**FIGURE 2 Fracture Stress of Evaluated HMA Mixtures**

**TABLE 2 t-Test Analysis for Fracture Stress Differences**

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>HMA Mixes</th>
<th>Fracture Stress (MPa)</th>
<th>$t_{\text{statistic}}$</th>
<th>$t_{\text{critical two-tail}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>H7-C: 15% RAP</td>
<td>PG 58-28</td>
<td>2.3</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>H7-C: 15% RAP</td>
<td>H7-RFB: 20% RAP + 1% CRM</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H7-C: 15% RAP</td>
<td>H7-RTB: 20% RAP + 0.5% CRM</td>
<td>2.4</td>
<td>-0.23</td>
<td></td>
</tr>
<tr>
<td>H7-C: 15% RAP</td>
<td>H35-C: 20% RAP</td>
<td>3.0</td>
<td>-3.08</td>
<td></td>
</tr>
<tr>
<td>H7-RFB: 20% RAP + 1% CRM</td>
<td>H7-C: 15% RAP</td>
<td>2.1</td>
<td>1.78</td>
<td></td>
</tr>
<tr>
<td>H7-RFB: 20% RAP + 1% CRM</td>
<td>H7-RTB: 20% RAP + 0.5% CRM</td>
<td>2.4</td>
<td>-1.02</td>
<td></td>
</tr>
<tr>
<td>H7-RFB: 20% RAP + 1% CRM</td>
<td>H35-C: 20% RAP</td>
<td>3.0</td>
<td>-3.96</td>
<td></td>
</tr>
<tr>
<td>H7-RTB: 20% RAP + 0.5% CRM</td>
<td>H35-RFB: 20% RAP + 1% CRM</td>
<td>2.1</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>H7-RTB: 20% RAP + 0.5% CRM</td>
<td>H35-RFB: 20% RAP + 1% CRM</td>
<td>2.4</td>
<td>1.69</td>
<td></td>
</tr>
<tr>
<td>H7-RTB: 20% RAP + 0.5% CRM</td>
<td>H35-C: 20% RAP</td>
<td>2.4</td>
<td>-48.5</td>
<td></td>
</tr>
<tr>
<td>H115-C: 20% RAP</td>
<td>PG 64-34 and PG 64-34P</td>
<td>2.3</td>
<td>53.5</td>
<td></td>
</tr>
<tr>
<td>H115-C: 20% RAP</td>
<td>H115-RFB: 20% RAP + 1% CRM</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2. Rut Characterization

The rut depths measured in this study suggest that all evaluated mixtures are relatively good compared to the suggested rut-depth criteria of less than 10 mm after 10,000 cycles for conventional dense-graded HMA mixtures. TABLE 3 highlights the results for maximum rut depths after 10,000 cycles, post compaction consolidation at 1,000 load cycles, and creep slopes between tests for the evaluated HMA mixtures.

It is observed that maximum rut depths did not exceed 4 mm after 10,000 cycles with no evidence of stripping or damage due to moisture. Comparing test results between respective mix matrixes demonstrates the effectiveness of both methods used in the wet-process rubberized-RAP mixtures to minimize rutting, and gives an indication that the potential to incorporate higher RAP contents into such mixtures exists. The RAP only mixtures indicated significant rut improvement with increase in RAP from 15 to 20%. FIGURE 3 compares the mean values between post-compaction consolidation and maximum rut depth after 1,000 and 10,000 cycles respectively. FIGURE 4 compares mean creep slopes between the evaluated mixtures in this study. The creep slope represents the slope of the first steady state portion in the deformation vs. number of passes graph.

A higher creep slope suggests the mix is susceptible to rutting.

Higher creep slopes in this study are consistent for mixtures with more pronounced wheel impressions. It is observed that the dense-graded terminal blend mix is the least susceptible to rutting. This is closely followed by the gap-graded field blend mixtures in the following order: H35-RFB, H115-RFB, and H7-RFB.

Analysis of Variance (ANOVA) was conducted for the maximum rut depth, post-compaction consolidation depth and creep slope for each mix. Statistical differences were found in post-compaction consolidation rut depth for H35-C, H115C and H7-RTB, but these differences were lost for the maximum rut depth of the mixtures. This explains why those mixtures behaved similarly regardless of differences in mix type, addition of crumb rubber or change in the binder grade. It is concluded that no statistical difference is observed from the ANOVA. Stripping Inflection Point (SIP) could not be determined for the evaluated mixtures at any load cycle less than 10,000. A correlation analysis was conducted, but no strong correlation was observed between any of the variables. It is concluded that the evaluated mixtures are not susceptible to moisture damage or stripping since stripping slope was not detected either graphically from the rut depth data or by visual inspection of the tested samples.

TABLE 3 RUT Test Data from HWTD

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Max. Rut Depth after 10,000 Cycles (mm)</th>
<th>Post-Compaction Consolidation after 1,000 Cycles (mm)</th>
<th>Creep Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test 1</td>
<td>Test 2</td>
<td>Test 1</td>
</tr>
<tr>
<td>H7-C</td>
<td>3.38</td>
<td>3.38</td>
<td>2.26</td>
</tr>
<tr>
<td>H7-RFB</td>
<td>2.04</td>
<td>2.39</td>
<td>1.46</td>
</tr>
<tr>
<td>H7-RTB</td>
<td>1.85</td>
<td>2.66</td>
<td>1.23</td>
</tr>
<tr>
<td>H35-C</td>
<td>2.93</td>
<td>2.98</td>
<td>1.70</td>
</tr>
<tr>
<td>H35-RFB</td>
<td>2.42</td>
<td>2.64</td>
<td>1.87</td>
</tr>
<tr>
<td>H115-C</td>
<td>2.31</td>
<td>1.90</td>
<td>1.56</td>
</tr>
<tr>
<td>H115-RFB</td>
<td>1.69</td>
<td>2.66</td>
<td>1.01</td>
</tr>
</tbody>
</table>
The resistance to rutting, stripping and moisture damage could be attributed to good aggregate skeleton bond, good compactability and the mixtures exceeding the minimum 80 percent requirement for Tensile Stress Ratio (TSR). The blended binder stiffness marginally met or exceeded the minimum 2.2KPa specification; see details below:

- 15% RAP + PG 58-28 (H7-C) = 3.86
- 20% RAP + PG 58-28 + 20% CRM (H7-RFB) = 3.21
- 20% RAP + PG 58-28 + 10% CRM (H7-RTB) = 2.82
- 20% RAP + PG 58-28 (H35-C) = 3.54
- 20% RAP + PG 58-28 + 20% CRM (H35-RFB) = 2.56
- 20% RAP + PG 64-34 (H115-C) = 2.22
- 20% RAP + PG 64-34P + 20% CRM (H115-RFB) = 2.48

This gives credibility to the observed rut behaviour since improvements in rutting resistance is primarily a function of the binder’s stiffness or rutting parameter (G*/sin δ). This observation further suggests that the amount of RAP, binder type and CRM blend method all had positive impact on the stiffness of the resulting binder blend.

The MTO specifies a 6 mm criterion for very slight rut on field pavements (28). Comparing the laboratory rut data with those obtained from some field trial sections further confirms the
effectiveness of RAP and CRM as a valuable component of typical Ontario HMA mixtures. A good correlation is evident and noticeably below MTO’s minimum rut criterion as detailed below: (29):

- H7-RTB: 20+58-28 = 1.90 mm
- H7-RFB: 20+58-28 = 2.48 mm
- H115-C: 20+64-34 = 2.49 mm
- H115-RFB: 20+64-34P = 2.04 mm

These field survey of rut depths were completed by the MTO in June 2013 using its Automated Road Analyzer (ARAN).

4.3. Mix Stiffness Characterization

The stiffness of a flexible pavement is dependent on vehicle speed and pavement temperature. A lower stiffness at low temperatures will help to minimize fatigue and low temperature cracking. To reduce rutting potential, a higher dynamic modulus at high temperatures is desirable. A comprehensive stiffness assessment of the evaluated HMA mixtures is expressed in FIGURE 5.

All recycled mixtures exhibited low stiffness at high loading frequencies (low temperatures), and were more elastic at low loading frequencies (higher temperatures). In particular, the terminal blend wet-process mix (H7-RTB) indicated the lowest stiffness at low temperature. H35-C
indicated the highest stiffness at low temperatures. It is worthy to mention that a greater impact of CRM in the mix is felt at temperatures lower than -28°C. It could easily be argued that stiffness between mixtures are comparable at the higher temperatures. However, a critical examination of FIGURE 5 shows that the rubberized-RAP mixtures with PG 58-28 are more elastic compared to the RAP HMA mixtures. The rubberized-RAP mix with PG 64-34P is observed to be more rut resistant compared to the RAP mix with PG 64-34. To verify these observations, the mix stiffness parameter (E*/Sin φ) calculated at 54°C and a loading frequency of 5Hz are detailed as follows:

- H7-C: 15% RAP = 2719.35
- H7-RFB: 20% RAP + 1% CRM = 2534.71
- H7-RTB: 20% RAP + 0.5% CRM = 3189.68
- H35-C: 20% RAP = 3050.99
- H35-RFB: 20% RAP + 1% CRM = 2277.71
- H115-C: 20% RAP = 3788.38
- H115-RFB: 20% RAP + 1% CRM = 3900.48

Note that the greater the E*/sin φ, the less susceptible the material is to rutting. The results show that H7-RTB is noted to have the highest rut resisting potential. H35-20% RAP indicated least resistance to rutting in comparison to H7-15% RAP. However, combining RAP and CRM provided a good balance between binder stiffness, mix stiffness, and durability. The results were also consistent with those from the HWTD.

5. CONCLUSIONS
This study explored the feasibility of designing and constructing conventional Ontario Superpave rubberized-RAP HMA mixtures without compromising pavement performance. In this paper the rutting resistance, thermal crack resistance and stiffness of mixtures incorporating 0.5 to 1% CRM and 20% RAP were characterized. These were compared between themselves, and with mixtures containing 15 and 20% RAP. The following specific observations are noted:

1. Stiffness characterization and low temperature crack tests results clearly demonstrated the performance potentials of the rubberized-RAP mixes over the RAP only mixes.
2. The observed trend indicated improvements in rutting with increasing RAP contents, and validates literature findings regarding improved rutting properties of gap-graded asphalt rubber mixtures compared to dense-graded conventional mixtures. However, terminal-blend wet process performed slightly better than the field-blend wet process mixtures.
3. In general, the mix stiffness characterization at high temperatures appear to be consistent with the Superpave rutting parameter of G*/sin (δ) of the recovered blended binder. However, positive differences observed with HWTD for rut characterization suggests that G*/sin (δ) did not accurately capture the contribution of the blended binder in rutting susceptibility.
4. A similar trend is observed for the low temperature continuous true grade whereas a much better performance is observed with the Thermal Stress Restrained Specimen Test (TSRST) method. This could be attributed to type of solvent used for extraction and recovery or validation of the fact that rubberized binders are not easily characterized.
The overall conclusions is that the evaluated mixtures have better resistance to thermal cracking at low temperatures and can equally resist rutting or permanent deformation at high temperatures. The research strongly suggests the usage of RAP in combination with CRM since an extraordinary resistance to low temperature cracking and rutting was observed with the addition of 10 (0.5%) to 20 (1%) CRM to HMA mixtures containing 20% RAP, and PG 58-28 and 64-34 binders. The observations further indicate that these evaluated mixtures could have better fatigue resistance properties, and could ultimately have a longer service lives. It has been almost Four (4) years since these trial sections were placed, and field monitoring results appear to be consistent with the laboratory performance evaluations.

6. RECOMMENDATIONS AND NEXT STEPS
This paper is based on preliminary studies evaluating the past, present and future use of rubberized asphalt in Ontario. The inadequacy of the Superpave G*/sin (δ) rutting parameter in predicting the rutting and thermal cracking performance of some of the evaluated mixtures have been recognized. An alternative test method capable of capturing the contributions of the asphalt binder in rutting and thermal crack resistance is recommended. The flexural fatigue properties of the mixes will be evaluated. In addition to the potential for higher RAP considerations in rubberized mixtures, it is recommended that CRM used in typical Ontario RMA mixtures be subjected to both cryogenic and ambient methods of grinding. This could be a more effective way of incorporating CRM into Ontario HMA to ensure better or comparable performance with conventional mixtures. The implication of this would be higher initial construction costs, but the many benefits associated with rubberized pavements including its elongated service life would provide a trade-off over the pavement’s lifecycle; especially in terms of maintenance or the need to carry out major rehabilitation. It is strongly recommended that the field demonstration sections be continually monitored for crack evaluation and other distress types.

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