Cracking and Rutting Performance of Asphalt Mixtures Incorporating RAP and RAS

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Abstract

The use of recycled materials in hot-mix asphalt (HMA) has been encouraged by transportation agencies across Canada and elsewhere to save construction costs, preserve natural resources and reduce impact on the natural environment. Reclaimed asphalt pavement (RAP) has now become feasible source of acceptable quality and cost-effective recycled material in pavement construction that contributes to sustainable growth by reducing the consumption of virgin aggregates and asphalt binder as well as reduction in carbon footprints by reducing fuel consumption from that required for the equivalent quantities of virgin aggregates and virgin asphalt binder production. Some agencies have also started to use the recycled asphalt shingle (RAS), at least on a trial basis, while some others started to explore the potential use. Nevertheless, highway agencies, like Manitoba, require performance evaluation of HMA mixtures containing both RAP and RAS or RAS only to allow them as acceptable materials and/or to determine the acceptable proportions for pavement construction. The objective of this study is to investigate the performance of HMA mixtures in Manitoba containing both RAP and RAS for a potential move to allow RAS in the HMA to advance sustainability in pavement construction. In the experimental phase of this project, three local asphalt mixtures including a virgin mix, a mix that contains RAP only, and a mix that contains both RAP and RAS were assessed in terms of cracking and rutting performance as well as moisture susceptibility. Cracking resistance was evaluated using the Illinois Flexibility Index Test, while rutting and moisture resistance were evaluated using the Hamburg Wheel-Tracking Test. Results showed that RAP and RAS combination improved both rutting and moisture resistance but led to a more brittle behaviour with low cracking resistance of asphalt mixtures.

Keywords:

Hot-mix asphalt (HMA), reclaimed asphalt pavement (RAP), recycled asphalt shingles (RAS), Illinois Flexibility Index Test (I-FIT), Hamburg Wheel-Tracking Test (HWTT).

1.0 Introduction

1.1 Background

Usage of recycled materials in hot-mix asphalt (HMA) can take place in several forms including reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS). The integration of RAP materials into HMA mix design and construction has become a common practice due to their environmental and economic benefits. The use of RAS is still mostly in trial and evaluation phase. In addition to reducing the quantities of asphalt waste disposal, RAP and RAS could be feasible alternatives for virgin aggregates and asphalt material which aids in decreasing overall pavement construction costs and preserve natural resources. As a result, highway agencies are drawing more attention on using RAP and RAS in HMA mixtures to accomplish sustainable pavement construction with reduced carbon footprints.

Despite being advantageous from an environmental and economic aspect, the different origins as well as properties of RAP and RAS materials make the performance of HMA mixtures a major point of concern. Variability of RAP particle sizes can create challenges in meeting volumetric mix design requirements [1]. Moreover, the increased stiffness of RAP binders due to aging can accelerate premature cracking of HMA mixtures [2]. Similarly for RAS, the very high binder content and stiffness as well as the presence of deleterious materials (such as wooden chips and roofing nails) require even a greater consideration than RAP materials [3]. Consequently, substantial use of RAP and RAS materials is still discouraged by highway agencies; thus, additional work is required to accurately evaluate the performance of HMA mixtures containing RAP and RAS.

1.2 Objectives and Scope

HMA with RAP and RAS materials can yield a promising long-term pavement performance if used properly in HMA mixtures [3]. A performance-testing program was conducted by the Department of Civil Engineering at the University of Manitoba to evaluate cracking and rutting performance of local HMA mixtures containing RAP and combination of RAP and RAS. The objective of this study is to analyze the cracking and rutting behaviour of mixtures containing RAP as well as RAP and RAS to assess the suitability of utilizing these reclaimed and recycled materials in HMA mixtures for moving towards a more sustainable and environmentally friendly pavement construction.

In this study, three local loose asphalt mixtures including a virgin mix with 100% virgin aggregates and asphalt binder, a mix containing RAP only, and a mix containing RAP and RAS were obtained from recent pavement construction projects and were compacted in the laboratory to produce test specimens for cracking and rutting evaluation. The Illinois Flexibility Index Test (I-FIT) was conducted to assess the fatigue cracking performance and the Hamburg Wheel-Tracking Test (HWTT) was conducted to assess rutting and stripping performance of the three HMA mixtures. The relationship between these cracking and rutting performance parameters and material properties of corresponding sample groups is explained in this paper. Finally, a performance space diagram is used to place the results of the three sample groups with respect to cracking and rutting test criteria. This diagram aids in comparing and tuning the performance of the tested mixes and choosing possible applications.

2.0 Materials

In this study, three loose surface asphalt mixtures obtained from two different pavement construction projects in Manitoba were investigated. The three mixtures comprised of a virgin mix, a mix containing 10% RAP, and a mix containing 10% RAP and 3% RAS. The two mixes containing RAP and RAS materials were obtained from the same project; hence, they had similar gradation as well as aggregate type and binder. The virgin mix is a coarser mix with different type of aggregate and binder. Table 1 shows the properties and aggregate gradation of the three asphalt mixtures.

Table 1. Aggregate gradation and properties of asphalt mixtures

Sieve size (mm)	Percent passing		
	Virgin mix	RAP only	RAP and RAS
25	100.0	100.0	100.0
19	100.0	100.0	100.0
12.5	93.8	92.8	92.9
9.5	80.4	79.5	79.7
4.75	52.8	61.3	61.1
2.36	39.1	50.3	48.9
1.18	27.3	42.4	38.9
0.60	18.1	33.3	28.7
0.30	10.0	18.9	16.8
0.15	4.9	7.4	8.5
0.075	3.1	4.5	5.8
NMAS (mm)	12.5	12.5	12.5
% RAP	–	10	10
% RAS	–	–	3
Type of aggregate	Granite	Gravel	Gravel
Virgin binder PG grade[1]	58-37 P	64-37 P	64-37 P
Asphalt content (%)	5.15	5.10	5.80

1. "P" indicates polymer modified binder.

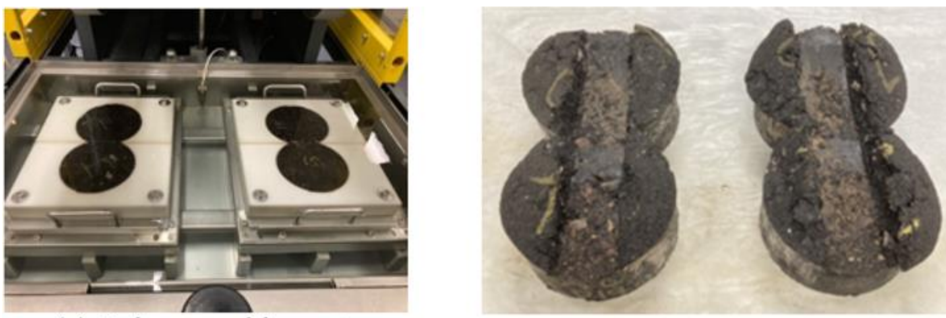
3.0 Performance Tests

3.1 Rutting Test

The Hamburg Wheel-Tracking Test (HWTT) was used to evaluate both rutting and moisture resistance of the three asphalt mixtures. It was conducted according to AASHTO T 324 procedure [4]. The HWTT equipment tracks two steel wheels, each exerting a force of approximately 703 ± 4.5 N on the underlying specimen. The wheels travel back and forth at a constant speed of 26 cycles/minute (52 passes/minute) over the specimen and rut depth at the center of each wheel pass was monitored throughout the test. The test was conducted at a temperature of 45 ± 1°C which was controlled by immersing the specimens in the HWTT water tank during the test (see Figure

1). The test temperature was selected based on experiences with HWTT equipment and local HMA mixtures in Manitoba.

To fabricate HWTT specimens, loose asphalt mixtures were compacted in a Superpave gyratory compactor to an air void range of 7 ± 0.5% to produce 150 mm height compacted asphalt briquettes. As these mixtures had already experienced short-term aging due to the plant mixing process, no short-term conditioning was conducted in the laboratory prior to gyratory compaction. Two compacted asphalt briquettes of 150 mm diameter were prepared for each mix and a disc of 62 ± 2 mm height was sawed from the top and bottom of each briquette to produce four identical discs (test specimens). Each disc was then sawed by approximately 6 mm at one edge to create a contact surface of enough width for the wheel motion of HWTT. Subsequently, each pair of discs that were sawed from the same compacted briquette were aligned together at the sawed edge and fitted in high-density polyethylene (HDPE) moulds as shown in Figure 1a. Figure 1b shows the specimens after the completion of HWTT test.



(a) Submerged in water tank before test

(b) After test

Figure 1. HWTT Specimens

The output of HWTT is a plot of the number of wheel passes versus rut depth at the center of wheel pass as shown in Figure 2. This plot is called an HWTT curve and represents several parameters that characterize rutting and moisture resistance of an HWTT specimen.

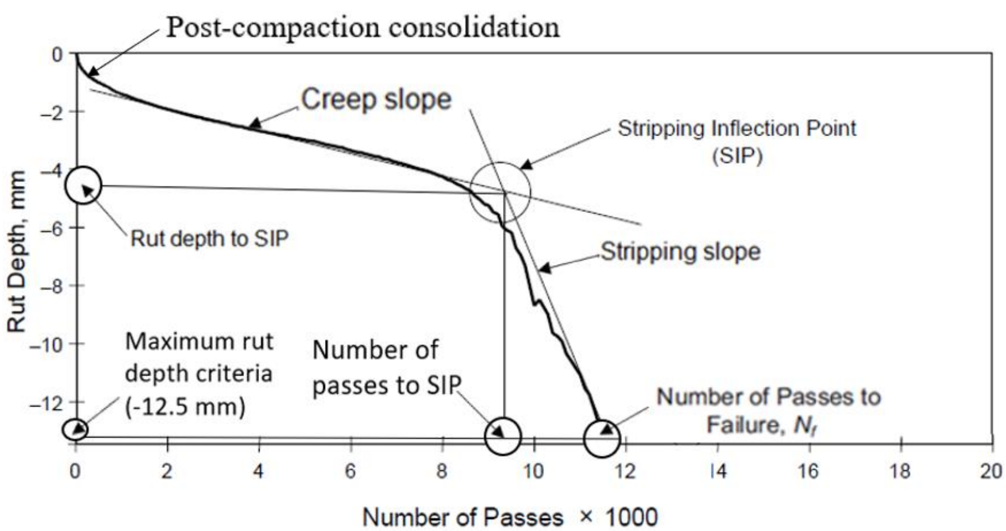


Figure 2. Typical HWTT curve and HWTT output parameters [4]

Post-compaction consolidation is the deformation that happens to the specimen in the first 1,000 wheel passes and is caused by densification of the asphalt mixture. Creep slope is the rate of deformation after post-compaction consolidation and prior to stripping. Stripping slope is the rate of deformation during stripping phase (i.e., after separation of asphalt binder from aggregates due to water). Stripping inflection point (SIP) is the number of passes at the intercept between creep and stripping slopes. The number of passes to SIP is an indication of the specimen's susceptibility to moisture. Rut depth to SIP is the deflection value in the middle of wheel pass at the intercept between creep and stripping slopes. Maximum rut depth criterion is assigned at the beginning of the test and represents the deflection value in the middle of wheel pass at the end of the test. The number of passes to failure is an indication of the specimen's rutting resistance.

3.2 Cracking Test

The I-FIT was used to evaluate fatigue cracking potential of the three asphalt mixtures at intermediate temperature. It was conducted according to AASHTO T 393 procedure [5]. I-FIT specimens were conditioned at a test temperature of 25 ± 0.5°C for 2 hrs ± 10 minutes in an environmental chamber prior to being mounted on the test apparatus. During the test, a loading head exerts a contact load of 0.1 ± 0.01 KN to the semi-circular specimen in stroke control at a loading rate of 0.05 KN/s. When a contact load of 0.1 KN is reached, the test is performed using load line displacement control at a rate of 50 mm/min. The applied load increases until a crack initiates at the notch, and then the load starts decreasing until the test stops at load values less than 0.1 KN.

To fabricate I-FIT specimens, one Superpave gyratory compacted asphalt briquette to an air void range of 7 ± 0.5% at 150 mm height was prepared for each mix. Two identical discs of 50 ± 1 mm thickness were then sawed from the middle of each briquette and each disc was split into two identical halves to create four semi-circular I-FIT replicates for one mix. Finally, a notch of 15 ± 1 mm depth and 2.25 mm width was cut using a tile-saw in the middle of the flat side of each semi-circular specimen. The purpose of the notch is to determine the point of crack initiation during the test. Figure 3 shows an I-FIT specimen mounted on the test apparatus before (Figure 3a) and after conducting (Figure 3b) the test.

(a) Before test

(b) After test

Figure 3. I-FIT Specimen

The output of I-FIT test is a load-displacement curve as shown in Figure 4, which represents several parameters that characterize cracking resistance of an I-FIT specimen.

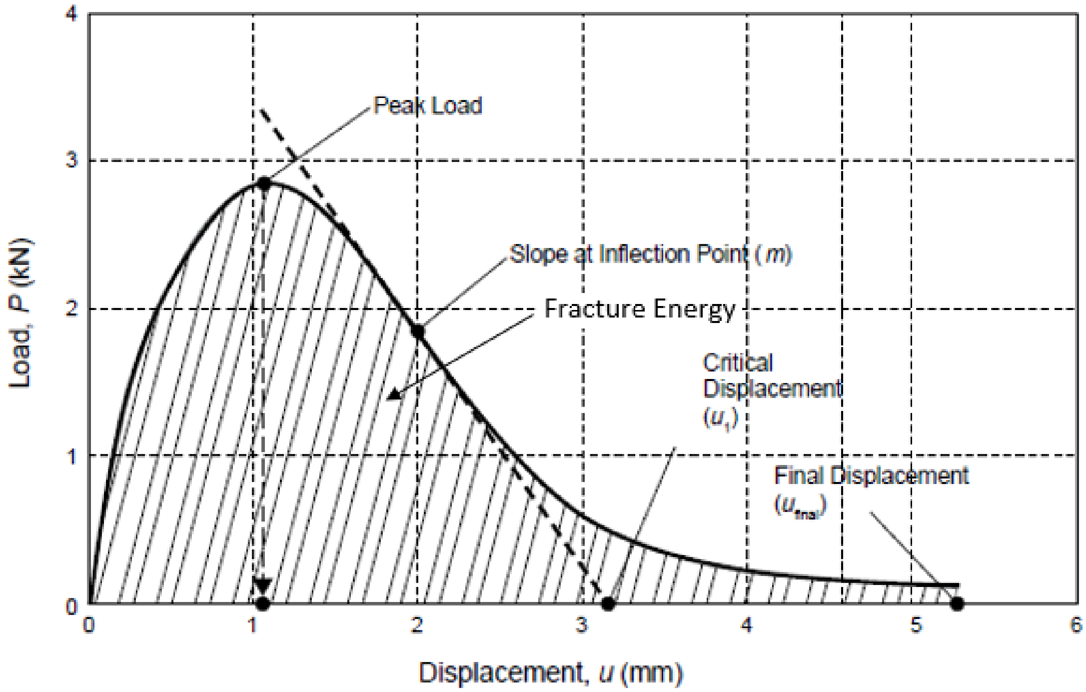


Figure 4. Typical load-displacement curve and I-FIT test output parameters [5]

Fracture energy is the total energy required to fail an I-FIT specimen completely and is represented by the area under the load-displacement curve. It is influenced by the peak load and post-peak slope. Peak load is the highest load applied to an I-FIT specimen during the test. The tensile strength can be calculated by dividing the peak load by the fracture area of an I-FIT specimen (fracture area is the area of the flat side of the specimen opposite to the curved edge). Post-peak slope is the slope of the tangential curve at the first inflection point after peak load. It is an indication of the mixture's ductility. A steeper slope represents a more brittle mixture. When the post-peak slope is extended downwards, it intercepts with the displacement axis at a point called critical displacement, which is also an indication of mixture's ductility. Fracture energy is used in conjunction with post-peak slope to determine the flexibility index. Flexibility index is calculated by dividing the fracture energy by the post-peak slope. It is the main indicator of fatigue cracking resistance, with a higher flexibility index value representing a lower cracking potential.

4.0 Results, Analysis and Discussion

4.1 Rutting Performance

Table 2 shows the values of HWTT test output parameters for the two replicate specimens of the three asphalt mixtures considered in this study. Test end criteria had been selected based on the high temperature performance grade (PG) of asphalt binder used in the mix design. For the virgin mixture with a high temperature PG grade of 58ºC, a maximum of 10,000 passes and 12.5 mm rut depth were selected to be the test end criteria. For mixtures containing RAP and RAS with a high temperature PG grade of 64ºC, a maximum of 15,000 passes and 12.5 mm rut depth were selected to be the test end criteria. Several State Departments of Transportation use the same criteria for mixtures having a similar high temperature PG grade of asphalt binder [6]. Nevertheless, no universal criteria had yet been developed for moisture resistance in HWTT equipment.

Table 2. HWTT test results of asphalt mixtures

Mix	Sample	Creep Slope (mm/pass)	Stripping Slope (mm/pass)	Number of passes to SIP	Rut depth at SIP (mm)	Number of passes to failure (12.5 mm)	Rut depth at 20,000 passes (mm)
Virgin mix	1	0.000115	-	-	-	-	4.35
	2	0.000128	-	-	-	-	4.35
RAP only	1	0.000087	-	-	-	-	3.79
	2	0.000068	-	-	-	-	3.26
RAP and RAS	1	0.000047	-	-	-	-	2.66
	2	0.000043	-	-	-	-	2.48

Table 2 shows that all three mixtures were highly resistant to permanent deformation. In addition, rutting resistance was improved with integration of RAP and RAS materials. The contribution of aged RAP and RAS binders to total binder content as well as the use of a virgin binder with higher PG grade in the mix design stiffened the mixes leading to lower rutting potential for RAP as well as RAP and RAS mixtures. Consequently, virgin mix (i.e., the mix with a softer virgin binder and no recycled materials) had the highest creep slope indicating the least resistance to rutting. Furthermore, none of these three mixtures undergo stripping during the HWTT which indicates an acceptable moisture performance of all mixtures. However, the higher creep slope of the virgin mix indicates that it can reach stripping earlier than mixtures containing RAP and RAS. Although the virgin mixture was collected from different project with different aggregate source, the results for RAP as well as RAP and RAS mixtures indicate that they can exhibit good rutting and moisture performance. Figure 5 shows the HWTT curves of the three asphalt mixtures which represent the HWTT output parameters demonstrated in Table 2.

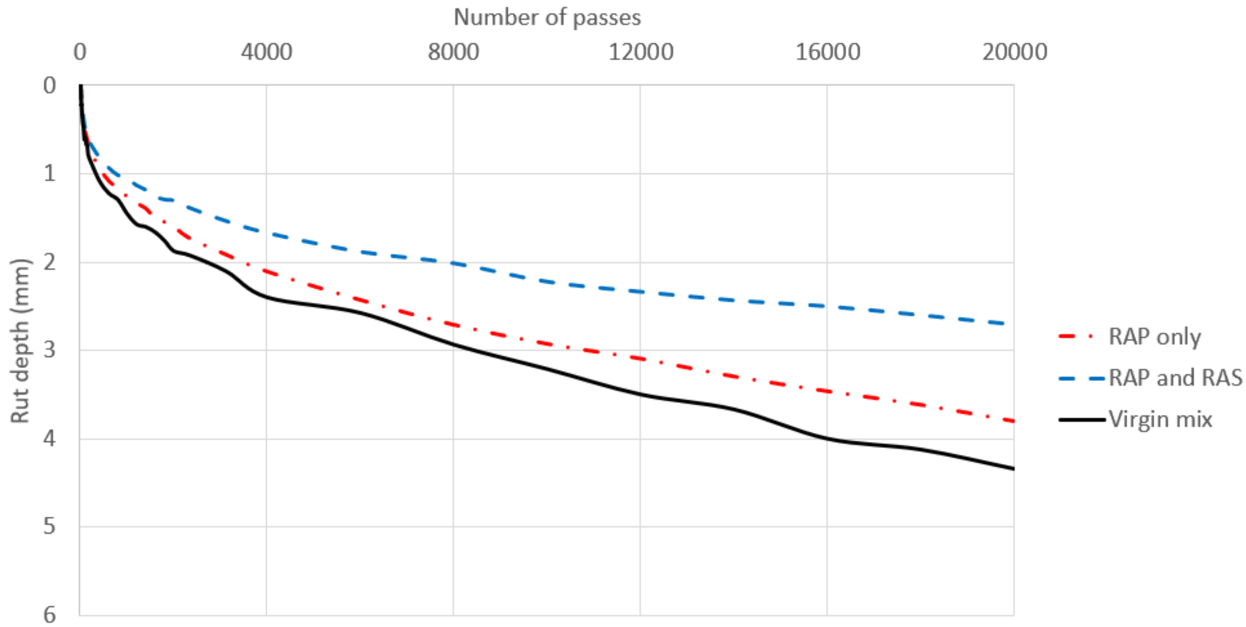


Figure 5. HWTT curves of asphalt mixtures

4.2 Cracking Performance

Table 3 shows the statistics of I-FIT test output parameters for four semi-circular replicates of the three asphalt mixtures considered in this study. Currently, there are no criteria developed for the evaluation of fatigue cracking potential using the I-FIT test. However, the Illinois Department of Transportation had specified a rudimentary flexibility index value of 8 for the assessment of cracking resistance of asphalt mixtures [6].

Table 3 shows that the RAP and RAS mixture failed to fulfill the minimum requirement of flexibility index (FI) value while the other two mixes met the FI threshold. Both low critical displacement and steep post-peak slope indicate a brittle behaviour of the RAP and RAS mixture. RAS binders are highly oxidized and very stiff, with average high temperature PG grades above 140ºC and average low temperature PG grades above 0ºC [7]. Therefore, a small proportion of RAS caused a significant reduction in the fatigue cracking performance. Table 3 also shows that virgin mix had better cracking performance than that of RAP only mix; however, they both met the minimum requirements of the I-FIT test. Low post-peak slope, peak load and tensile strength values are all indicators of a good ductile behaviour for the virgin mix. This can be attributed to the absence of recycled materials as well as the use of a softer virgin binder in the mix design and production. In a nutshell, RAP and RAS materials contribute to mitigation of cracking performance of asphalt mixtures.

Table 3. I-FIT test results of asphalt mixtures

Parameter	Statistical Property	Mix		
		Virgin mix	RAP only	RAP and RAS
Fracture Energy (J/m^2)	Average	1609.95	1889.78	1725.35
	Minimum	1469.15	1799.46	1571.79
	Maximum	1740.72	1970.14	1875.04
	Standard Deviation	115.87	69.95	125.54
	Coefficient of Variation (%)	7.20	3.70	7.28
Peak Load (KN)	Average	1.70	2.29	2.81
	Minimum	1.65	2.12	2.77
	Maximum	1.79	2.39	2.85
	Standard Deviation	0.06	0.12	0.04
	Coefficient of Variation (%)	3.71	5.09	1.38
Post-Peak Slope	Average	0.88	1.44	2.41
	Minimum	0.73	1.05	2.09
	Maximum	1.13	1.69	2.72
	Standard Deviation	0.18	0.29	0.26
	Coefficient of Variation (%)	20.17	19.77	10.67
Flexibility Index	Average	18.86	13.63	7.24
	Minimum	13.93	10.65	5.78
	Maximum	22.68	18.76	8.39
	Standard Deviation	4.34	3.59	1.12
	Coefficient of Variation (%)	22.99	26.34	15.47
Tensile Strength (Psi)	Average	34.23	45.45	55.29
	Minimum	33.33	42.98	54.64
	Maximum	35.48	47.00	56.02
	Standard Deviation	0.90	1.79	0.67
	Coefficient of Variation (%)	2.64	3.94	1.21
Critical Displacement (mm)	Average	3.96	3.50	2.70
	Minimum	3.75	3.32	2.40
	Maximum	4.17	3.87	2.89
	Standard Deviation	0.22	0.25	0.23
	Coefficient of Variation (%)	5.64	7.10	8.48

In addition to flexibility index, other parameters in Table 3 represent important properties of mixtures containing RAP and RAS. Average fracture energy values of mixtures containing RAP and RAS are higher than that of the virgin mix despite having a higher cracking potential. This suggests the significance of post-peak slope in the assessment of cracking resistance in conjunction with fracture energy since the low post-peak slope of virgin mix increased its flexibility index. Moreover, tensile strength values and peak loads are appropriate indicators of mixture stiffness since mixtures containing RAP and RAS had higher tensile strengths and peak loads than that of the virgin mix. Figure 6 shows the load-displacement curves of the three asphalt mixtures which represent the I-FIT test output parameters demonstrated in Table 3.

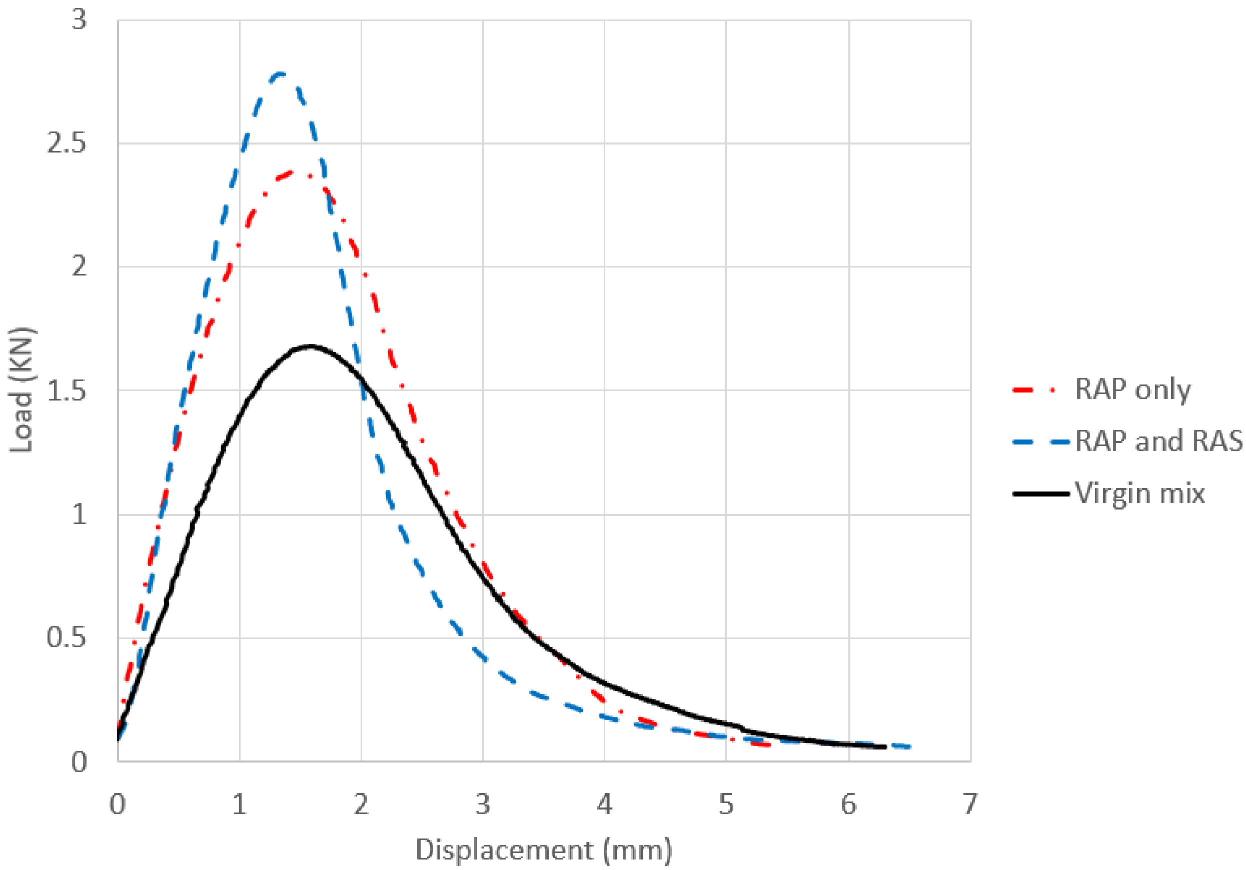


Figure 6. Load-displacement curves of asphalt mixtures

5.0 Performance Space Diagram

Figure 7 shows a performance space diagram (PSD) that displays the locations of rutting and fatigue cracking performance test results of the three asphalt mixture groups based on average rut depth at 20,000 passes and range of flexibility index values (minimum, average and maximum). The range of rut depth values of mixture groups was not considered in the PSD because rutting results were all located in one quadrant, unlike the range of flexibility index values which combined between two quadrants for the RAP and RAS mixture group. The four quadrants of a PSD are used to determine if asphalt mixtures meet the desired performance criteria as well as to decide possible applications for the tested mixtures based on their location within the quadrant [6].

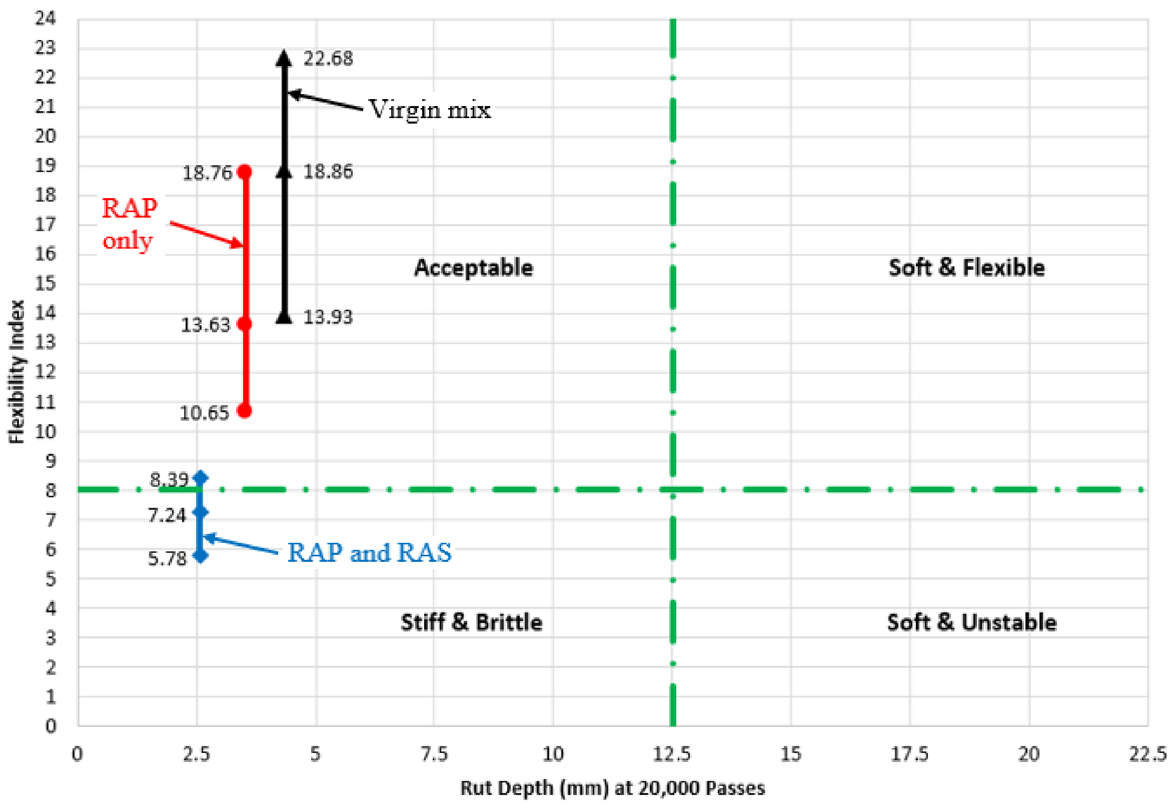


Figure 7. Performance space diagram of asphalt mixtures

Figure 7 shows that virgin mix and RAP only mix displayed the best performance by being located entirely in the stiff and flexible quadrant indicating a high fatigue cracking and rutting resistance. This means that these two mixtures can be used reliably on heavy traffic roads such as freeways and urban arterials. On the other hand, RAP and RAS mix was predominantly located in the stiff and brittle quadrant indicating a high rutting resistance, but low cracking resistance. Thus, it can be a good candidate for the bottom layer of a full-depth pavement (i.e., non-surface mix). Overall, the PSD had proved that mixtures containing recycled materials can demonstrate better results in at least one performance test, while RAP mixtures can provide acceptable cracking and rutting performance like virgin mixes.

6.0 Conclusions and Recommendations

Three loose asphalt mixtures including a virgin mix, a mix containing RAP only, and a mix containing RAP and RAS were collected from two different roadway construction projects in Manitoba. All mixtures were compacted in the laboratory to produce specimens according to fatigue cracking and rutting performance test standards. Cracking performance was determined using the I-FIT test and rutting performance was determined using the HWTT test. Results showed that the addition of RAP and/or RAS increases cracking potential; however, they improve resistance to permanent deformation or rutting.

This research once again proved that the inclusion of RAP and RAS materials can show improvements in at least one parameter of asphalt mixture performance testing. This will allow transportation agencies in Manitoba to optimize the use of RAP and RAS for producing an acceptable asphalt mixture that balances the cost, pavement performance, and environmental impact. Nevertheless, additional testing of asphalt mixtures with higher proportions of RAP needs to be completed to better understand the behaviour of these mixtures as well as their practicality in roadway construction. Furthermore, there is a need for testing a wider range of mixtures to modify cracking and rutting tests acceptance limits according to local environmental conditions and traffic loading levels in Manitoba. The thermal cracking potential of RAP/RAS mixture, issues with testing and characterizing RAS including the extracted binders, issues with variability and suitability of RAS sources, and issues with quality control and quality assurance of mixtures containing RAS will require extensive investigation and assessment. These will allow transportation agencies to better rank asphalt mixtures in terms of all the requirements.

7.0 References

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