Laboratory Testing of Vancouver HMA Mixes Containing Recycled Asphalt Shingles

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Paper prepared for presentation at the

Development of New Technologies for Classification of Materials Session

of the 2010 Annual Conference
of the Transportation Association of Canada
Halifax, Nova Scotia

ABSTRACT

Recycled asphalt shingles (RAS) contain asphalt cement and high quality aggregate that may be a useful supplement to natural, virgin aggregates and asphalt cements. RAS originating from recycled construction material can be crushed and added to asphalt mixes, similar to reclaimed asphalt pavement (RAP). Scraps from asphalt shingles production that are commonly considered as waste material have been used in pavements in Ontario for more than 10 years as an alternative to sending them to landfills. Metro Vancouver is focusing primarily on post-consumer waste shingles, meaning those that have already provided a service life as a roofing material. Metro Vancouver retained Golder Associates to carry out a study on using RAS as an additive in asphalt mixes through sustainability development impacts, environmental impacts, and technical performance. The technical phase of this study focuses on performance evaluation of hot-mix asphalt (HMA) mixes containing RAS.

There were six mix types included in the study: a conventional binder course mix from British Columbia used here as a control mix; a mix with 15.0 percent RAP; and mixes with a rejuvenator and with 3.0 and 5.0 percent RAS, and 15.0 percent RAP and 3.0 and 5.0 percent RAS. The asphalt mix performance testing includes: dynamic modulus; resilient modulus; resistance to rutting in the Asphalt Pavement Analyzer (APA); fatigue endurance in a four point bending beam test; and low temperature cracking susceptibility in the Temperature Stress Restrained Specimen Test (TSRST).

This paper presents the results of the first three tests and includes an analysis and discussion related to the behavior of the mixes. Besides the obvious effect of mix hardening when RAS and/or RAP are added, it also looks at the impact of the addition of a rejuvenator. Based on the results of the laboratory testing, field trials will be carried out. The main objective of the study is to determine what the maximum acceptable amount of RAS and RAS/RAP combination is that will not have negative impact on the performance of asphalt pavements. It will then form the base for the development of paving specifications for asphalt with RAS additives.

1.0 INTRODUCTION

Metro Vancouver is responsible for establishing a framework to manage municipal solid waste for over 2 million residents in the Lower Mainland of British Columbia. As part of the Zero Waste Challenge, Metro Vancouver is evaluating alternatives to divert solid waste from landfills.

The demolition and construction industry landfills more than 400,000 tonnes of demolition and construction waste annually. Approximately 80,000 tonnes per year (20 percent) of that waste stream consists of end-of-life asphalt roofing shingles from re-roofing of single family and multi-family homes.

Asphalt shingles are commonly used on homes in Canada and it is estimated that 80 percent of residential roofs are covered in asphalt shingles. These shingles consist of high quality fine aggregate, asphalt cement and fibre [1]. Current practice for replacing roofs includes sending the used asphalt shingles to the landfill which is a burden on the environment and also a loss of valuable material. It has been recognized that RAS can be used as a supplemental source of fine aggregate and asphalt cement in HMA which is beneficial to the environment and the paving industry.

Newcomb et al [2] evaluated the behavior of dense-graded and Stone Mastic Asphalt (SMA) containing asphalt roofing shingles. Mixes containing 5.0 percent and 7.5 percent RAS were evaluated and two different penetration grade asphalt cements were used in the mixes. The resilient modulus values for all the mixes containing 5.0 percent RAS showed similar trends, regardless of the type of asphalt cement that was used. The mixes containing 5.0 percent RAS consistently exhibited lower indirect tensile strengths when compared to the virgin mixes. The mixes containing 7.5 percent RAS generally had lower or equivalent indirect tensile strengths than the mix with 5.0 percent RAS; however, at colder test temperatures they showed higher strengths. The results of this work indicate that when higher quantities of RAS are incorporated in hot mix asphalt it can result in stiffer mixes which may show brittle characteristics during loading at low temperatures.

Grzybowski [3] compared the rut susceptibility of mixes containing RAS with conventional mixes in accelerated laboratory testing. The testing was carried out using a Georgia DOT Loaded Wheel Tester. After 8000 cycles the mix containing 10 percent RAS showed less rutting than the conventional mix. The rut depth of the RAS modified mix was lower by about 3.0 mm, a very significant improvement in rutting resistance. However, it was pointed out that harder mixes may exhibit greater potential for thermal and fatigue cracking.

The work by Grzybowski and Newcomb et al indicate that the potential use of RAS in hot mix asphalt has been known for some time. An extensive study on using shingle waste from production called Manufactured Shingle Modifier (MSM) in HMA was carried out in Canada [4]. A detailed laboratory study was conducted at the University of Waterloo in 2007/2008 regarding the incorporation of RAS into HMA mixes in Ontario [5]; the study is continued with more mixes being evaluated. The depletion of aggregate resources, high prices of new asphalt cement, awareness of the deterioration of the environment and emphasis on the importance of pavement sustainability have brought the use of shingles to the attention of the pavement industry once again.

2.0 PROJECT OBJECTIVES

The intent of this research was to evaluate the feasibility of adding RAS to asphalt mixes used in Metro Vancouver without compromising pavement performance. In order to evaluate the impact of RAS addition several mix types were prepared including a control mix incorporating only virgin materials and mixes with various quantities of RAS and RAP. For comparison purposes, all mixes were included in the same testing program. The program includes testing of the main mechanistic characteristics of asphalt mixes: dynamic modulus; resilient modulus, rutting resistance; fatigue endurance; and susceptibility to low temperature cracking.

An understanding of the impact of RAS on HMA characteristics and performance should allow pavement engineers in Metro Vancouver to incorporate the optimum amount of RAS in HMA mixes.

3.0 HMA MIXES

The mix types used in the study are summarized in Table 1.

Table 1 Mix Types

Mix	Virgin Aggregate (%)	RAP (%)	RAS (%)	Rejuvenator* (%)
1	100.0	0.0	0.0	0.0
2	85.0	15.0	0.0	0.3
2B	85.0	15.0	0.0	0.0
3	97.0	0.0	3.0	0.3
4	95.0	0.0	5.0	0.3
5	82.0	15.0	3.0	0.3
6	80.0	15.0	5.0	0.3

*Rejuvenator was added at a rate of 0.3 percent of asphalt cement.

Mixes 1 and 2B are binder course mixes used throughout Metro Vancouver for arterial roads. All RAS material used in the mixes was post-consumer waste material, having been on local roofs for a number of years. The recycled shingles were ground to a size of about 6-7 mm chips. The quantity of RAS material included in the mixes was determined by weight of the mix. The rejuvenator used in this study has recently been used in British Columbia as an additive in hot-in-place recycling mixes that contained up to 20.0 percent RAP and 5.0 percent RAS.

4.0 TESTING

The testing has not been completed yet. This paper describes the results of the following testing: dynamic modulus; resilient modulus; rutting resistance in the Asphalt Pavement Analyzer (APA).

4.1 Asphalt Pavement Analyzer

APA testing is used to evaluate the rutting resistance of a mix by running a loaded wheel across the sample on an inflated rubber hose. The samples were tested in accordance with AASHTO TP 63-09, “Standard Method of Test for Determining Rutting Susceptibility of Asphalt Paving Mixtures Using the Asphalt Pavement Analyzer (APA)” [6]. The samples were conditioned and tested in air at 58°C which is representative of the climate in the Vancouver area. The hose was inflated to 750 kPa and the wheel applied a load of 100kN to the sample. The wheel ran for 8,000 cycles, with one cycle including two passes over the sample. The average speed of lading in the APA is about 0.6 m/s which is about 2.2 km/hour. It can be assumed that the frequency of loading is about 0.5 Hz.

In this project, three samples of each mix were tested; each sample consisted of two Superpave Gyratory prepared cylinders. The cylinders were 150 mm in diameter and 75 mm in height.
As the test was being run, measurements of the rut depth were taken across the sample, one per cycle. Figure 1 shows an APA loaded for testing of two samples. The concaved steel wheels run along the black rubber hoses. The wheel repeatedly passes across the same area of the samples resulting in rut formation. The rut depth is recorded for each sample rather than for each separate specimen. Figure 2 shows two of the specimens that have been tested in the APA.

Figure 1 APA testing configuration

Figure 2 Specimens after APA testing

4.2 Dynamic Modulus Testing

Dynamic modulus testing evaluates the modulus of the mix under various temperature and traffic loading conditions. The testing was carried out in accordance with AASHTO TP 62-07, “Determining Dynamic Modulus of Hot Mix Asphalt (HMA)” [7]. Samples were tested at six frequencies and five temperatures. The samples were set to a particular temperature and then tested at each frequency. The following testing frequencies were used: 25 Hz; 10 Hz; 5 Hz; 1 Hz; 0.5 Hz; and 0.1 Hz. The higher frequencies represent the impact of fast moving traffic and the lowest frequency portraying slow or near static traffic. The samples were tested at: -10°C; 4°C; 21°C; 37°C; and 54°C. In each test, the samples were loaded at all six frequencies in succession from high to low. The samples were loaded with a sinusoidal cycle and the amplitude of the load varied depending on the temperature of the sample but was constant at the various frequencies within each temperature. The samples were conditioned to the test temperature and held at the particular temperature during testing by use of an environmental chamber. The dynamic modulus value of a specimen at a particular temperature and frequency was calculated as a function of the stress and strain experienced by the sample. As the asphalt cement is considered to be a visco-elastic material, the samples in general showed more strain and therefore lower modulus at lower frequencies, where the stress was applied to the samples for a longer time period, than during high frequency loading.

Superpave gyratory cylinders were initially prepared and then cored for testing. Three specimens were tested for each mix, all 100mm in diameter and 150mm in height. Figure 3 shows a sample being tested for dynamic modulus within an environmental chamber.

Figure 3 Dynamic modulus testing in an environmental chamber

4.3 Resilient Modulus Testing

Resilient modulus testing was carried out in accordance with ASTM D 7369-09, “Standard Test Method for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension Test” [8]. Superpave gyratory samples were used in the testing. Sample loading was based on the results of indirect tensile testing which was carried out in accordance with ASTM D 6931-07, “Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures” [9]. The IDT strength of Mix 1, the control mix, was used for resilient modulus testing of all mixes for consistency. Figure 4 shows a photo IDT of testing.

Resilient modulus testing involves samples being loaded repeatedly in compression along the vertical diametral plane. The vertical movement was recorded using linear variable displacement transducers while extensometers recorded the horizontal movement of the sample. Each sample was tested twice, with the sample being rotated 90° between tests.

For the purpose of this project one sample was tested per mix. The samples were 150mm in diameter and 50mm in thickness. The testing was carried out at an ambient temperature of about 21°C. Figure 5 shows resilient modulus testing.

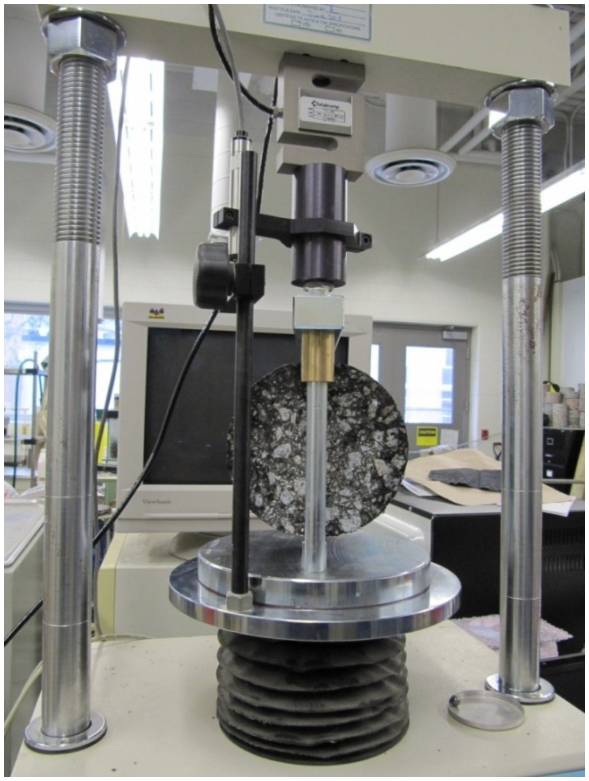

Figure 4   Indirect tensile strength testing

Figure 5   Resilient modulus testing

5.0 TEST RESULTS AND ANALYSIS

The same testing program was carried out on each mix. The results of all testing to date is outlined in the following section. The testing of the mixes will continue and will include flexural fatigue beam and TSRST testing. The results of all five types of performance testing should illustrate the changes that occur to hot-mix asphalt characteristics when various quantities of RAS are incorporated in the mix.

Table 2 shows a summary of the APA results for all six mixes. Figure 6 shows the average deformation rate of each mix. The results of the APA testing indicate that Mixes 1, 2B, 4 and 6 all have almost the same rutting resistance. It was anticipated that Mixes 1 and 2B would perform similarly as they are consistently used throughout Metro Vancouver. Mix 4 contains 5.0 percent RAS and rejuvenator indicating that this combination offsets the stiffness induced by the inclusion of RAS without causing the mix to become soft. Mix 3 contains 3.0 percent RAS and the same amount of rejuvenator as Mix 4 and the rutting results of Mix 3 show a softer mix with a final deformation of 6.0mm. Mixes 5 and 2 demonstrate the substantial effect that rejuvenator has on mixes containing RAP. In the case of Mix 2 the stability was sacrificed and the result was the largest deformation of all the mixes. Mix 5 also had a large deformation. The APA results of Mix 6 indicate that with enough RAS content, RAP can be used in a mix including rejuvenator and the result is performance similar to conventional virgin and RAP mixes. The deformation of Mix 6 was the least, being slightly less than the two conventional mixes.

Table 2 Summary of APA Testing Results

Number of Cycles	Average Permanent Deformation in APA (mm)						
	Mix 1	Mix 2	Mix 2B	Mix 3	Mix 4	Mix 5	Mix 6
8,000	5.1	7.9	5.1	6.0	5.1	7.4	5.0

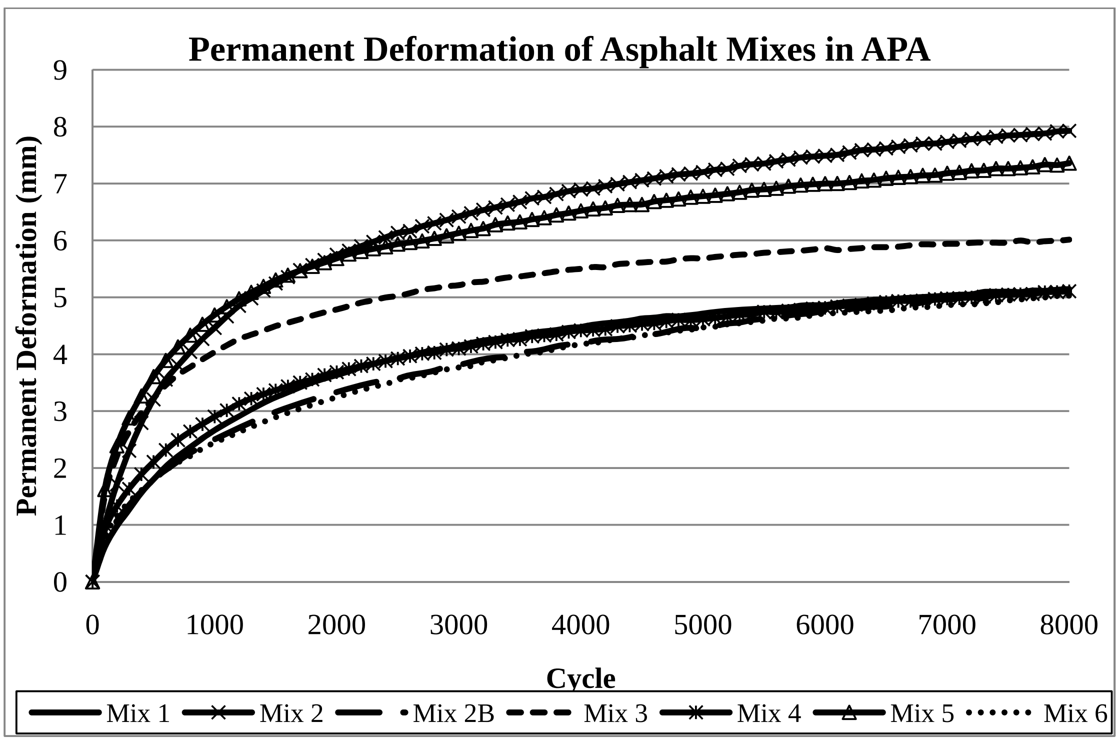

Figure 6 Average permanent deformation in the APA

Table 3 shows the average dynamic modulus of each mix at each temperature and frequency. Figure 7 shows the dynamic modulus master curves for all the mixes. The dynamic modulus values in temperatures 21°C, 37°C and 54°C were of particular interest in the analysis. Mixes 1, 2B and 6 generally exhibited the highest dynamic modulus values. Mixes 2, 3 and 5 exhibited the lowest modulus values and Mix 4 was in the middle. Mixes 1 and 2B were conventional mixes without rejuvenator. When the rejuvenator was added to the mixes (Mixes 2, 3 and 5), their stiffness significantly dropped. However, when as much as 5 percent of RAS was added (Mixes 4 and 6) the mix stiffness increased again, relatively close to the original value.

Table 3 Dynamic Modulus Testing Results

Mix	Frequency (Hz)	Temperature (°C)				
		-10	4	21	37	54
Mix 1	25.0	23,982,500	16,573,500	5,348,400	2,383,750	934,610
	10.0	23,079,000	15,947,000	6,062,600	2,283,800	744,665
	5.0	22,592,000	15,376,500	6,038,900	2,072,350	642,165
	1.0	20,398,500	12,796,500	4,436,400	1,460,050	464,555
	0.5	19,590,000	11,881,000	4,024,450	1,319,300	416,885
	0.1	17,444,500	9,731,700	3,165,100	1,040,250	348,910
Mix 2	25.0	22,435,000	14,162,500	5,018,700	1,839,900	555,710
	10.0	21,358,500	12,783,000	4,441,300	1,455,550	442,545
	5.0	20,128,000	11,501,000	3,843,650	1,262,400	391,095
	1.0	16,773,500	8,686,650	2,607,400	961,815	319,020
	0.5	15,226,000	7,584,950	2,324,800	873,895	300,585
	0.1	12,493,500	5,663,050	1,801,950	747,700	269,640
Mix 2B	25.0	19,834,000	12,492,000	8,940,600	3,668,400	1,135,600
	10.0	19,253,000	11,422,000	7,659,000	2,963,800	834,980
	5.0	18,353,000	10,598,000	6,730,800	2,396,800	688,430
	1.0	16,194,000	8,548,400	4,719,900	1,634,000	495,870
	0.5	15,207,000	7,705,400	4,099,200	1,355,700	451,570
	0.1	13,074,000	6,219,000	2,984,400	1,027,800	376,200
Mix 3	25.0	15,611,000	10,048,600	4,414,567	1,796,567	559,017
	10.0	15,384,333	9,641,700	4,061,767	1,538,200	451,563
	5.0	14,782,000	9,031,067	3,643,967	1,328,967	395,363
	1.0	12,715,000	6,829,267	2,513,000	983,057	312,707
	0.5	11,957,667	6,236,833	2,289,633	899,973	292,560
	0.1	10,092,467	4,964,033	1,818,233	757,963	262,307
Mix 4	25.0	21,045,500	11,558,000	5,170,700	1,982,250	616,770
	10.0	20,255,500	10,654,500	4,774,400	1,717,400	515,495
	5.0	19,057,500	9,813,650	4,240,350	1,480,700	452,740
	1.0	16,365,500	7,599,950	2,870,600	1,079,750	342,605
	0.5	15,278,000	7,132,100	2,625,500	969,720	318,975
	0.1	13,053,500	5,254,650	2,057,050	791,825	275,155
Mix 5	25.0	15,079,667	10,795,167	4,615,400	1,829,100	589,463
	10.0	14,838,667	9,768,233	3,937,200	1,470,900	467,360
	5.0	14,170,667	9,019,067	3,447,300	1,270,033	399,977
	1.0	12,104,333	6,646,900	2,336,167	950,363	308,127
	0.5	11,558,667	5,940,000	2,143,967	862,460	290,163
	0.1	9,977,967	4,617,167	1,669,400	715,833	251,130
Mix 6	25.0	14,013,000	11,345,000	6,975,300	1,441,500	726,210
	10.0	13,735,000	10,285,000	6,096,700	1,322,000	571,770
	5.0	13,009,000	9,508,300	5,363,600	790,990	482,710
	1.0	10,931,000	7,399,200	3,798,400	469,860	358,440
	0.5	10,007,000	6,735,000	3,471,000	309,970	326,270
	0.1	8,312,900	5,341,300	2,608,900	860,200	268,080

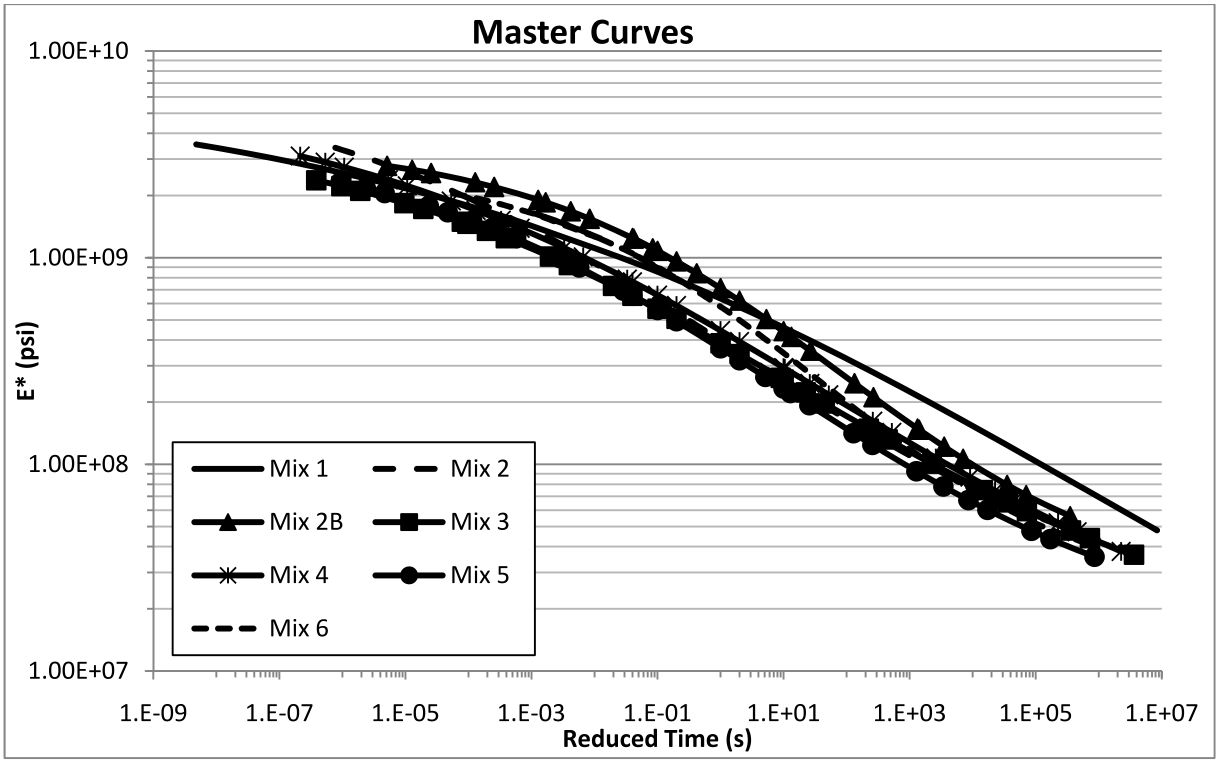

Figure 7 Dynamic modulus master curves of all tested mixes

Table 4 shows the resilient modulus results and the peak indirect tensile strength for each mix. Figure 8 shows a graph of the average resilient modulus for each of the mixes. The resilient modulus values of Mixes 1, 2B and 6 were the highest, higher than 3,000 MPa, while the resilient modulus values of Mixes 2, 3 and 5 were the lowest, about 2,000 MPa or lower. Mix 4 had the resilient modulus value in the middle, about 2,500 MPa. It should be noted that Mixes 1, 2B, 4 and 6 exhibited better resistance to rutting in the APA than the other mixes.

Table 4 Summary of the Indirect Tensile Strength and Resilient Modulus Results

Mix	Sample	Indirect Tensile Strength (kN)	Measured Resilient Modulus (MPa)	Average Resilient Modulus (MPa)
Mix 1	1-7A	18.4	3,827	3,642
	1-7B		3,457	
Mix 2	2-20A	10.1	2,091	2,044
	2-20B		1,997	
Mix 2B	2B-7A	15.2	3,187	3,123
	2B-7B		3,059	
Mix 3	3-27A	7.7	1,989	1,904
	3-27B		1,819	
Mix 4	4-37A	12.0	2,640	2,474
	4-37B		2,307	
Mix 5	5-47A	9.9	1,861	1,776
	5-47B		1,690	
Mix 6	6-3A	15.7	3,208	3,286
	6-3B		3,364	

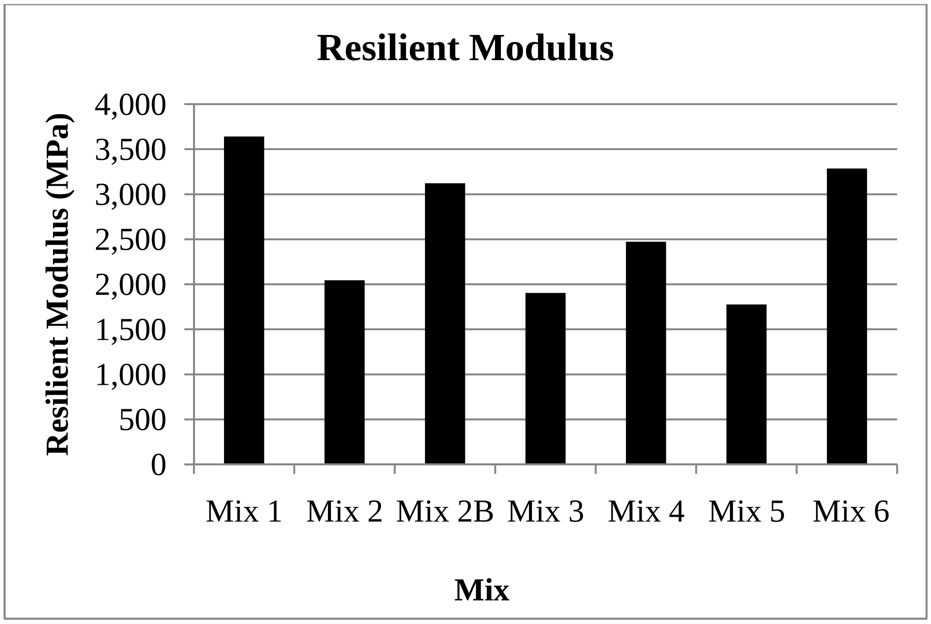

Figure 8 Average resilient modulus of all tested mixes

6.0 SUMMARY

The results presented in this paper focus on rutting resistance and strength properties of the seven mixes containing various quantities of RAS and RAP. Future testing will further evaluate the impact this additive will have on the fatigue endurance and the low temperature cracking susceptibility of HMA mixes.

In summary the testing to date has shown that the conventional mixes (Mixes 1 and 2B) exhibited the best rutting resistance and the highest values of dynamic and resilient modulus. The mixes with 0.3 percent rejuvenator, 0 percent RAS and with or without RAP (Mixes 4 and 6) exhibited similar performance to the conventional mixes. The mixes with 0.3 percent rejuvenator, 3.0 percent RAS, and with or without 15 percent of RAP exhibited larger rutting depth in the APA and lower modulus values.

It was observed that when the rejuvenator was added to the mixes, their rutting resistance and stiffness significantly dropped. However, when as much as 5.0 percent of RAS was then added to the mixes, their rutting resistance and mix stiffness improved again, with the values relatively close to those of the conventional mixes.

In conclusion the testing to date indicates that asphalt mixes containing RAS can perform adequately and results show trends similar to that of common mixes in Metro Vancouver. The addition of rejuvenator in mixes containing less than 5.0 percent RAS appears to decrease the quality of the mix by softening and reducing strength of the mix. Adequate performance in this project indicates results that are at least similar to those of the currently used mixes; 1 and 2B.

The benefits of using RAS in asphalt mixes include the reduction of waste in landfills, which in turn results in societal and environmental benefits. In addition, RAS replaces what would have been virgin material and therefore reduces the demand on natural resources. Finally using relatively low cost RAS as a source of expensive asphalt cement and high quality aggregate is cost beneficial to owners.

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