WHO THOUGHT RECYCLED ASPHALT SHINGLES (RAS) NEEDED TO BE LANDFILLED: WHY NOT BUILD A ROAD?

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ABSTRACT

The University of Waterloo's Centre for Pavement and Transportation Technology, CPATT, is committed to working with public and private sector partners to develop sustainable technologies. Recycled Asphalt Shingles (RAS) is a product that contains approximately 30% asphalt cement by mass weight. Sources of RAS include trimmings from shingle insulation and decommissioned shingle roofs. Reuse of these materials leads to financial savings through avoidance of disposal costs and reduction of the amount of virgin asphalt binder required in HMA. This paper presents results from a recent study involving Miller Paving Limited, CPATT, and Materials Manufacturing Ontario (MMO). In addition École de Technologie Superieure (ETS) in Montreal was involved in the project as a subcontractor to CPATT, carrying out some of the sample testing (1).

In order to measure the performance of mixes which incorporate RAS a laboratory study was performed in the John J. Carrick Pavement Laboratory at the University of Waterloo and ETS. Five asphalt pavement mix designs were considered:

1. Mix 1 (control) -HL8, Virgin Material
2. Mix 2 -HL8, 20% RAP Material
3. Mix 3 -HL8, 20% RAP Material, 1.4% Shingles
4. Mix 4 -HL8, 20% RAP Material, 3.0% Shingles
5. Mix 5 -HL8, 3.0% Shingles

To compare the various mix designs the dynamic modulus test, resilient modulus test, Thermal Stress Restrained Specimen Tensile Strength Test (TSRST), and French wheel rutting test were run for all five mix designs. The dynamic modulus test was used to measure the elastic properties of the mixtures, an indicator of how a mix will perform over a range of loading and temperature scenarios. The resilient modulus test provides an indication of the fatigue and thermal cracking potential as well as the quality of materials employed in the asphalt mixture. The TSRST assesses the thermal cracking resistance of a mix design while the French wheel rutting test estimates the rutting susceptibility of a mix. Overall the results are very encouraging and have also involved several field placements. Initial analysis of these field placements will also be presented (1)

INTRODUCTION

The Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo represents a partnership for innovation. It was created in 2002, and is directed at focusing on a state-of-the-art research infrastructure for tackling specific problems, developing new technologies, training and increasing the talent pool of skilled people, carrying out technology transfer and establishing sustained partnerships. CPATT in cooperation with Miller Paving Limited and Ontario Centre of Excellence Materials Manufacturing Ontario (OCEMMO) as well as subcontractor École de Technologie Superieure (ETS) in Montreal undertook an investigation of the use of recycled asphalt shingles (RAS) in a HL8 base course mix.

Five asphalt pavement mix designs were considered, incorporating varying quantities of Recycled Asphalt Pavement (RAP) and shingles. Mix designs were compared using the results of the dynamic modulus test and resilient modulus test run in the CPATT laboratory and the Thermal Stress Restrained Specimen Tensile Strength Test (TSRST) and French wheel rutting test run at ETS (1).

2.0 Background

Pavement design procedures that result in a higher resistance to deformation, longer service lives, and satisfactory surface characteristics are needed to satisfy the increased demand in road usage. The expected performance and service life of pavements are decreased by distresses such as rutting, fatigue, and low temperature cracking, distresses caused by increased axle loads, traffic volume, environmental conditions, and construction and design errors.

The modification of hot-mix asphalt (HMA), in which recycled asphalt shingles (RAS) is added, is one of the techniques that have been developed to cope with these types of failures. Incorporating RAS in HMA has the potential to improve the performance and service life of pavements. As well, utilizing RAS in asphalt pavements decreases the volume of asphalt shingles being disposed of in landfill sites and decreases the amount of virgin asphalt cement required to produce asphalt pavements.

Thus, there is a need to examine the long term performance of mixes incorporating RAS under various environmental and traffic conditions, paying close attention fatigue, rutting, and low temperature cracking.

3.0 Recycled Asphalt Shingles (RAS)

Shingles are primarily composed of asphalt cement, hard rock granules and fillers, and fibres. Since poly-fibre shingles contain approximately 30% asphalt cement (by mass), using RAS in HMA decreases the amount of virgin asphalt cement required, thus decreasing input costs to produce HMA. Studies have also found an improvement in HMA properties when small amounts of RAS, such as 5%, are incorporated, however this improvement is dependent upon the source of the shingles. (2). However, it should be further noted that shingles manufactured with cellulose fibres contain approximately 30% asphalt cement with 15 – 20 years in-service.

Generally, asphalt roofs require replacement or recovering after 12 to 20 years. Each year, the roofing replacement of residential and commercial buildings in the United States generates 8 to 10 million tons of old roofing waste. Historically, shingles have made up nearly 3% of municipal solid waste with only 5% of this valuable solid waste not ending up in landfills. (3,4)

3.1 Benefits of RAS in HMA

Many benefits for the use of shingles in HMA exist including financial savings, environmental preservation, and improved end results. Recycling HMA avoids the expense associated with disposal of shingle waste in landfill sites and reduces the amount of waste entering landfill sites, benefiting the environment. The amount of virgin asphalt cement required in HMA mixes is also reduced by incorporating RAS, creating a cost savings. Studies have also found increased resistance to low temperature cracking and high temperature rutting in HMA which contain factory waste RAS. (2)

3.2 RAS Studies and Trials

Incorporating roofing shingle scrap in HMA test sections began in Minnesota in 1990. Interest continued in Canada and the United States with studies and trials in many states as well as the province of Ontario. Throughout these trials, RAS addition rates have varied from 3 to 10% (by mass). (5) The results of these studies have lead Departments of Transportation (DOT) in various states to set specifications limiting the amount and type of shingles to be included in asphalt pavements. Many of these specifications specify that pavements can be comprised of no more than 5% shingles and that these shingles may only come from manufacturing scrap. In Ontario, the City of Brampton allows 3% shingles in asphalt concrete, however allows both old and new roofing shingles to be incorporated. (6)

In a New Jersey study very little difference was found between conventional HMA pavements and a ground shingle HMA pavement after a number of years in service when compared in terms of rut depth, cracking, and skid resistance. (5) In a Texas DOT study it was found that as much as 5% roofing waste could be incorporating in typical HMA surface mixes and as much as 10% in base mixes while still complying with Texas DOT specifications. In addition, it was found that prior mixing, roofing waste must be shredded to facilitate proper incorporation. As well compaction temperatures must be raised to accommodate the stiffness of the roofing material. (3)

3.3 RAS Engineering Properties

Roofing shingle properties of importance when developing HMA designs include asphalt cement content, asphalt hardness, and gradation. The asphalt cement content of shingles is approximately 30% for the cellulose fibres, however this number may vary necessitating the determination of shingle asphalt content as shingle asphalt content dictates how much virgin asphalt cement is required. The asphalt hardness (viscosity/penetration) of shingles is typically much higher than asphalt cement used in pavements. As a result, it is necessary to use a much softer virgin asphalt cement binder to account for the difference. Due to the gradation of shingle particles, minus 4.75 mm, RAS act as a supplement for fine aggregates in HMA. (5)

3.4 RAS Construction Consideration

In order to properly accommodate the incorporation of RAS in HMA it is necessary to modify construction procedure, including material handling and storage as well as mixing, placing, and compacting. The largest construction concern created by including RAS is agglomeration of processed shingles. Agglomerated shingles result in poor shingle dispersion in the mix and can be avoided by either shredding shingles immediately prior to mixing; or combining RAS with fine aggregate; or blending with RAP (where permissible) if the RAS will not be used immediately. All other aspects of pavement construction remain unchanged. (5)

3.5 Other Issues

Beyond performance, recycling options for pavement that include RAS need to be examined. The necessity to screen shingles for foreign materials (nails, organics, flashing, and felt underlay) and asbestos, a formerly acceptable shingle ingredient, as well as other ingredients that have a negative impact on asphalt plant emissions and produced mixes needs to be examined. (5)

4.0 Laboratory Testing

Although there are various aspects of utilizing RAS that need to be examined, this project focused on the use of RAS in Superpave 19C. The following mixes were tested (% by mass):

Mix 1 (control)	-Superpave 19C, Virgin Material
Mix 2	-Superpave 19C, 20% RAP Material
Mix 3	-Superpave 19C, 20% RAP Material, 1.4% Shingles
Mix 4	-Superpave 19C, 20% RAP Material, 3.0% Shingles
Mix 5	-Superpave 19C, 3.0% Shingles

Table 1 summarizes the volumetric properties of the five mix designs. The dynamic modulus test and resilient modulus test were performed on samples of all five mix designs in the CPATT laboratory while the TSRST test and the French wheel rutting test were run in the ETS laboratory. In order to validate the results, three replicate samples were run for each mix for each test. This provided information on the typical range of test results and statistical indication of performance. The results are outlined in the following sections.

4.1 Dynamic Modulus

The dynamic modulus, a representation of the elastic properties of a material, is determined by subjecting an asphalt mix to a repetitive, compressive, sinusoidal load. The resulting values are dependent on both temperature and loading frequency. (7) A low dynamic modulus at high temperatures is desirable to reduce rutting, while a high dynamic modulus at low temperatures is desirable to reduce fatigue cracking.

Table 1: Volumetric Properties of Mix Designs

			Mix #1	**Mix #2**	**Mix #3**	**Mix #4**	**Mix #5**
	Criteria	**Required**	**Selected**	**Selected**	**Selected**	**Selected**	**Selected**
N_{design} - Gyrations	Selected	75	75	75	75	75	75
%G_{mm} @ $N_{initial}$	Maximum	90.5%	86.9%	87.6%	87.6%	91.5%	87.8%
Air Voids (%) @ N_{design}	Approximately	4.0%	4.2%	4.0%	4.0%	4.0%	4.0%
VMA (%)	Minimum	13.0%	13.7%	14.0%	13.9%	13.0%	13.4%
VFA (%)	Minimum	65.0%	69.3%	71.4%	71.2%	69.2%	69.9%
	Maximum	75.0%					
Dust Proportion	Minimum	0.6	0.91	0.72	0.78	1.13	1.06
	Maximum	1.2					
Tensile Strength Ratio (%)	Minimum	80.0%					
Virgin AC Content			4.60%	3.80%	3.41%	2.61%	3.41%
AC from RAS (%)			0.0	0.0	0.42	0.9	0.9
Total Recycled AC (%) **			0.0	0.8	1.19	1.99	1.19

** Based on Design AC of 4.6%

Dynamic modulus testing was performed at the University of Waterloo, following AASHTO TP62-03, *Standard Test Method for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension*. In accordance with this procedure five temperatures were considered: 46.1^{o}C, 37.8^{o}C, 21.1^{o}C, 4.4^{o}C and -10^{o}C. Samples were 100 mm in diameter and 150 mm in height. The results of the dynamic modulus testing for all five mixes are summarized in Table 2 and a sample plot is displayed in Figure 1. At low temperatures Mix 1 (control) and Mix 2 (20% RAP) had the highest dynamic modulus, indicative of lower fatigue susceptibility. At high temperatures Mix 3 (20% RAP and 1.4% shingles), Mix 4 (20% RAP and 3.0% shingles), and Mix 5 (3.0% shingles) had the lowest dynamic modulus, Mix 4 being the most prominent mix. Thus, the inclusion of shingles lowered the dynamic modulus, indicative of a lower rutting susceptibility.

Table 2: Dynamic Modulus Testing Results

		Mean Dynamic Modulus (MPa)				
Mix	**Frequency (Hz)**	**46.1°C**	**37.8°C**	**21.1°C**	**4.4°C**	**-10°C**
Mix 1	0.1	278	323	978	6275	11628
	0.5	333	427	1796	9252	15492
	1.0	381	520	2514	10633	17084
	5.0	587	968	4681	13997	20573
	10.0	818	1315	5667	15296	21423
	25.0	1249	2034	7376	17206	23166
Mix 2	0.1	341	356	769	5734	13044
	0.5	398	451	1383	8459	16607
	1.0	451	532	1851	9760	18093
	5.0	714	935	4033	12913	21465
	10.0	999	1222	4531	14165	22205
	25.0	1462	1853	6086	16022	24203
Mix 3	0.1	244	338	842	3726	8000
	0.5	303	451	1402	5623	10911
	1.0	358	540	1778	6571	12192
	5.0	559	925	3185	9104	15125
	10.0	725	1201	3868	10061	15965
	25.0	1179	1800	5028	11534	17624
Mix 4	0.1	257	282	448	1239	5125
	0.5	300	351	616	1914	7218
	1.0	343	407	744	2405	8306
	5.0	481	627	1582	4202	11292
	10.0	606	781	1504	4284	12125
	25.0	922	1102	1991	5422	13971
Mix 5	0.1	288	326	480	813	3068

	0.5	318	376	633	1217	4836
	1.0	361	421	746	1496	5785
	5.0	482	605	1148	2815	8573
	10.0	597	737	1386	2989	9272
	25.0	944	1030	1805	3829	11012

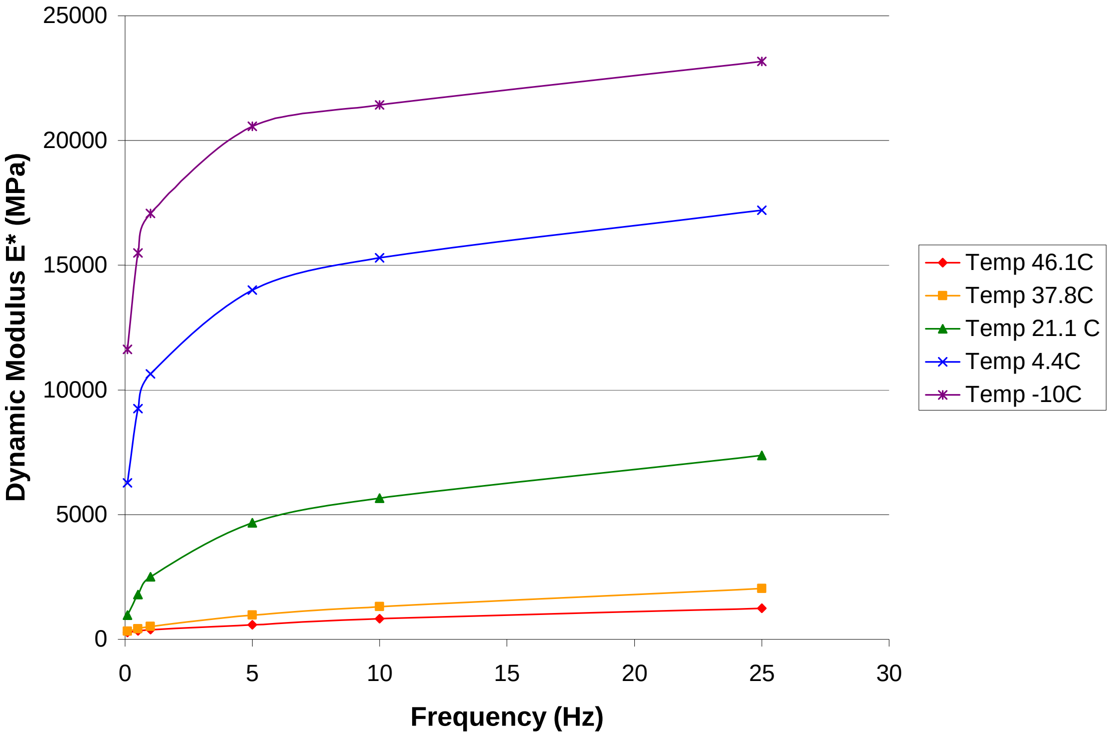

Figure 1: Dynamic Modulus vs. Frequency for Mix #1

4.2 Resilient Modulus

The resilient modulus indicates the fatigue and thermal cracking susceptability of a pavement and the quality of the materials in the asphalt mix (7). The test was perfomed at the University of Waterloo following the AASHTO TP31, *Stnadard Test Method for Determining the Resilient Modulus of Bituminous Mixtures by Indirect Tension*, substituting a six inch diameter specimen in place of a four inch diameter specimen and testing at a single temperature (25°C). During resilient modulus testing three replicate samples for each mix design were run three times each at two different orientations. The second orientation involved rotating the sample 90° in order to ensure resilient modulus test results were independent of orientation.

The mean and standard deviation of the resilient modulus values produced for each mix design are shown in Table 3 for both orientations. It can be observed that resilient modulus is dependent upon the orientation of the specimen during testing. However, the relationship between the mix designs does not appear to be impacted by the orientation of the specimen. Mix 1 (control) was found to have the highest resilient modulus while Mix 5 (3.0% shingles) had the lowest. The remaining mixes fell sequentially between Mix 1 and Mix 5. A typical data plot resulting from resilient modulus testing showing both horizontal and vertical deformation can be found in Figure 2.

Table 3: Resilient Modulus Test Results

	Resilient Modulus (MPa)			
	0° Orientation		**90° Orientation**	
Mix	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**
1	1500	110	1666	157
2	1330	210	1357	114
3	1339	182	1205	105
4	816	32	606	130
5	617	91	576	112

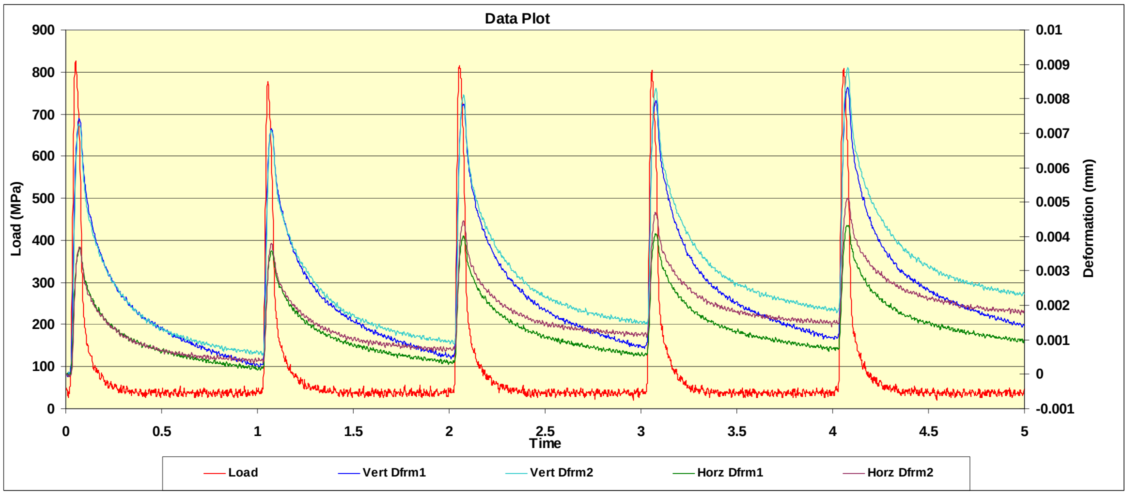

Figure 2: Typical Plot Result From Resilient Modulus Testing

As part of the resilient modulus testing, the indirect tensile strength test was carried out to determine the tensile strength of the specimens. Testing was performed on three samples for each of the five mix designs. The mean and standard deviation of the tensile strengths measured are shown in Table 4. Mix 3 (20% RAP and 1.4% shingles) was found to have the highest tensile strength, followed by Mix 1 (control) and Mix 2 (20% RAP). Mix 4 (20% RAP and 3.0% shingles) and Mix 5 (3.0% shingles) were found to have the lowest tensile strength, Mix 5 being the lesser of the two.

Table 4: Mean Tensile Strenght of Mixes

Mix	Tensile Strength (kPa)	
	Mean	Standard Deviation
1	507.3	11.7
2	454.2	45.2
3	556.8	67.5
4	341.9	60.3
5	288.1	50.1

4.3 Rutting

Testing was performed at ETS to determine the rut susceptibility of the five mixes. Each mix was tested at six different cycle durations: 100, 300, 1,000, 3,000, 10,000 and 30,000 cycles. Two moulds were tested for each mix design and the mean percentage rut depth based on the original slab thickness was computed for all six variations in the number of cycles, the results of which are shown in Table 5. The higher the percentage rut depth the greater the susceptibility of the mix to rutting. Hence, the higher percentage rut depth for each set of moulds was accepted as representing the rutting potential. A summary of the results in which the greater of the two replicate percentage rut depths was accepted is provided in Table 6 and displayed in Figure 3.

Mix 2 (20% RAP) performed the worst, having the greatest rut depth in all six variations of the number of cycles. Mix 4 (20% RAP and 3.0% shingles) had the best overall performance, having the lowest rut depth in all but the 30,000 cycle test. However, it should be noted that the percentage rut depths are all very small relatively speaking and all of these mixes should perform well in the field.

Table 5: Rutting Test Results for All Moulds Tested

Mix	Mould	% Rut Depth 100 Cycles	300 Cycles	1,000 Cycles	3,000 Cycles	10,000 Cycles	30,000 Cycles
Mix 1	Mould A	1.94	2.24	2.86	3.35	3.90	3.88
	Mould B	1.78	2.24	2.74	3.13	3.76	3.95
Mix 2	Mould A	2.54	3.34	3.77	4.28	5.02	5.31
	Mould B	2.65	3.34	3.80	4.31	5.08	5.48
Mix 3	Mould A	1.94	2.14	2.86	3.33	3.84	4.08
	Mould B	1.66	2.14	2.52	3.05	3.55	3.77
Mix 4	Mould A	1.24	1.49	1.99	2.41	2.98	4.00
	Mould B	1.29	1.59	2.01	2.53	3.20	4.27
Mix 5	Mould A	1.6	1.96	2.36	2.88	3.6	4.31
	Mould B	1.36	1.66	2.13	2.61	3.29	4.16

Table 6: Summary of Rutting Test Results

Mix	% Rut Depth 100 Cycles	300 Cycles	1,000 Cycles	3,000 Cycles	10,000 Cycles	30,000 Cycles
Mix 1	1.94	2.24	2.86	3.35	3.90	3.95
Mix 2	2.65	3.34	3.80	4.31	5.08	5.48
Mix 3	1.94	2.14	2.86	3.33	3.84	4.08
Mix 4	1.29	1.59	2.01	2.53	3.20	4.27
Mix 5	1.60	1.96	2.36	2.88	3.60	4.31

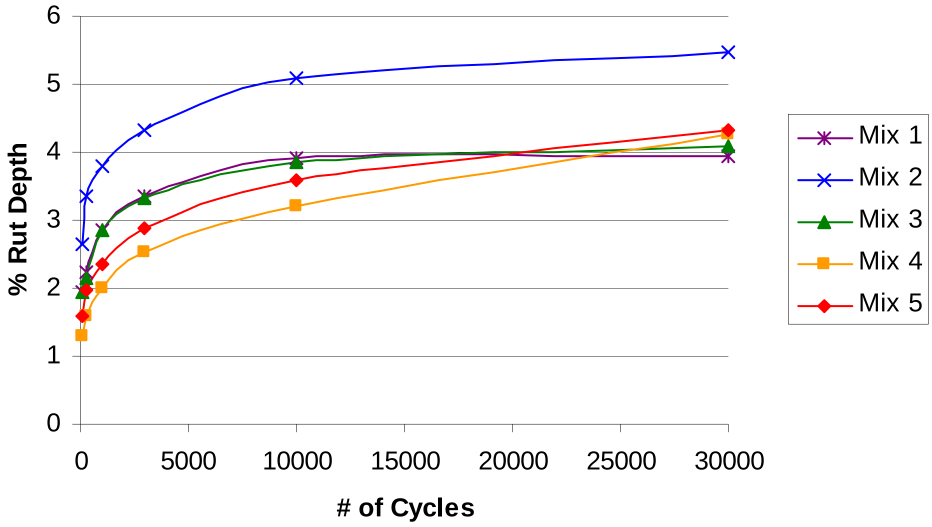

Figure 3: Percentage Rut Depth vs. Number of Cycles

4.4 TSRST

Thermal Stress Restrained Specimen Testing (TSRST) was performed at ETS to determine the low temperature cracking susceptibility of the five mixes. Each mix was tested three times. Mix 4 was tested two additional times due to poor result repeatability. Specimens were cooled at a constant rate while being restrained from contracting. At failure the tensile strength (stress) and temperature were recorded, as shown in Table 7. The mean and standard deviation of the stress at failure and fracture temperature for each mix are also shown. The temperature versus stress relationship throughout the duration of the test is shown in Figures 4 and is presented for Mix 1.

Mix 3 (20% RAP and 1.4% shingles) reached the highest temperature prior failure, while Mix 1 (control) withstood the highest stress prior failure. The temperature and stress reached by Mix 4 (20% RAP and 3.0% shingles) and Mix 5 (3.0% shingles) prior failure was significantly lower than the temperature and stress reached by Mix 1, Mix 2 (20% RAP), and Mix 3. In addition, the repeatability of the results for Mix 4 and Mix 5 was poor, perhaps indicative of poor mix consistency. Thus, incorporating a large quantity of shingles into a mix, such as 3.0%, encourages thermal cracking. However, a small quantity of shingles, such as 1.4%, is quite manageable when used in combination with RAP, enduring harsher temperatures than an equivalent mix not containing shingles.

Table 7: Summary of TSRST Results

Mix	Specimen	Stress (MPa)	Mean Stress (MPa)	Std Dev of Stress (MPa)	Temp (°C)	Mean Temp (°C)	Std Dev of Temp (°C)
Mix 1	A2	3.52	3.43	0.08	-28.9	-28.7	0.5
	A3	3.37			-29.0		
	A4	3.40			-28.1		
Mix 2	A1	3.13	3.01	0.30	-28.6	-29.4	0.9
	A3	2.67			-29.3		
	A4	3.22			-30.3		
Mix 3	A2	3.00	2.86	0.16	-32.8	-32.6	0.3
	A3	2.69			-32.2		
	A4	2.89			-32.7		
Mix 4	A1	1.38	0.57	0.47	-38.2	-19.9	11.6
	A2	0.50			-18.2		
	A3	0.25			-9.2		
	A4	0.26			-11.2		
	A5	0.47			-22.7		
Mix 5	A2	0.08	0.16	0.15	-4.4	-9.3	7.3
	A3	0.33			-17.7		
	A4	0.06			-5.9		

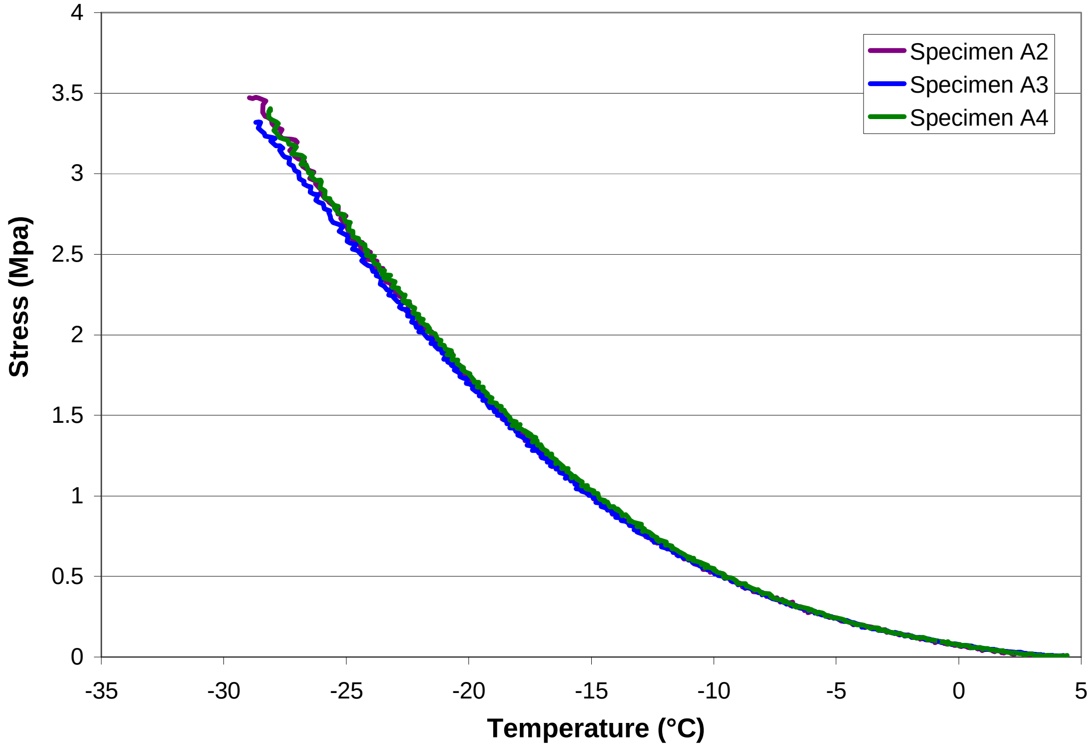

Figure 4: TSRST Stress vs. Temperature for Mix 1

5.0 Conclusions

This paper summarizes work that was carried out in partnership with the CPATT, Miller Paving Limited, Ontario Centre of Excellence Materials Manufacturing Ontario (OCEMMO) as well as subcontractor École de Technologie Superieure (ETS) in Montreal. The investigation involved the use of recycled asphalt shingles (RAS) in a Superpave 19C base course mix with various percentages of RAP and recycled shingles. The dynamic modulus test results showed that a mix that performs well at high temperatures will not necessarily perform well at low temperatures. Mix 1 (control) and Mix 2 (20% RAP) were found to have the lowest susceptibility to fatigue, while Mix 3 (20% RAP and 1.4% shingles), Mix 4 (20% RAP and 3.0% shingles), and Mix 5 (3.0% shingles) were found to have the lowest susceptibility to rutting, Mix 4 being the best in terms of rutting resistance. Mix 1 performed the best according to the resilient modulus testing, a test of fatigue and thermal cracking susceptibility, followed by Mix 2 and Mix 3. The TSRST test, a test of low temperature cracking susceptibility, found Mix 3 to be the most resistant to thermal cracking, followed by Mix 1 and Mix 2. In rut testing, Mix 4 had the best overall performance, while Mix 2 had the worst. However, relatively speaking, all mixes performed well under this test and it would be expected that there would be limited rutting in the field as all of the mixes displayed less than four percent rutting.

The overall laboratory analysis would indicate that Mix 3 (20% RAP and 1.4% shingles) is the better overall mix as compared to Mix 4 (20% RAP and 3.0% shingles) or Mix 5 (3.0% shingles). Certainly care should be exercised when adding shingles to the mix and proper engineering should be carried out prior to adding shingles. In closing the results are optimistic and from an environmental standpoint, there are many potential benefits to allowing shingles to be added to the mix. In closing it would be ideal to optimize thermal and rut resistance properties, whereby selection of the RAS and RAP blend by optimized to ensure both thermal resistance and rutting resistance are optimized.

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