Recycled Asphalt Shingles in Hot Mix Asphalt

Jim McGraw[1], Adam Zofka[2], Dan Krivit[3], Joe Schroer[4], Roger Olson[1], and Mihai Marasteanu[2]

Abstract

Using recycled asphalt shingles in hot mix asphalt (HMA) has been a developing technology for more than two decades with growing acceptance by both construction contractors and government agencies. With the recent spike in asphalt and cement prices, there is increasing pressure to find such acceptable recycled supplements to virgin materials. The state of Minnesota has sponsored several research studies on the use of recycled shingles in HMA over the past 15 years. This paper describes a recent study that investigated the use of both tear-off shingle and manufacturer shingle combined with traditional reclaimed asphalt pavement materials. A parallel study performed in Missouri is also included in the investigation.

Key words: tear-off shingle, manufacture waste shingle, reclaimed asphalt pavement, low temperature, BBR, IDT.

Introduction

Late last year, the American Association of State and Highway Transportation Officials (AASHTO) adopted a provisional standard specification that itemizes specific requirements for using recycled asphalt shingles (RAS) in hot mix asphalt. This AASHTO shingle recycling specification is significant in that it provides for a national standard guideline for state and local highway departments to use when specifying materials engineering requirements. Paving contractors and HMA producers can then design their paving material production to meet these state and local specifications if allowed to use RAS in their HMA. The new AASHTO shingle recycling specification does not address other pavement applications such as hot-in-place, cold-in-place, or cold recycled.

[1] Minnesota Department of Transportation, Maplewood, MN
[2] University of Minnesota, Minneapolis, MN
[3] Dan Krivit and Associates
[4] Missouri Department of Transportation

The oral presentation was made by Mr. Olson and Professor Marasteanu.

Most studies that have analyzed the impact of including RAS in HMA have concluded that there is potential for savings in costs of virgin asphalt binder due to the addition of RAS without sacrificing pavement performance, if appropriate quality assurance and quality control procedures are followed. This is the most important economic driving force accelerating the development of shingle recycling today.

The cost of virgin asphalt binder has been rising rapidly, especially in recent months. Figure 1 displays one representation of this trend using the New Jersey Department of Transportation published data on asphalt cement selling prices from suppliers in the northern part of the state. This chart shows the relative change over 17 years. Recent figures from Minnesota also indicate that the price per ton for many PG grades have doubled compared to last year.

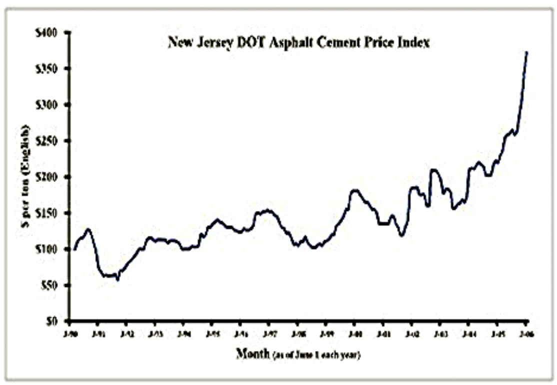

Figure 1. Asphalt Cement Price Index, NJDOT.

The mineral aggregates used in manufacturing shingles are also valuable commodities in HMA. Even the fiber in recycled shingles can be an asset to the pavement matrix in the right application and depending on the type of mix. Finally, the prices for land filling construction and demolition debris, such as mixed roofing material, are also increasing. As environmental regulations and landfill prohibitions continue to increase, so will the tipping fees for roofing debris.

A new provisional AASHTO standard specification allows the use of either manufacturers (post-industrial) shingle scrap or tear-off (post-consumer) shingle scrap as an additive in HMA. It is estimated that about 11 million tons of tear-off roofing material is generated each year in the United States. This is about ten times the amount of manufacturers scrap. In addition, AASHTO adopted a companion recommended practice to provide additional guidance for designing new HMA which incorporates RAS. Specific considerations include: shingle aggregate gradation, performance grade (PG) of the virgin and RAS binder and relative reduction of the virgin asphalt binder due to replacement by RAS binder.

Requirements within the AASHTO specification include a number of important details. First, the final RAS product must be sized and screened such that 100 percent passes a ½-in. sieve screen. This is important because it was found that the size of RAS can be expected to affect the fraction of shingle asphalt binder that contributes to the final blended binder. RAS ground to a finer size passing a No. 4 sieve can be expected to effectively utilize as much as 95 percent of the total available asphalt. The designer must be prepared to adjust the performance grade of virgin asphalt binder to compensate for this effect.

Second, the actual maximum addition rate of RAS is left as an option for the contractor. Most states have established fixed maximum limits on the amount of RAS in the HMA, usually 5 percent by weight. The new AASHTO spec states that if the quantity of RAS asphalt binder exceeds 0.75 percent by weight of the new HMA, the RAS binder and the virgin asphalt binder shall be further evaluated to ensure the performance grade of the final blended HMA complies with the originally specified performance grade requirements.

To help maintain the engineering performance of the final HMA pavement, the new AASHTO specification limits the maximum amount of deleterious material allowed in the RAS. It is recognized that these are stringent limits suggested by AASHTO, but recycling professionals continuously work to develop improved systems to clean up the mixed roofing material and tear-off RAS.

The state of Minnesota has sponsored several research studies on the use of recycled shingles in HMA over the past 15 years. Continuing this trend, several recycling projects are currently underway. The Minnesota Office of Environmental Assistance (OEA) is one of several agency sponsors of an extensive lab study project. One of the objectives is to determine if and how a new tear-off specification can be developed. Mn/DOT's current specification only allows the use of manufacturers shingle scrap in HMA. Missouri Department of Transportation (MoDOT) has a new shingles recycling specification that was originally released in early 2005. They are also interested to investigate the properties of HMA supplemented with tear-off RAS and have agreed to participate in this joint laboratory study. This paper presents the results of this study.

Minnesota Project

The Minnesota Department of Transportation (Mn/DOT) has an existing standard construction materials specification that allows the use of recycled manufacturer shingles in hot-mix asphalt (HMA). Our estimates indicate there is about 40,000 tons per year of this manufacturer shingle scrap generated by the three shingle manufacturing plants in Minnesota. This current Mn/DOT specification prohibits the use of tear-off (post consumer) shingle scrap. Estimates indicate there is about 400,000 tons per year of tear-off shingle scrap generated. Mn/DOT materials engineers need additional empirical data from a controlled research study on the HMA impacts of using residential tear-off shingle scrap compared to manufacturer shingle scrap.

The Minnesota Office of Environmental Assistance (now an office of the Minnesota Pollution Control Agency) provided a grant for laboratory testing of hot-mix asphalt (HMA) derived in part from tear-off asphalt shingles. The intent of this study was to look at the feasibility of drafting a tear-off shingle specification. Mn/DOT wanted to look at the effects the addition of shingles to asphalt binder and mixture properties. Many warm weather states see the benefit of adding shingle to HMA to help with rutting resistance. Colder weather states like Minnesota are more concerned with fatigue and thermal cracking.

Materials

Dan Krivit and Associates (DKA) was able to secure the participation of Dem-Con Landfill and Resource Recovery in Shakopee, Minnesota to help source and sort the loads of mixed roofing waste into approximately 50 tons of clean, sorted tear-off shingles only. Dem-Con staff identified eligible loads of mixed roofing waste that contained a higher percentage of tear-off shingles from private, residential homes. These loads were redirected to a transfer station tipping area inside an enclosed building. Using a Bob-Cat type of skid-steer loader with a grapple bucket, Dem-Con staff then re-tipped the mixed roofing waste onto the tip floor. Then, Dem-Con staff hand picked out the non-shingle debris such as metal, plastic, wood and other waste. The clean, shingles only material was re-piled, loaded and then shipped to the Bituminous Roadways, Inc. (BRI) shingle recycling plant / aggregate pit / hot-mix asphalt facility in Inver Grove Heights. BRI ground and screened the clean tear-off shingles into a recycled asphalt shingles (RAS) product. Dakota County ordered the hot-mix asphalt (HMA) for the CSAH 26 project base course. About 40 tons of the tear-off RAS was incorporated into the specified mix.

Three mixes were designed for Dakota County Project 19-626-15 and are shown in Table 1. The contractor Bituminous Roadways Inc (BRI) did the mix designs and provided gyratory test specimens and loose mix for the Indirect Tensile Testing (IDT) and Performance-Grade (PG) testing. All three mixtures contain the same virgin asphalt binder PG 58-28.

Table 1: Sample Types and HMA Mix Design

Mixture ID	Number of samples	Percent RAP	Percent Tear-off	Percent Manufacture Waste
Control	4	20	0	0
Tear-off	4	15	5	0
Manufacture waste	4	15	0	5

The mixture containing 20% RAP was used as the control; Mn/DOT allows 20% RAP without a change in grade of asphalt binder.

Experimental Approach

To determine variability in the processing of waste shingles for use in HMA, ten random samples were taken of each type of recycled product used in the mixes in the project. Each of these recycled products were tested for % asphalt binder, PG grading on recovered binder, gradation, % glass fiber and paper content in extracted aggregate. Glass fiber and paper are considered deleterious material. The Provisional AASHTO specification allows 0.5%. Glass fiber content was determined by collecting glass fibers in extracted aggregate on a larger sieve (No. 4). The remaining aggregate sample was weighed and sent through an asphalt ignition oven to burn off the paper. The difference in weight was reported as % paper. There has been some speculation that the glass fibers may make asphalt mastic that is beneficial to mix performance.

Asphalt binder extractions were performed using AASHTO T-164 Method A (Centrifuge Method). Toluene was used as the extraction solvent. Fines were removed from the extract by high speed centrifuging. The binder recovery method used was ASTM D 5404- Standard Practice for Recovery of Asphalt from Solution Using Rotary Evaporator. The Performance-Grade (PG) of the extracted asphalt binders was determined by AASHTO R-29- Standard Practice for Grading or Verifying the Performance Grade of an Asphalt Binder.

Asphalt binder extraction results for the two shingle sources showed a similar standard deviation (~ 2%) for the 10 samples tested (Figure 2, Tables 2 and 3).

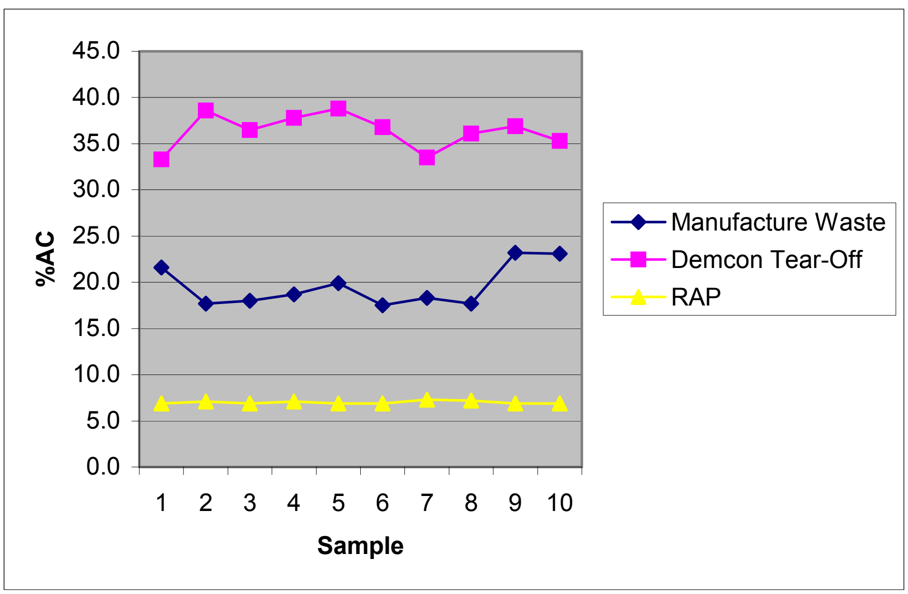

Figure 2. Shingle Asphalt Binder Content

Table 2. Manufacture Waste Shingle PG Grading Results

BC Sample #	%AC	Wt loss %	PG High	PG Low
05BC286	21.6	-0.153	135.4	-11.70
05BC287	17.7	-0.146	143.5	-10.00
05BC288	18.0	-0.576	144.3	-6.10
05BC289	18.7	-1.204	153.9	-10.90
05BC290	19.9	-0.718	137.6	-12.50
05BC291	17.5	-0.685	140.7	-11.30
05BC292	18.3	-0.908	138.7	-11.30
05BC293	17.7	-1.428	149.0	-11.40
05BC294	23.2	-1.300	134.4	-12.70
05BC295	23.1	-0.745	139.5	-11.90
Average	19.6	-0.800	141.7	-11.0
Std Dev	2.3	0.4	6.1	1.9

Table 3: Demcon Tear Off Shingle PG Grading Results

BC Sample #	%AC	Wt loss %	PG High	PG Low
05BC296	33.3	-1.740	129.9	-1.30
05BC297	38.6		124.8	0.00
05BC298	36.5	-1.300	121.2	3.70
05BC299	37.8	-0.632	121.8	-0.90
05BC300	38.8	-0.915	124.1	6.00
05BC301	36.8	-1.036	132.9	2.80
05BC302	33.5	-1.830	126.7	2.00
05BC303	36.1	-1.290	123.1	-6.90
05BC304	36.9		122.6	-4.8
05BC305	35.3	-1.815	133.1	10.6
Average	36.4	-1.300	126.0	1.1
Std Dev	1.9	0.4	4.5	5.1

The manufacturer waste average % binder was 19.6 while the tear-off average was 36.4. This difference in asphalt content was adjusted in the mix design procedure. For the 5% allowable shingles the contribution to total asphalt binder content for the manufacturer RAS would be about 1% and the tear-off RAS would be 1.8%. The implication of this is the tear-off mixes would have less virgin binder and stiffer mixes. Data from Table 4 indicates that the RAP used was very uniform.

Table 4. BRI RAP PG Grading Results

BC Sample #	%AC	Wt loss %	PG High	PG Low
05BC306	6.9	-0.650	77.5	-25.3
05BC307	7.1	-0.650	76.4	-24.4
05BC308	6.9	-0.790	74.7	-25.8
05BC309	7.1	-0.710	76.7	-26.3
05BC310	6.9	-0.710	75.7	-27.0
05BC311	6.9	-0.885	75.4	-25.9
05BC312	7.3	-0.930	75.2	-26.2
05BC313	7.2	-0.735	76.4	-25.9
05BC314	6.9	-0.653	75.7	-26.2
05BC315	6.9	-0.747	76.9	-25.1
Average	7.0	-0.7	76.1	-25.8
Std Dev	0.2	0.1	0.9	0.7

The Figures 3, 4, 5 and 6 and Tables 5, 6, 7 and 8 for AC content, processed shingle extracted gradation and mixture gradations, indicate that the contractor maintained very good quality control. On sieves finer than No. 10, the tear-off has finer gradation than manufacture waste. This might have been a result of the additional processing steps taken to remove all metal.

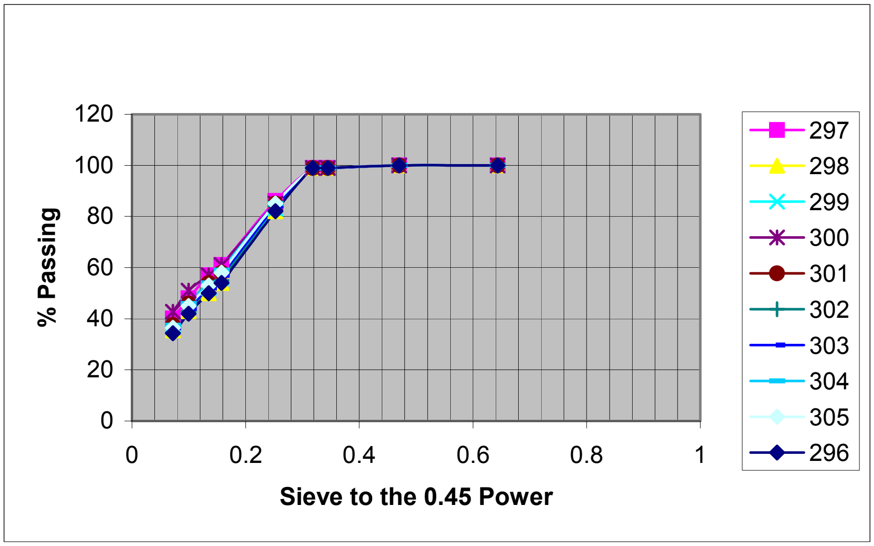

Figure 3. Demcon TOSS Extracted Gradation

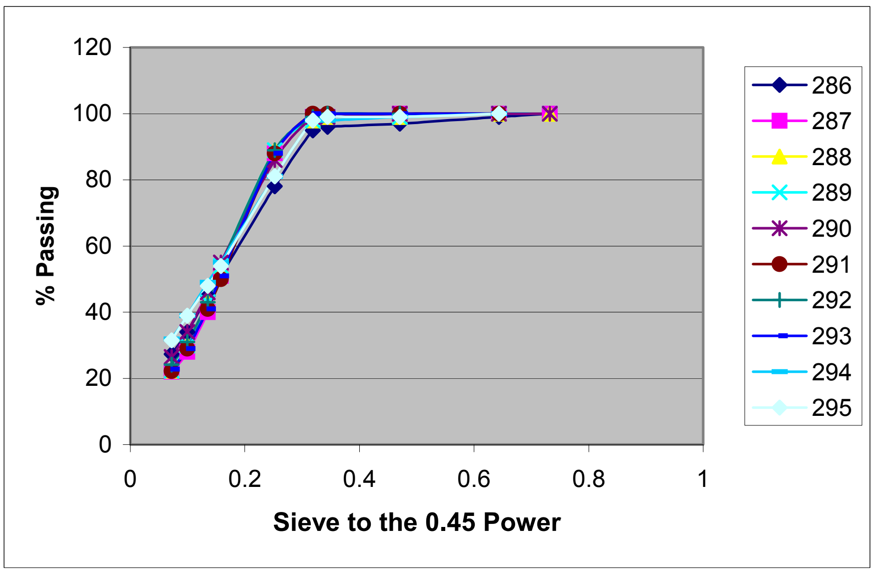

Figure 4. Manufacture Waste Shingle Extracted Gradation

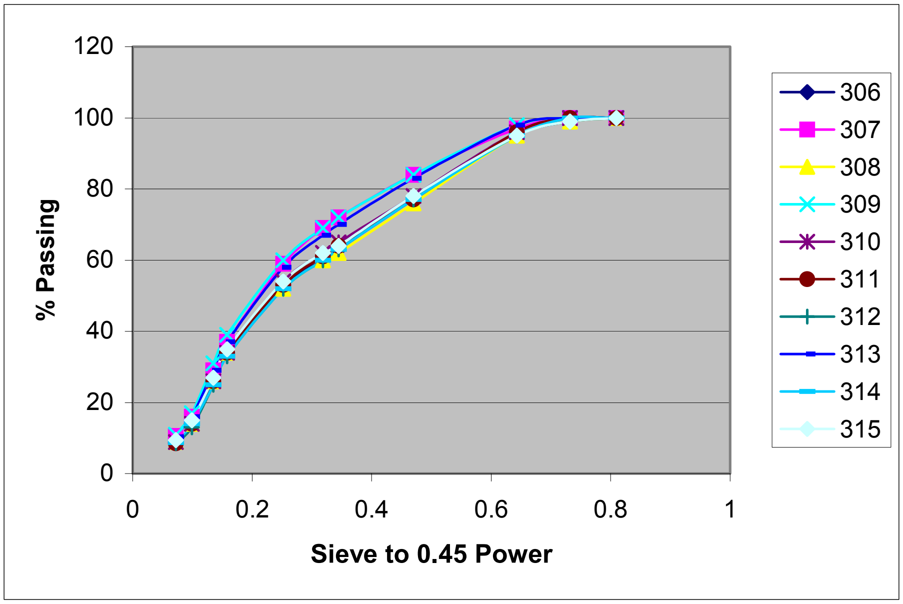

Figure 5. RAP Extracted Gradation

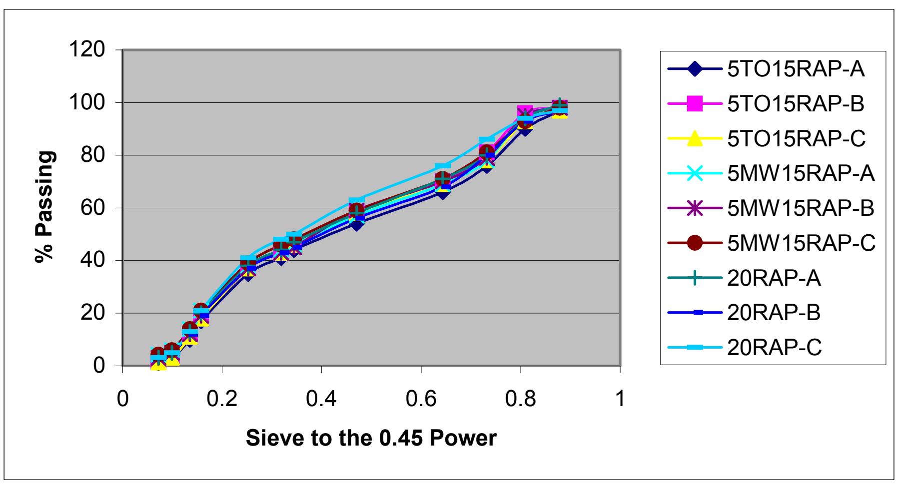

Figure 6. Shingle HMA Mix Extracted Gradation

Table 5. Tear-Off Shingle Extracted Gradation

3/8	#4	#8	#10	#16	#40	#50	#100	#200	Fibers	Paper	Total
100	100	99	99	82	54	50	42	34.3	0.53	14.2	14.73
100	100	99	99	86	61	57	48	40.1	0.58	20.2	20.78
100	100	99	99	82	54	50	43	35.4	0.61	17.1	17.71
100	100	99	99	83	56	52	45	37.5	0.69	18.5	19.19
100	100	99	99	85	61	57	51	42.7	0.92	19.2	20.12
100	100	99	99	85	58	54	46	37.6	0.93	16.6	17.53
100	100	99	99	84	55	50	43	34.4	0.47	13.7	14.17
	100	99	99	84	57	52	44	36.5	0.52	16.5	17.02
100	100	99	99	85	59	54	46	37.4	0.85	18.2	19.05
100	100	99	99	85	58	53	45	36.4	0.54	15.4	15.94
								Average	0.66	16.96	17.62
								Std. Deviation	0.17	2.12	2.22

Table 6. Manufacture Waste Shingle Extracted Gradation

1/2	3/8	#4	#8	#10	#16	#40	#50	#100	#200	Fibers	Paper	Total
100	99	97	96	95	78	51	45	34	27.4	3.76	2.25	6.01
100	100	100	99	99	88	51	40	28	22.0	0.88	1.15	2.03
100	100	99	99	98	89	54	43	30	22.3	1.06	1.16	2.22
100	100	99	99	98	89	54	43	30	22.3	1.9	1.6	3.5
100	100	100	99	99	86	55	46	34	26.5	0.9	0.91	1.81
	100	100	100	100	88	50	41	29	22.2	0.3	0.98	1.28
	100	100	100	99	89	54	43	31	24.2	1.43	0.99	2.42
	100	100	100	100	88	51	41	29	22.8	1.17	0.82	1.99
	100	99	98	98	81	55	49	39	31.9	2.60	1.92	4.52
	100	99	99	98	81	54	48	39	31.5	3.35	1.59	4.94
									Average	1.74	1.34	3.07
									Std. Deviation	1.15	0.48	1.59

Table 7. RAP Extracted Gradation

5/8	1/2	3/8	#4	#8	#10	#16	#40	#50	#100	#200
100	99	95	77	63	60	53	34	27	14	8.9
100	100	97	84	72	69	59	37	29	16	10.6
100	99	95	76	62	60	52	34	26	14	8.9
100	100	98	84	72	69	60	39	31	17	11.0
100	100	96	78	65	62	54	34	26	14	8.9
100	100	96	77	64	61	53	34	26	14	8.5
100	99	95	77	63	60	52	33	25	13	8.6
100	100	98	83	70	67	58	37	29	16	10.3
100	100	95	77	63	60	52	33	25	14	8.7
100	99	95	78	64	62	54	35	27	15	9.4

Table 8: Shingle HMA Mix Extracted Gradations

Sample ID	3/4	5/8	1/2	3/8	#4	#8	#10	#16	#40	#50	#100	#200
TO + RAP	97	90	76	66	54	44	41	35	17	10	3.0	1.1
TO + RAP	98	96	81	70	58	46	43	37	18	11	3.0	1.4
TO + RAP	97	93	78	69	58	46	43	37	18	11	3.0	1.3
MW +RAP	98	95	78	69	57	46	44	38	21	14	6.0	4.2
MW + RAP	98	95	79	70	59	45	43	37	19	12	5.0	3
MW + RAP	98	93	81	71	59	48	46	39	21	14	6.0	4.3
20% RAP	99	94	80	71	58	47	44	38	20	13	5.0	3.1
20% RAP	97	93	80	68	56	45	43	37	19	12	5.0	3
20% RAP	97	94	86	76	63	50	48	41	21	13	5	3.2

Manufacture waste shingles had high fiber content but lower paper in extracted samples. The average values were 1.74% for glass fibers with standard deviation of 1.15, and an average of 1.34 % for paper content with standard deviation of 0.48, indicating a variable amount of deleterious material. The acceptable total deleterious material in the Provisional AASHTO specification is 0.5%. The contribution of the glass fibers to binder and mixture properties needs to be investigated.

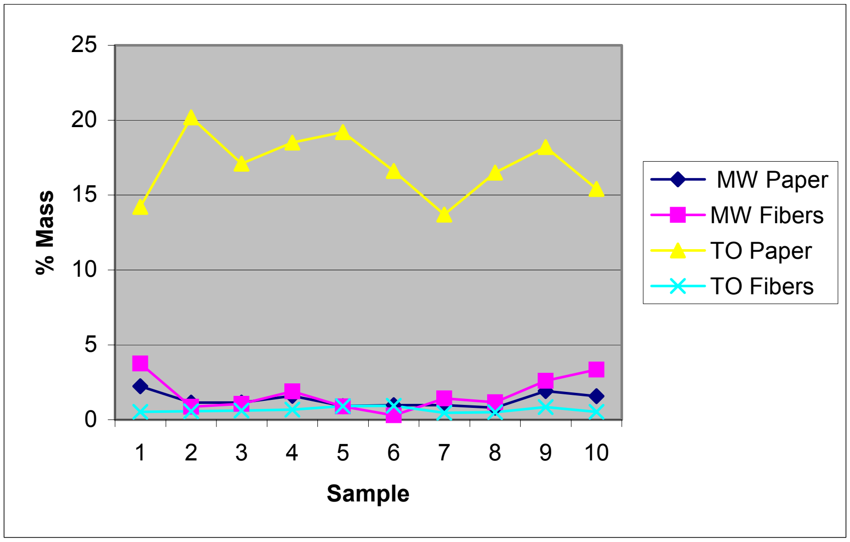

Figure 7. Deleterious Materials in Extracted Shingles

Since the shingles will go through a hot mix plant, Rolling Thin Film Oven tests (RTFO) were run on the extracted binder. Surprisingly, larger than expected losses with large standard deviations were obtained. On the average, virgin binders have a RTFO loss of about 0.5% as shown in Figure 7.

The average RFTO mass loss of 0.8 % and the high standard deviation indicate a wide range of loss upon heating. These losses could be from the softer asphalt extracted from roofing felt incorporated into the recycled shingles (RAS). There was speculation that the loss could be from combustion of paper and other deleterious material in the RAS. The mass loss seen in this test needs further investigation.

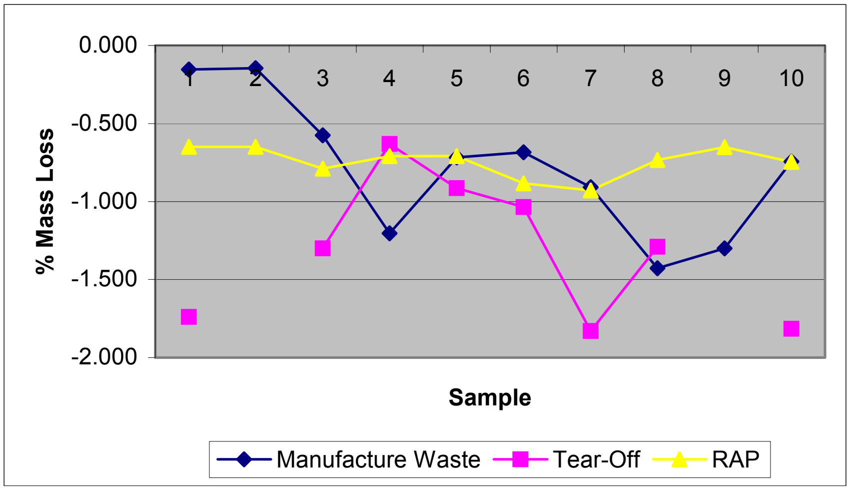

Figure 8. Shingle Binder RTFO Mass Change

To make sure that the asphalt recovery process did not leave fibers in the asphalt, ash tests were run on the recovered asphalt from the three mixes. Results from Figure 8 and Table 9 show that the shingle asphalt contents were close to the 99.95% requirement for asphalt binder except for the RAP binder sample. It is unclear why the RAP binder had higher ash content.

Table 9: Binder Ash Tests

	Manufacture waste	Tear-off	RAP
Crucible tare	15.852	26.152	25.276
Crucible + Sample	17.910	28.156	27.335
Sample Weight before	2.058	2.004	2.059
Cruc + Sample after	15.866	26.172	25.359
Sample Weight after	0.014	0.020	0.083
% AC	99.32	99.002	95.969

The recovered binder from the three mixes was performance-graded according to AASHTO R-29. Comparing PG grading results to the 20% RAP mix, the manufacture waste RAS mix graded 1 full PG grade on the high temperature properties while the tear-off RAS mix graded 1 ½ grade higher. Replacing 5% RAP with shingles does have an effect on the binder stiffness. The PG grading results are plotted in Figure 9 and 10 and listed in Tables 10, 11 and 12.

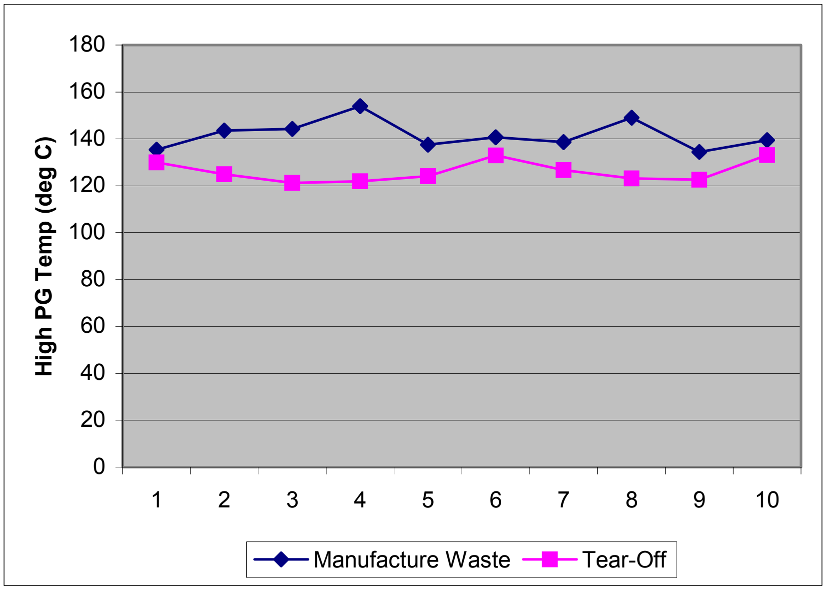

Figure 9. Shingle Binder High Temperature PG Grade

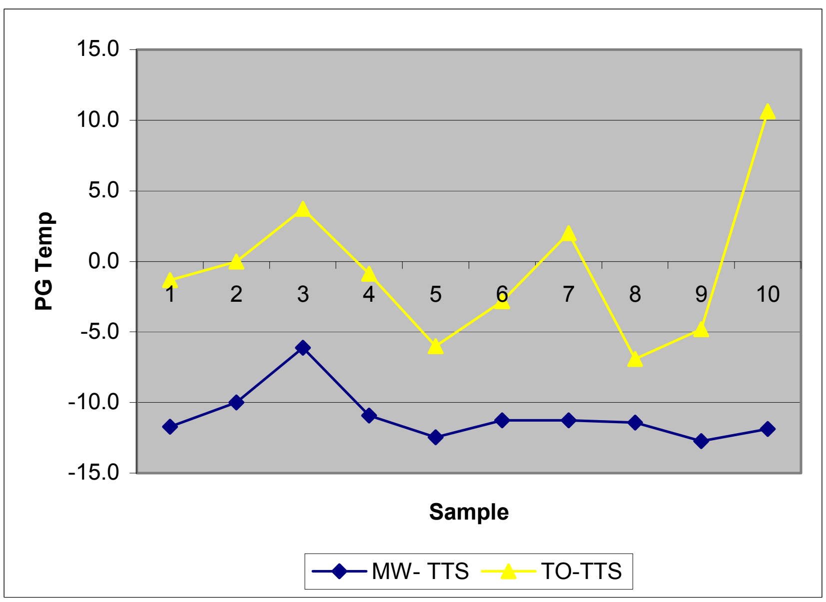

Figure 10. Shingle Mix Low Temperature PG Grading

Low temperature PG data is m-value controlled. Due to the fact that the RAP binder has good low temperature properties, the addition of tear-off did not result in much change in low temperature properties. The manufacture waste mix on the other hand showed a change of ½ grade on the low end. The manufacture waste mix binder would be graded at –22.

Table 10. Tear-off Mixture PG Grading Results

Replicate	%AC	PG High	PG Low
1	6.2	73.0	-31.5
2	6.2	73.4	-28.0
3	6.2	73.1	-26.9
Average	6.2	73.2	-28.8
Std. Deviation	0.0	0.2	2.4

Table 11. Manufacture Waste Mixture PG Grading Results

Replicate	%AC	PG High	PG Low
1	6.2	70.6	-26.2
2	6.2	71.3	-26.4
3	6.1	70.9	-26.0
Average	6.2	70.9	-26.2
Std. Deviation	0.1	0.4	0.2

Table 12. 20% RAP Mixture PG Grading Results

Replicate	%AC	PG High	PG Low
1	6.3	63.9	-30.3
2	6.0	64.5	-28.9
3	6.1	64.3	-28.5
Average	6.1	64.2	-29.2
Std. Deviation	0.2	0.3	0.9

Analysis of BBR and DT Results
A more detailed summary of the BBR data for the binders extracted from the three mixtures is presented in Table 13.

Table 13. BBR Results for the Minnesota Samples

Temp	Binder	S(60s)	Average	m(60s)	Average
-12	15%RAP + 5% Tear-off	107	115	0.303	0.307
		123		0.311	
-18		206	**206**	0.264	**0.264**
		206		0.264	
-12	15% RAP + 5% Manufacture waste	99	103	0.329	0.326
		106		0.322	
-18		182	**182**	0.289	**0.289**
-18	20% RAP	173	**170**	0.325	**0.324**
		166		0.322	
-24		313	329	0.237	0.250
		384		0.236	
		331		0.263	
		288		0.264	

One immediate observation from the data obtained at -18°C is that the addition of shingles slightly increases the stiffness but significantly lowers the m-value, indicating a significant change in relaxation properties. Also, for the mixtures with shingles, the stiffness values corresponding to m-values of 0.300 are very low. It becomes therefore important to calculate thermal stresses for the three mixtures. In addition, Direct Tension tests were performed to identify differences between the three binders in terms of fracture resistance.

Master curves of the creep stiffness were first obtained and are plotted in Figure 11. It can be seen that the two binders with shingles are "softer" at the shorter times or low test temperatures but also have flatter curves (lower m-values) than the RAP only binder, which makes them stiffer at the higher loading times or higher test temperature. This may indicate that the shingles binders may behave worse with respect to fatigue cracking rather than low temperature. The plots also indicate that the binders with tear-off shingles are slightly stiffer than the binders with manufacture waste shingles. This can be better seen in Figure 12 which includes plots of the pure shingles binders as well as a PG58-28 binder in PAV condition (included for comparison purposes). The plots clearly show that the binder in tear-off shingles is much stiffer than the binder in manufacture waste shingles. The figure also shows that the addition of shingles softens the resulting binder at low temperatures; however, they change very little with increase in temperature and become stiffer than the RAP and PG58-28 binder as the temperature increases.

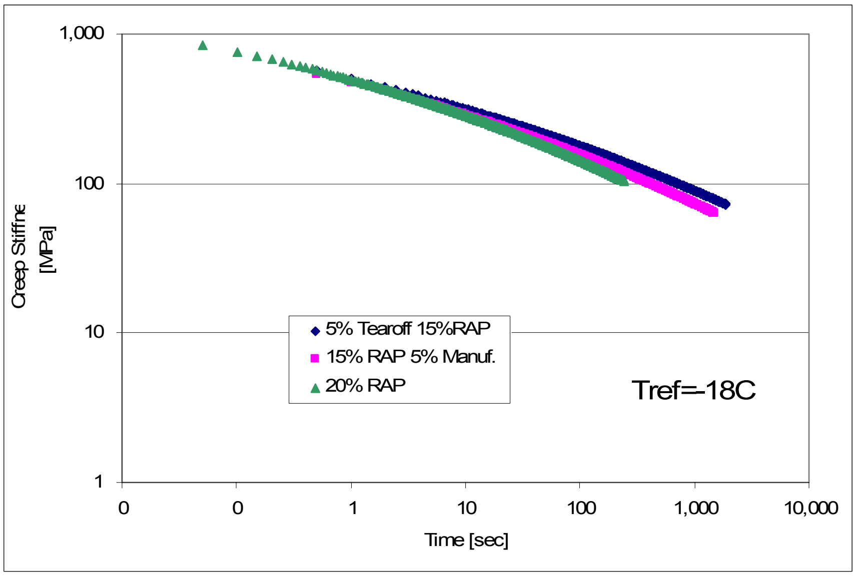

Figure 11. Creep stiffness master curves for the three binders

This trend is also reflected in the thermal stresses plots shown in Figure 13. The binders containing manufacture reject shingles build up less thermal stress compared the RAP binder and less than the tear off shingles. All appear to accumulate less thermal stress than a typical PG58-28 binder. Thermal stresses were calculated according to AASHTO MP1a standard.

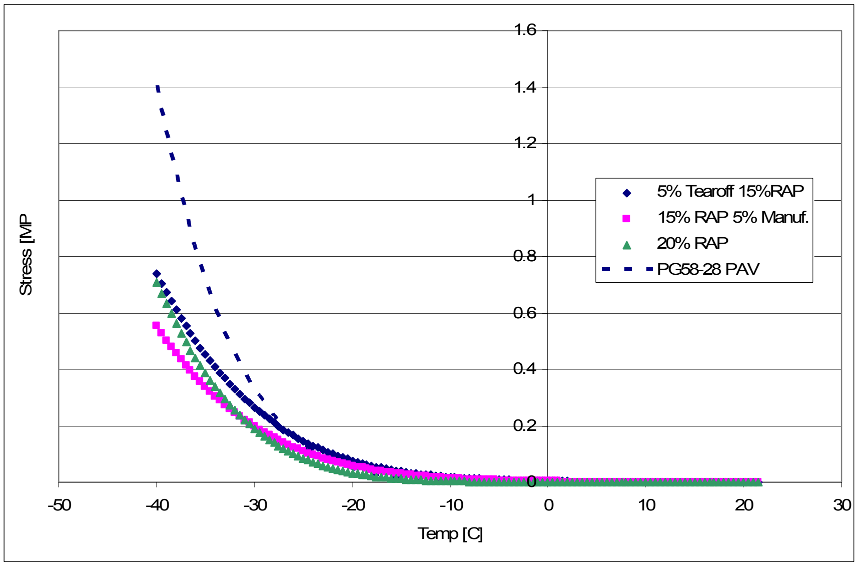

Figure 12. Creep stiffness master curves comparison

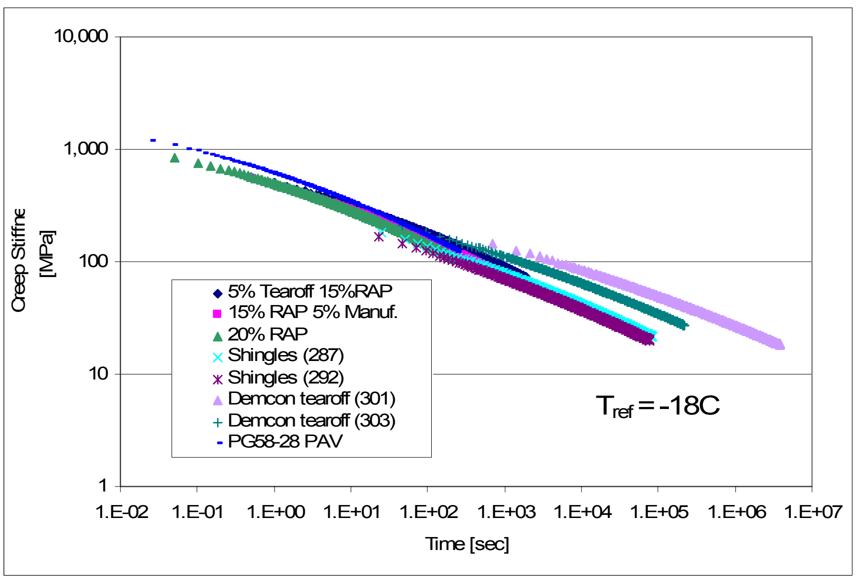

Figure 13. Thermal stress comparison

To obtain critical temperatures, Direct Tension tests were performed at three temperatures. The results are shown in Figure 14. Figure 15 shows the plots used to obtain the critical temperature.

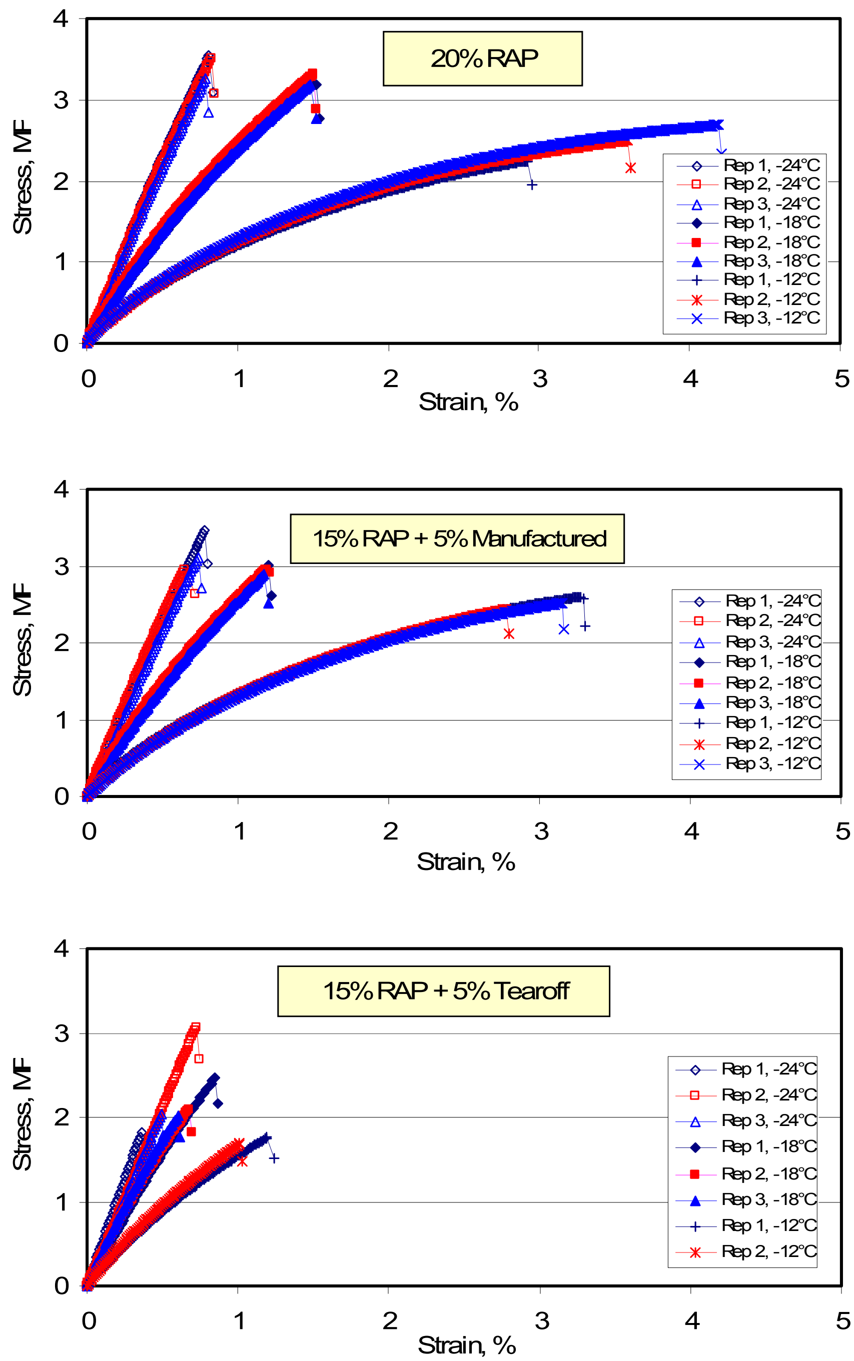

Figure 14. Direct Tension Results

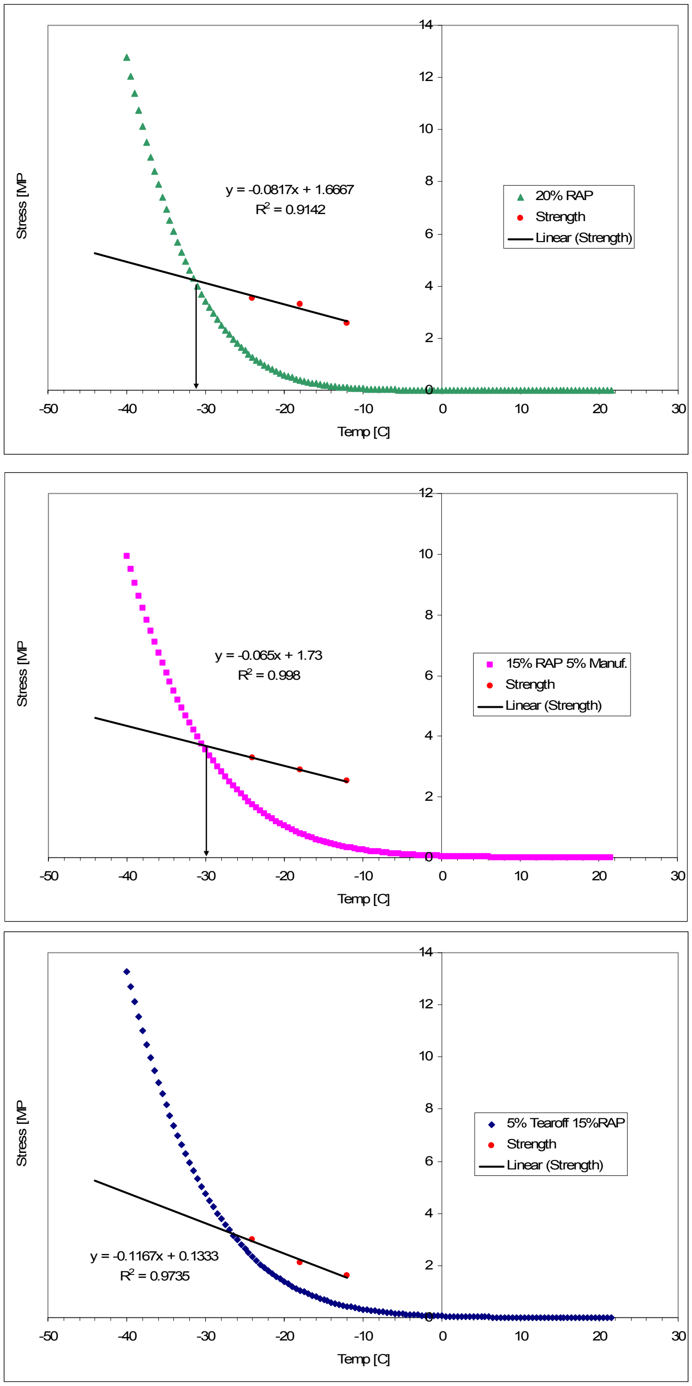

Figure 15. Critical Temperature Comparison

The results show very little difference between the 20% RAP and the manufacture waste shingles. The tear-off shingles have a more brittle behavior in particular at the two higher temperatures.

The strength values were further used to create strength master curves and intersect them with the thermal stress curves. Figure 15 shows the three plots that indicate that the addition of manufacture shingles does not affect T_{cr}; however, the addition of tear-off shingles increases the critical temperature by a few degrees.

Indirect Tensile Mixture Tests

Indirect tensile tests (IDT) were performed on the eight HMA mixtures according to AASHTO TP 9: Standard Test Method for Determining the Creep Compliance and Strength of HMA. BRI collected four random HMA loose samples from each of the three types of test mixes: "control", "manufacturer" and "tear-off". Samples were deemed to be representative and "typical" of normal product. The IDT stiffness (at 100 seconds and 500 seconds) and strength results are summarized in Tables 14 and 15, respectively and also presented in Figures 16 to 18. Note that all three mixtures contain the same virgin asphalt binder PG 58-28.

Table 14. Mix Creep Stiffness Results, GPa

Mixture	Temp. [°C]	@ 100sec.		@ 500sec.	
		Average	COV [%]	Average	COV [%]
20% RAP	0	0.2	17.2	0.1	9.0
	-10	2.7	54.9	1.1	63.1
	-20	10.0	14.1	5.6	4.2
15% RAP + 5% Tear off	0	0.5	60.2	0.2	58.9
	-10	5.0	25.5	2.3	12.8
	-20	13.5	3.2	8.7	2.3
15% RAP + 5% Manufacture waste	0	0.2	42.5	0.1	50.1
	-10	5.5	19.8	2.7	31.2
	-20	8.2	6.9	5.3	5.8

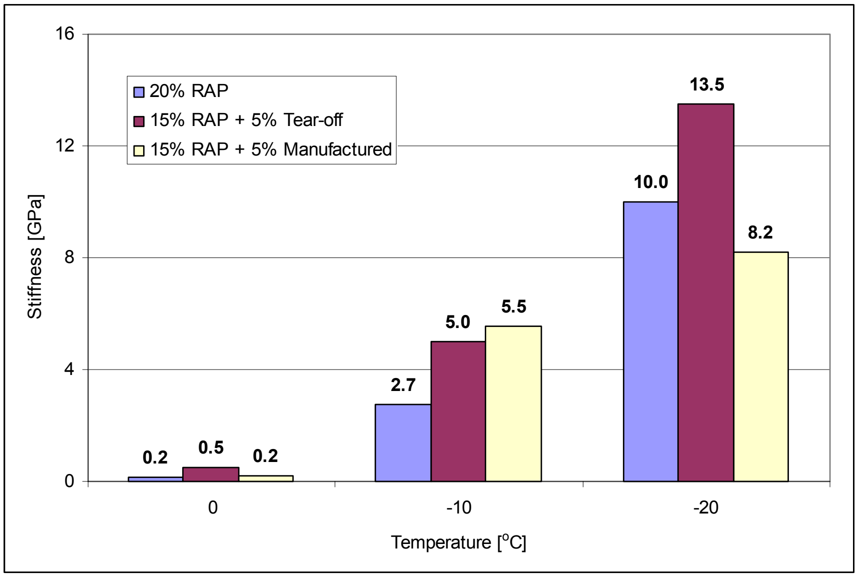

Figure 16. Mix Stiffness @ 100sec.

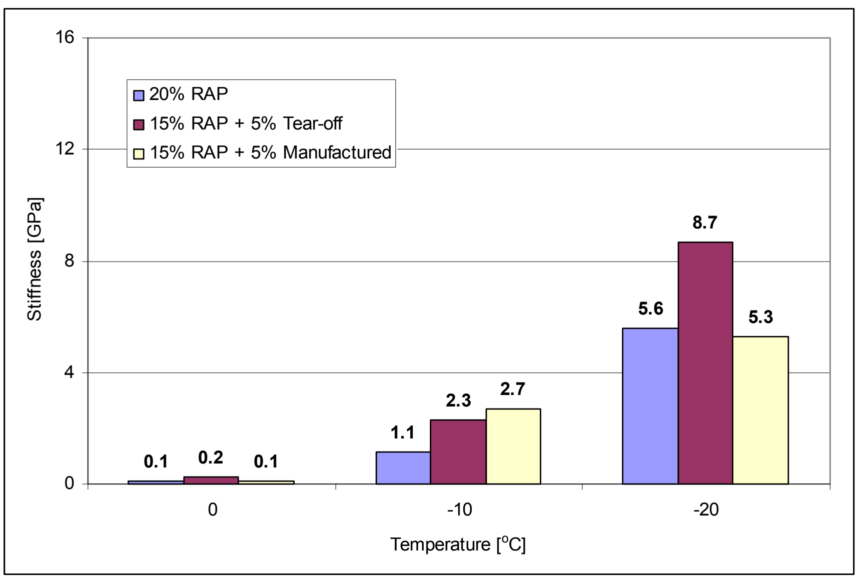

Figure 17. Mix Stiffness @ 500sec.

The stiffness results indicate that the addition of tear off RAS material increases significantly the stiffness of the mixtures at all test temperatures. The highest increase can be observed at the lowest temperature, -20°C. Addition of manufacture waste RAS material caused the increase in stiffness only at 0°C and -10°C whereas stiffness for this material at -20°C reached the lowest observed value from all tested materials, which confirms the trend seen in the BBR asphalt binder data.

Table 15. Tensile Strength Results

Mixture	Temp. [°C]	Tensile Strength [MPa]	
		Average	COV [%]
20% RAP	0	3.2	0.14
	-10	4.6	3.54
	-20	4.8	4.19
15% RAP + 5% Tear-off	0	3.2	7.54
	-10	4.5	11.15
	-20	5.1	7.06
15% RAP + 5% Manufactured	0	2.9	-
	-10	4.5	2.79
	-20	5.3	6.87

Note: for manufacture waste mixture, only one specimen was tested at 0°C and the result is reported without COV.

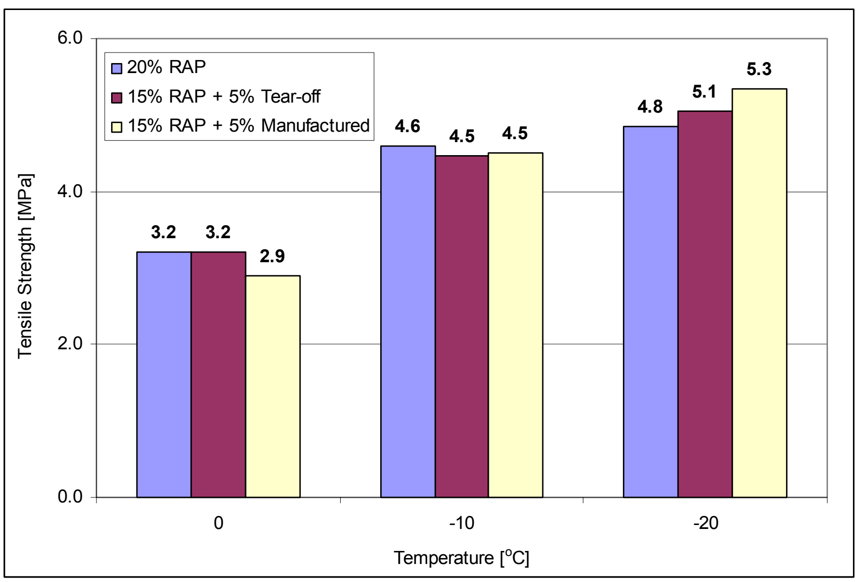

Figure 18. Tensile Strength, Minnesota Mixtures

The strength results indicate that the tensile strength properties were not significantly affected by the addition of shingles. This contradicts the binder strength data for the extracted tear off binders.

Missouri Project

Pace Construction Company's Quality Control team designed three different MoDOT SP190C asphalt mixes with the following characteristics:

- 19.0 mm (3/4 in.) nominal aggregate
- Design level 3,000,000 to< 30,000,000 ESAL's
- N design 100 gyrations on a Gyratory compactor
- VMA minimum 13.0
- TSR @ 7% +/- 0.5% air voids greater than 80 % using AASHTO T 283

The first mixture was designed with all virgin materials; the second mixture was designed using 20% recycled asphalt pavement (RAP); the third mixture was designed using 15% recycled asphalt pavement (RAP) and 5% ground tear off shingles (supplied by Peerless Resource Recovery of St. Louis). The tear off shingles came from single-family dwellings and were tested for asbestos on a regular schedule with oversight by St. Louis County Department of Health. Tear off shingles were ground and screened so that 100% passed a ¾ in.opening screen. The virgin aggregates were a Plattin limestone furnished by Bussen – Antire Quarry of St. Louis County.

In this study a PG 64-22 and a PG 58-28 binder were used in each separate mixture. Each mixture was designed with 0.25% antistrip additive (Pave Bond Lite) as a percentage of the virgin binder. Missouri DOT reviewed and approved the mixtures.

The SP190C mixture with 20% recycled asphalt pavement using a modified PG 70-22 binder had already been approved by MODOT when Pace requested that the above mixtures be used on a portion of a project already under contract. Approval was given to produce and lay approximately 500 ton of each mixture on US 61-67 (Lindbergh Blvd) in St. Louis County. QC and QA testing were done on the mixtures as if they were normal Superpave mixtures with additional samples taken to obtain the materials for the study. QC – QA results on these mixtures were within specifications and very close to the virgin mixture.

The mixtures were produced in a 500 ton per hour capacity Gencor counter flow drum plant, but produced at 250 tons per hour. The plant has only one recycle bin so the recycled asphalt pavement and ground takeoff shingles were pre blended through the plant cold feed bins and then added to the recycle bin as one material at the time of production.

MoDOT relaxed its deleterious specification from 0.5% on each aggregate fraction to a total of 3% for the takeoff shingle fraction, but allowing no more than 1.5% wood. Takeoff shingles are by their very nature very difficult to clean and only by hand sorting. There is some question as to what materials are deleterious.

TSR results show that the above change had little effect on stripping of the mixtures.

To address concerns related to the negative influence of aged asphalt in the shingles on low temperature properties the second and third mixtures were sent to University of Minnesota Civil Engineering Department to run indirect tensile tests (IDT) on the samples compacted to 5% air voids provided by Pace Construction Company. These samples were prepared from cold loose mix samples heated to the required temperature for compaction. The results of these tests will be used to help determine the grade of asphalt binder required to meet MoDOT specifications.

<u>IDT Results</u>

Table 16 presents the experimental details of the tests performed in the pavement laboratory at the University of Minnesota.

The tests were performed in accordance to AASHTO TP9-96: *Standard Test Method for Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device*. Please note that only two IDT specimens were tested at -10°C due to the limited number of IDT specimens that could be cut from the Superpave Gyratory compacted cylinders.

Table 16. Test details

Mixture	Temperature	Replicate designation	Average Thickness [mm]	Diameter [mm]
20% RAP PG 64-22	-10°C	17	43	150
		18	42	150
	-20°C	11	43	150
		12	44	150
		13	43	150
	-30°C	14	44	150
		15	44	150
		16	42	150
20% RAP PG 58-28	-10°C	27	44	150
		28	43	150
	-20°C	21	40	150
		22	41	150
		23	44	150
	-30°C	24	41	150
		25	42	150
		26	41	150
15% RAP + 5% shingles PG 58-28	-10°C	37	46	150
		38	42	150
	-20°C	31	41	150
		32	41	150
		33	43	150
	-30°C	34	40	150
		35	43	150
		36	42	150
15% RAP + 5% shingles PG 64-22	-10°C	47	46	150
		48	42	150
	-20°C	41	47	150
		42	41	150
		43	43	150
	-30°C	44	45	150
		45	46	150
		46	42	150

The IDT stiffness (at 100 seconds and 500 seconds) and strength results are summarized in Tables 17 and 18, respectively and also presented in Figures 19 to 24.

Table 17. Mix Creep Stiffness Results, GPa

Mixture	Temp.	@ 100sec		@500sec	
		Average	COV [%]	Average	COV [%]
20% RAP PG 64-22	-10°C	10.9	-	7.4	-
	-20°C	12.0	35.5	9.0	32.7
	-30°C	19.5	10.3	16.4	11.9
15% RAP 5% shingles PG 64-22	-10°C	9.5	5.91	5.9	1.6
	-20°C	34.4	26.6	27.5	20.6
	-30°C	34.7	-	30.3	-
20% RAP PG 58-28	-10°C	6.1	30.82	4.0	38.0
	-20°C	11.5	10.8	7.9	18.0
	-30°C	17.3	19.7	15.3	17.3
15% RAP 5% shingles PG 58-28	-10°C	8.1	-	5.7	-
	-20°C	16.7	43.7	12.9	37.4
	-30°C	21.4	48.2	15.9	30.2

Note: in some cases results from only one test were available and thus they are reported in Table 2 without COV.

The stiffness results indicate that the addition of shingles increases the stiffness of the mixtures significantly at the two lowest test temperatures, -20°C and -30°C. The highest increase can be observed for the stiffer binder grade mixture, the PG-22 for which the stiffness almost tripled in value at -20°C and doubled at -30°C. The increase was less significant for the softer PG-28, as expected.

The strength results indicate that for the PG-22 mixture, at temperatures below -10°C, the addition of shingles increases the mixture stiffness considerably. This increase will most likely result in very large thermal stresses developing in the pavements built with these mixtures which will lead to increased thermal cracking occurrence. This effect will also occur in the PG-28 mixtures but to a much lesser extent.

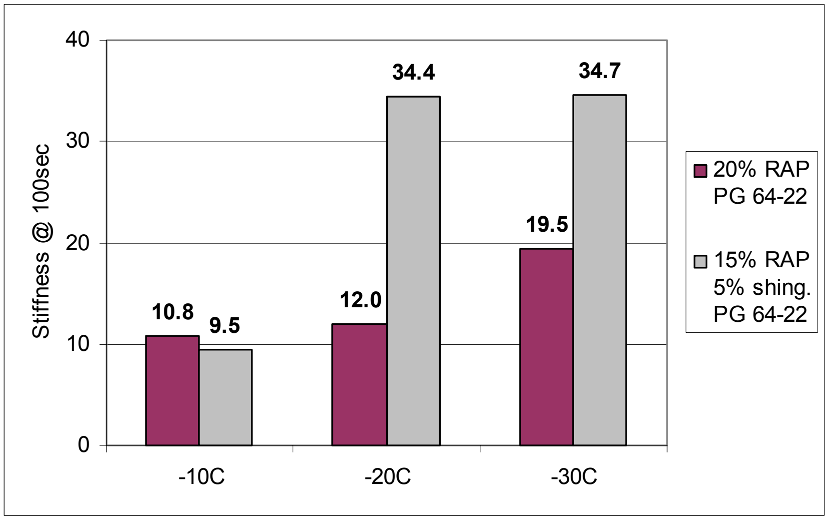

Figure 19. Mix Stiffness @ 100sec. (PG 64-22)

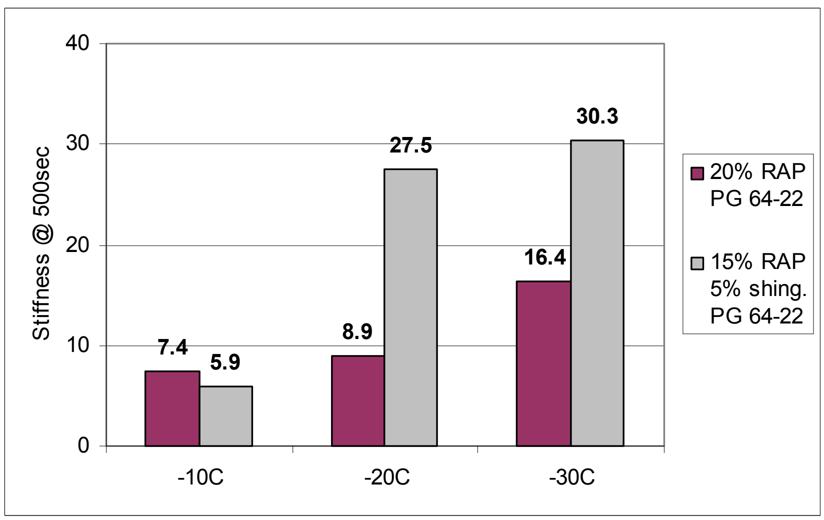

Figure 20. Mix Stiffness @ 500sec. (PG 64-22)

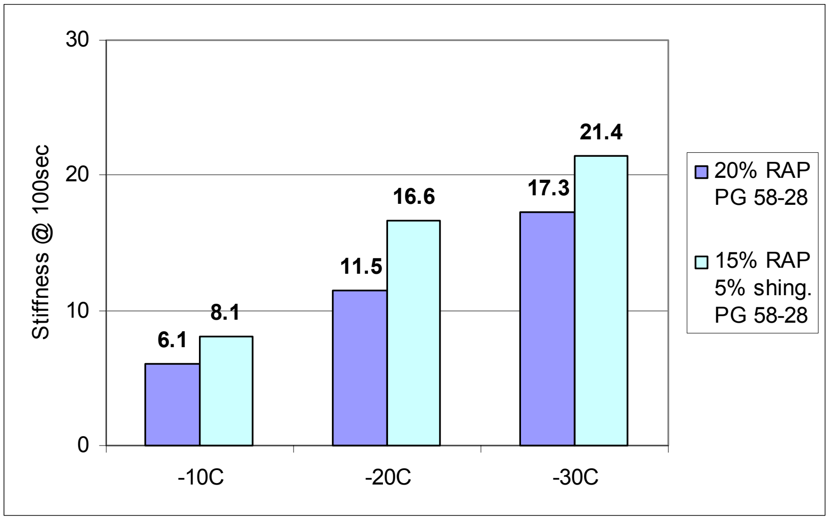

Figure 21. Mix Stiffness @ 100sec. (PG 58-28)

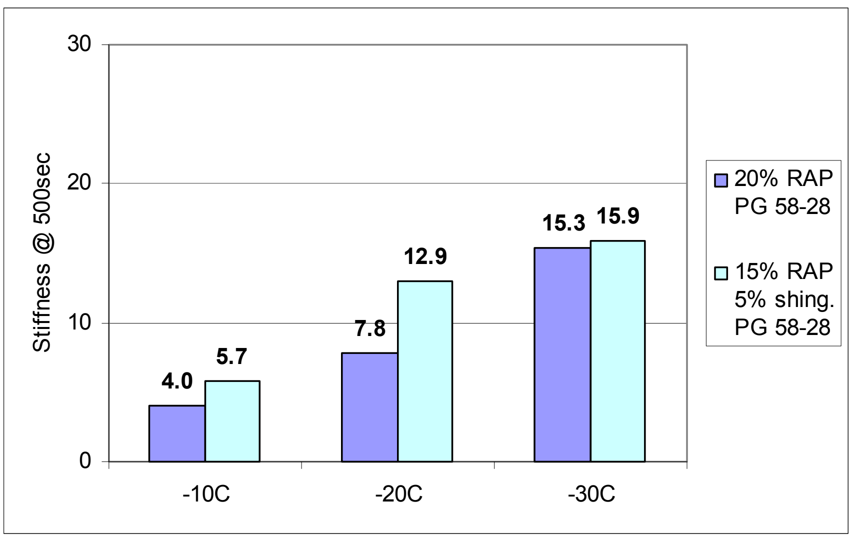

Figure 22. Mix Stiffness @ 500sec. (PG 58-28)

Table 18. Tensile Strength Results

Mixture	Temperature	Tensile Strength [MPa]	
		Average	COV [%]
20% RAP PG 64-22	-10°C	4.5	0.63
	-20°C	4.9	2.50
	-30°C	3.9	5.26
15% RAP 5% shingles PG 64-22	-10°C	4.7	3.85
	-20°C	4.3	13.26
	-30°C	4.2	1.73
20% RAP PG 58-28	-10°C	4.1	9.87
	-20°C	4.5	3.65
	-30°C	4.4	1.65
15% RAP 5% shingles PG 58-28	-10°C	4.4	4.85
	-20°C	4.5	3.27
	-30°C	4.5	3.49

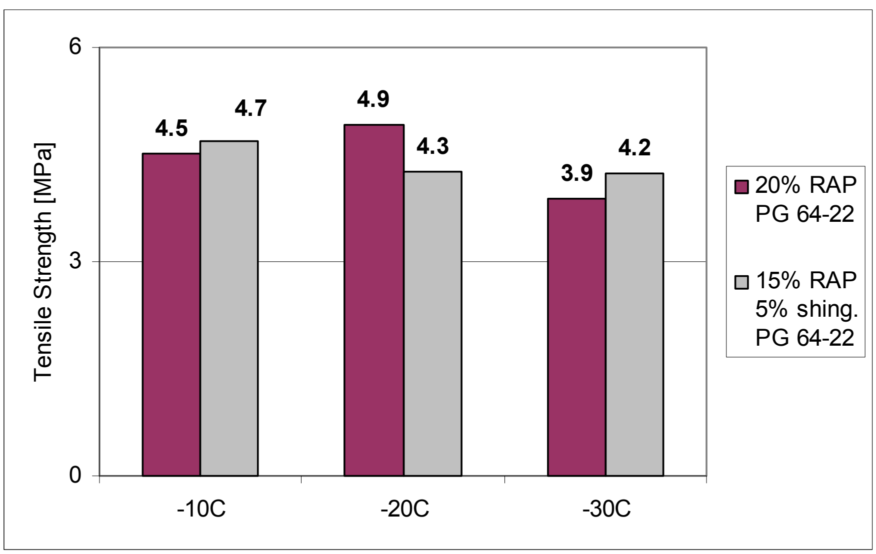

Figure 23. Tensile Strength (PG 64-22)

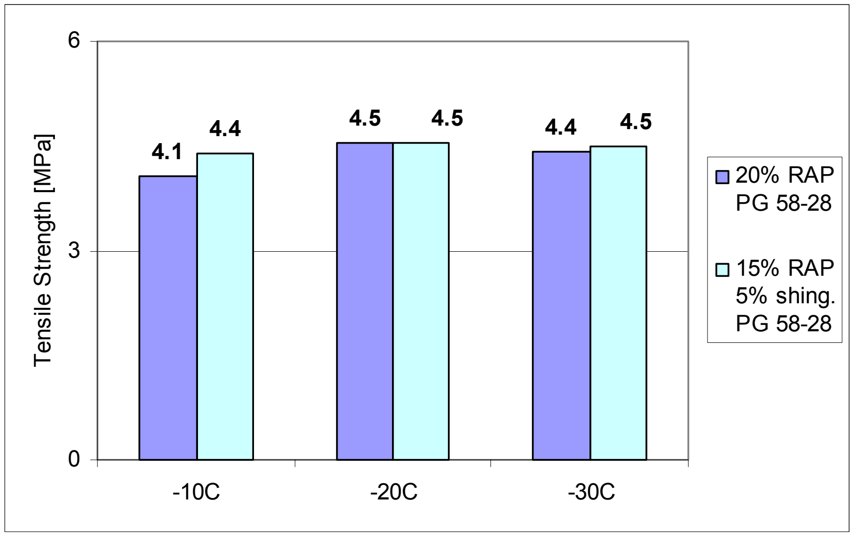

Figure 24. Tensile Strength (PG 58-28)

It is also worth mentioning that during the cutting process, the saw shutoff automatically due to the intense heat generated when cutting the specimens prepared with shingles. This did not occur for the specimens prepared only with RAP.

Comparison with Minnesota mixtures

The IDT results were compared with the Minnesota results for the 20% RAP mixtures and the 15% RAP + 5% tear-off shingles mixtures, both prepared with PG58-28 binder (not the same). The results are shown in Figures 25 and 26 and indicate lower stiffness values for the Minnesota RAP mixtures and for the combinations of RAP + RAS which also suggest differences in the tear-off RAS materials used in the two studies.

The difference in the RAP and shingles used in the two projects is also reflected in the PG limits of the extracted binders. For Minnesota materials, the PG limits for the 20% RAP extracted binder were 64.2-29.2 (see Table 12), while for Missouri the limits were 79.7-16. For Minnesota 15%RAP + 5% tear-off shingles the PG limits were 73.2-28.8 (see Table 10); for Missouri, the extracted binder from the similar mixture the limits were 99.5-4.

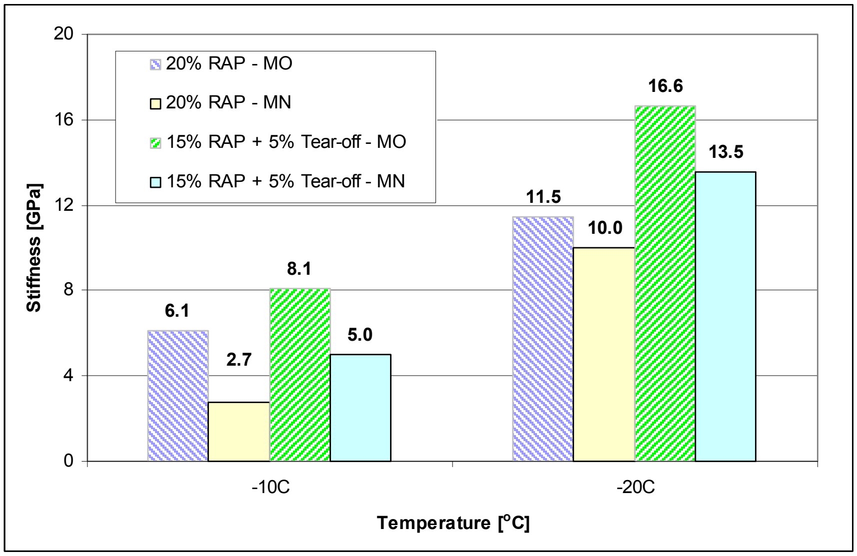

Figure 25. Mix Creep Stiffness @ 100sec

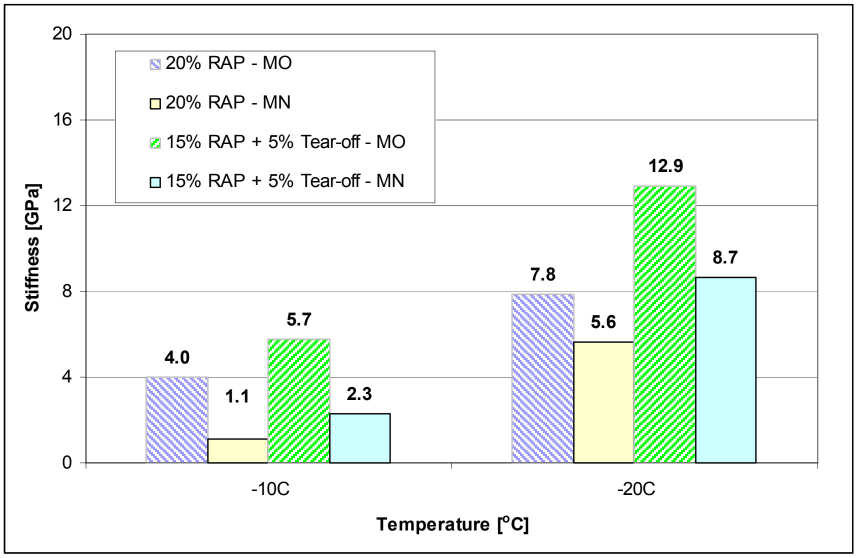

Figure 26. Mix Creep Stiffness @ 500sec

Conclusions and Recommendations

Two studies were conducted to evaluate the influence of recycled asphalt shingles addition to the low temperature properties of asphalt mixtures prepared with RAP.

In the Minnesota study, the same PG58-28 binder was used to prepare three different mixtures: 20%RAP, 15%RAP + 5% tear-off shingles, and 15%RAP + 5% manufacture waste shingles. The results indicated that the two types of shingles perform differently. The manufactured material seems to be beneficial, as it slightly increases the stiffness and did not affect the tensile strength of both mixtures and extracted binders. The binder critical temperature increased very little. The addition of tear off shingles appeared to affect properties in a more negative way, although it also increased only slightly the stiffness of the binders. However, it lowered the strength of the binder significantly at the higher test temperature and increased the binder critical temperature. This was not confirmed by the strength tests on mixtures, which did not indicate any significant reduction with the addition of tear off shingles. The extracted binder rheological data showed that the addition of shingles increases only slightly the stiffness but lowers the m-values significantly. This indicates that the addition of shingles lowers the temperature susceptibility of the binders making them stiffer than conventional and RAP modified binders at intermediate temperatures more characteristic of fatigue cracking distress.

In the Missouri study two binders, PG58-28 and PG 64-22, were used with a single source of RAP and a single source of tear off shingles. The test results indicate that for the PG-22 mixture, at temperatures below -10°C, the addition of shingles increased the mixture stiffness considerably. This increase would likely result in large thermal stresses developing in the pavements. This effect was less significant in the PG-28 mixtures. It is not clear if using a softer grade is a reasonable solution to meeting the grade for the final product as the use of a softer grade may increase the price of the mixture and make the addition of shingles less cost effective.

To validate the results of this study it becomes important to expand the analysis to more sources of materials and to build pavement sections that would offer critical field evaluation of these products.

References

1. AASHTO (July 2006 – a); “Use of Reclaimed Asphalt Shingle as an Additive in Hot Mix Asphalt: A Provisional Standard Specification (MP13)”, Association of American State Highway and Transportation Officials (Washington, D.C.; four pages).
2. AASHTO (July 2006 – b); “Provisional Standard Practice for Design Considerations when using Reclaimed Asphalt Shingles in New Hot Mix Asphalt (PP53)”, Association of American State Highway and Transportation Officials. (Washington, D.C.; six pages).
3. National Cooperative Highway Research Program (2001): Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method: Guidelines, Research Results Digest 253.
4. Standard Test Method for Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device, AASHTO TP9-96.
5. MnDOT (December 2005) - Minnesota Department of Transportation specification for scrap asphalt shingles as part of the “2360 Plant Mixed Asphalt Pavement, Combined 2360/2350 (Gyratory/Marshall design) specification” as originally amended on December 9, 2003 for the 2004 construction season. Mn/DOT Bituminous Office web page: www.mnroad.dot.state.mn.us/pavement/bituminous/specifications/2360-2350-Combined_2004.doc, refer to sub-item number 2360.2, A., a2h “Scrap Asphalt Shingles”.
6. MoDOT (March 2005) - Missouri Department of Transportation recycled shingles specification: “Substitution of Asphalt Shingles (MSP 03-01B)”. Revised as of March 9, 2005.

Discussion

MR. GERALD REINKE – Mihai, it appears from the data you showed from Jim McGraw, that, after he extracted the asphalt from the shingle RAP mixture, he then put it through the RTFO before he PAV’d it – is that correct?

PROF. MARASTEANU –I think I did not explain it correctly. He did it only for the extracted binders from the shingles and not from the mix. This was done because he assumed that they were going though the mixing process in the mixing plant.

MR. REINKE – Well then that brings up another question, because we’ve done testing on shingle mixes from Minnesota where we’ve extracted the asphalt from the mix, put that material through the PAV and what we have found is that a mix made with PG 58-28 plus shingles, grades out as a PG 64-28 and clearly your data was showing that nothing met a negative 28 on the bending beam. We were passing both S&M on that. So I guess there is still the question of was the RTFO done or wasn't it?

PROF. MARASTEANU – You'll have to ask Jim McGraw, but if I remember correctly, that was not done on the combination of shingles and RAP. Maybe we tested different sources, this is always a big issue.

MR. REINKE – Well given the contractor that you named there I would say we did.

PROF. MARASTEANU – Okay.

MR. DAVID JONES – Since you and Roger will probably be on the local arrangements committee for the Meeting in 2009 in Minneapolis, I would like to be the first to sign up for the fishing trip. My comment is – I can't wait for 20 below, (be still my heart). I'd like to caution, looking at the high weight loss on those RTFO values, I'm going to, and with the values you got, I'm going to guess that you had some solvent effects and they probably significantly affected your low temperature data. I'd be very careful about that. With those very stiff materials that you get from the shingles, it's very, very difficult to get the residual solvent off and you probably want to look at those using the SHRP extraction method and see how that goes.

PROF. MARASTEANU – This is a very good comment. Thank you.

MR. ROBERT KLUTTZ – Very interesting work. I think I maybe have a couple of answers for you on the difference between the tear-offs and the manufacturer reject. First one quick question on the manufacturer reject: were those tab cut-outs or whole shingles?

PROF. MARASTEANU - For the manufacturer reject?

MR. KLUTTZ – Most of the scrap that comes out of a shingle manufacturing process is tab cut-outs.

PROF. MARASTEANU – Most likely that's what it is.

MR. KLUTTZ – That's probably what it is, which means it's fairly simple – oh both? It is both. So on your tear-offs, when you're just testing the shingle, you only have the shingle there and usually a shingle is about 70% asphalt and 30% filler. But then you add granules so a shingle actually is only about 20% asphalt. I think why you are seeing 30% of the tear off is when you tear off the shingles, you tear off the felt paper tube, and that's about 50 or 60% asphalt. That also explains why that material is softer.

PROF. MARASTEANU – Yes, this is a very good point.

MR. KLUTTZ – And that also explains why that material is softer.

PROF. MARASTEANU –We should add this comment to the paper to clarify this issue. It is always good to learn new things. Thank you.

DR. ERVIN DUKATZ – My suggestion is a sign up list for all the fun things to do in Minnesota. I would like to add on to the last comment of Bob's on what was actually done in the mix. It's very, very important to classify what you are using, especially when you are using tear offs. There are some significant environmental concerns, from just tearing everything off of roofs, underlayment, wood and flashing with unknown coatings. So, I was glad to read in your paper that the materials that you did use for were sorted into just asphalt components. You have already had the comment on why you had 30% AC in the tear offs. The other comment and it has to be ancillary at this point, since my colleague has already spoken, is that in using tear off shingles for HMA pavements, you make an incredibly stiff pavement. It compacts very quickly. We had to run at low plant temperatures to keep odors down; the plant ran about 280 F. The mix compacted very quickly, very nice, they could see the finish roller from the back of the paver, for this project the finish roller was also the breakdown as well. It's always good, to have the breakdown roller insight of the paver. But the key point is that the mix was just incredibly, incredibly stiff, so I'd say some of your numbers showing softening were probably the solvent effect.

PROF. MARASTEANU – I believe that, thank you.

MR. KENNETH GRZYBOWSKI – A little bit on the composition of the shingles. When I did this work years ago, the fibers actually are a contributor to the mix properties, you should consider those. There are really not throw-away, they may be more valuable than the asphalt themselves. You are really looking at the ability to make an SMA or an OGFC with higher asphalt content, fiber reinforced, so that ought to be a way to look at this. The filler, the dust to asphalt ratio when you make your mix designs. You have to account that. Bob indicated that shingles have a lot of mineral filler, they do. If you don't take that in to account, then your mixes will be overly stiff. So you have to look at all of the ingredients. You had organic fibers there and their going to behave differently than the fiberglass fibers. But you have to look at it more from a mix standpoint. The reality of looking at extracted and neat binder with shingles probably has no real merit. That's not what happens. Shingles in the mix become a integral part of the binder, whereas in RAP we are still arguing if it black rock or not. The other thing is the size reduction with the shingles is critical. At minus ¾-in. you may not have in that pavement, gotten all of that down to a very fine size. If you manipulate the size of the shingles in the mixes you'll see that your properties change significantly. So you are all around where you need to be, but it's really got to focus on the mix.

PROF. MARASTEANU – I totally agree with you Ken. That's a very good comment. Yes, absolutely.

MR. ROBERT DUNNING – Shingles are composed of two parts: saturate, which you add for the felt, which has about 145 F softening point. The coating, is a 210 F to 220 F softening point, and in manufacturing a coating, you take, you have to add quite a bit of lube stock to dilute, to soften up the material before you air blow it, otherwise you can't blow it in the right areas. In making shingles you have to make absolutely certain that the saturant and the S in the coating are compatible. What happens if they're not, oil goes from the coating in to the softer saturant and then the shingle falls off. What I'm saying is if there are some anomalies, you could have cases where you have scineresis happening because the coating material is not compatible with the other asphalt that you are working with and so the data will be odd. It won't be because you did something wrong but because there is an incompatibility in the asphalt itself.

PROF. MARASTEANU – Yes, thank you, it is very important to know that this can happen.

MR. GALE PAGE – We had a pilot project some 25 years ago using AZTEC's shingle chopper, the first one, I guess and we have been trying to encourage the use of manufactured roofing waste in Florida for 25 years. Unfortunately I don't know what the deal is, whether they can't get a consistent supply of manufactured, processed roofing waste, or whether the economics in processing the material is prohibitive to make it happen. But we have been trying to encourage it for 25 years, it hasn't happened yet. We are working with a processor and that's I think the key, is to get the material processed. There are some issues with take-off's versus manufactured roofing waste other than just the stiffness of the binder. I noted that in the Missouri take-offs, it came from a single roof, that's kind of interesting. We don't see that kind of process to take off material. In Minnesota I think you used the adjectives "selected process take-offs". I think that's the key. In Florida, what we've found is that people want to come in and process a pile of take-offs which also include commercial roofing materials and also the wood and plywood, the nails, and the tar paper that was on the roof. And you're not going to do it after the fact. You have to do something up front to make sure that you don't have the deleterious materials in there: wood, paper and nails.

It can only occur before the fact, not trying to do it after the fact. At least from our experience. So, that's all I've got to say.

PROF. MARASTEANU – I would like to thank you all for your comments. This is what makes AAPT so unique and valuable! Many times, when I go back and read the papers in previous AAPT volumes, I spend a lot of time on the comments that follow the papers, because they give you a sense of the excellent forum for exchanging ideas that AAPT meetings provided over the more than seventy five years of activity. I think it is really great to have all these comments included as part of the next volume.