Final Report VTRC 10-R23

Virginia Transportation Research Council

research report

Investigation of the Use of Tear-Off Shingles in Asphalt Concrete

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Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 10-R23	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Investigation of the Use of Tear-Off Shingles in Asphalt Concrete		5. Report Date: May 2010 6. Performing Organization Code:
7. Author(s): G. W. Maupin, Jr.		8. Performing Organization Report No.: VTRC 10-R23
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 91273
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:
15. Supplementary Notes:		

16. Abstract:

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17 Key Words: Asphalt, tear-off shingles, hot mix, warm mix, fatigue tests, rut tests, recoveries, test sections	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.		
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 21	22. Price:

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FINAL REPORT

INVESTIGATION OF THE USE OF TEAR-OFF SHINGLES IN ASPHALT CONCRETE

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Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

May 2010
VTRC 10-R23

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ABSTRACT

This investigation focused on the use of asphalt shingles that had been removed from roofs and recycled into asphalt concrete. Upon invitation by the Virginia Department of Transportation (VDOT), three asphalt contractors produced and placed sections of asphalt concrete containing shingles. The sections were sampled and tested by the Virginia Transportation Research Council. Two base mixes and two surface mixes were produced, and one of the surface mixes was produced by both hot mix and warm mix technology. The laboratory tests used to evaluate the mixes were tests to determine conventional gyratory volumetric properties, gradation, and asphalt content; rut tests; fatigue tests; and tests to determine recovered asphalt properties.

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INTRODUCTION

In response to Virginia Senate Bill No. 469 in the 1990s, the Virginia Department of Transportation (VDOT) formed a committee to review materials and prepare methods to allow and encourage the use of recycled products in highway construction. Many waste materials were discussed, including roofing shingles, which contain asphalt, aggregate, and fibers. "The committee recommended that the Virginia Department of Transportation [VDOT] have its Research Council conduct some research in this area for possible future use if it is found that a reasonable supply of material is available and a proper mixture can be developed."[1] The Virginia Transportation Research Council (VTRC) conducted a literature review of the use of shingle waste in asphalt, and a draft special provision was developed by VTRC and VDOT personnel in 1999 to allow contractors to use the shingles in hot mix asphalt (HMA) upon request. A small paving project using the waste shingles would allow VDOT to evaluate the process for approval in possible future larger projects.

In 2006, Rose Brothers Paving of Ahoskie, North Carolina, submitted a request to VDOT to experiment with the use of manufacturing waste shingles on a secondary road overlay project near Franklin, Virginia. This type of waste is created during the manufacturing process and includes pieces of shingles and unsatisfactory whole shingles typically created during the manufacturing process. Approximately 2,000 tons of SM-12.5 surface mix containing 5 percent shredded manufacturing waste shingles and 2,000 tons of SM-12.5 surface mix containing 10 percent recycled asphalt pavement (RAP) were placed on the same project. The conventional mix containing RAP was installed at the same location to allow a comparison of the construction process and field performance. Both mixes contained PG 64-22 virgin binder, and the shingle waste came from a manufacturing facility in North Carolina. Since the results of all laboratory tests and early performance tests were encouraging, VTRC's Asphalt Research Advisory Committee (ARAC) recommended that research also be conducted on the use of tear-off roofing shingles.

An estimated 11 million tons of waste tear-off shingles removed from roofs is generated per year nationally.[2] Although records of separate construction debris are not tracked in Virginia, an estimate of waste shingles from Virginia roofs based on the proportion of population in Virginia compared to that of the United States is approximately 280,000 tons. If shingles contain approximately 25 percent asphalt binder, this waste product could supply 70,000 tons of binder annually in Virginia, which is enough binder to overlay or resurface 2,000 lane-miles of pavement.

However, using tear-off shingles presents several potential challenges that do not exist with the use of manufacturing waste shingles. Tear-off shingles have aged because of weathering exposure, possibly causing brittleness that could affect the durability of the pavement. In addition, asbestos was used in domestic shingles in small amounts prior to the mid-1980s. Reports of extensive asbestos testing indicated that asbestos has been detected in only very small amounts in very few samples[2,3]; therefore, it may not be a huge obstacle to shingle use. One possible approach to this problem would be to specify that roofing shingles must contain less than 1 percent asbestos. A material containing more than 1 percent asbestos is categorized as an asbestos-containing material by the National Emission Standards for Hazardous Air Pollutants. Another potential problem concerns deleterious materials such as metal flashing, nails, paper, and wood that may not be removed properly during the recycling process. The cleanliness of recycled shingle material ready to be incorporated into asphalt concrete will depend on the enforcement of specifications designed to provide an acceptable material.

Some states either allow the use of tear-off shingles or are experimenting with it. Missouri has used it to some extent since 2005. In 2009, the Missouri Department of Transportation (MoDOT) used a considerable amount of shingles in one-third of Missouri's asphalt mixes (J. Schoer, unpublished data). Missouri allows up to 7 percent shingles with no change in the grading of the virgin binder if the virgin binder provides at least 70 percent of the total binder in the mix. South Carolina has a permissive specification that allows 3 to 8 percent shingles, but its use has been limited.[4] The Construction Materials Recycling Association provides information for shingle recycling in asphalt mixes relating to the experiences of several states, references, research, recycling, etc., on its website.[5]

Generally, the early performance results of pavements containing recycled tear-off shingles have been good. Even though it is a waste material, it may offer some benefits such as rutting resistance, because of the presence of stiff binder and fibrous materials, and cracking resistance, because of the fibers.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the suitability of using tear-off shingles in asphalt concrete. The study was designed to determine whether mixes can be produced where excessive aging of the shingle additive is not detrimental to the mix durability.

The scope of the study was limited to several installations in Virginia constructed voluntarily by three asphalt paving contractors and tested by VTRC.

METHODS

Overview

VDOT issued an invitation for contractors to use tear-off shingles in a small tonnage of experimental mix in 2009 in order to gain experience with the material and allow VTRC to evaluate the product. A special provision had been developed for the experimental sections to be placed (Appendix A). Three asphalt contractors elected to try the material, producing a total of three surface mixes and two base mixes (Table 1).

Designs for the mixes are provided in Appendix B. The two BM-25.0A base mixes were produced by different contractors. One mix contained 5 percent shingles, and the other contained 4 percent shingles. Three SM-12.5A surface mixes were produced, including HMA and warm mix asphalt (WMA) versions of the same mix design by the same contractor in a "green plant." A green plant uses a small amount of water to foam the asphalt cement and provide workability at lower temperatures. Two of the surface mixes contained 5 percent shingles, and the third contained a combination of 18 percent RAP and 2 percent shingles.

Samples of mixture were taken from the truck before shipping to the paving site in each case in order to perform laboratory testing later. The target air-void content was the typical value reported through quality assurance testing by field personnel. Tests that were performed subsequently in the laboratory determined gyratory volumetric properties, rutting, and fatigue. In addition, binder was recovered from the mix and graded in order to help estimate future pavement performance.

Limited additional testing was done in the laboratory in an attempt to determine the true amount of binder in shingles and the relation between binder content determined by the ignition furnace and extraction methods. Indirect tensile testing was also performed to indicate if blending of the virgin binder and shingle binder could be influenced by the lower mixing temperatures that are typically used for WMA. The researcher thought tensile tests were appropriate simple tests that related to the behavior of the binder in this situation.

Table 1. Field Projects Containing Tear-off Shingle Waste That Was Sampled and Tested

Contractor	Type of Mix	% Recycled	Comments
Superior Paving Corp., Stevensburg, Virginia	BM-25.0A	4% shingles	
W-L Construction & Paving Inc., Strasburg, Virginia	BM-25.0A	4% shingles	Shingles pre-blended with No. 10 aggregate
Branscome Inc., Richmond, Virginia	SM-12.5A	2% shingles, 18% RAP	
W-L Construction & Paving Inc., Clear Brook, Virginia	SM-12.5A HMA	5% shingles	Shingles pre-blended with No. 10 aggregate
	SM-12.5A WMA	5% shingles	Shingles pre-blended with No. 10 aggregate

RAP = recycled asphalt pavement; HMA = hot mix asphalt; WMA = warm mix asphalt.

Test Methods for Field Samples

Volumetric Properties

Gyratory specimens were prepared with 65 gyrations in accordance with AASHTO T312[6]; this number of gyrations is the design compactive effort required for all asphalt mixes produced for VDOT. Air voids, voids filled with asphalt (VFA), and voids in the mineral aggregate (VMA) were determined for the gyratory specimens.

Rut Tests

Rut tests were performed with the Asphalt Pavement Analyzer (APA) in accordance with Virginia Test Method 110.[7] Tests were performed on beams 75 mm by 125 mm by 300 mm at 49° C using a load of 534 N and a hose pressure of 827 kPa. Rutting was measured manually after 8,000 cycles. The reported test result is the average rut depth measured manually on three beams tested at the same time.

Fatigue Tests

Fatigue tests were performed in accordance with AASHTO T 321,[6] a four-point flexural beam test. Failure of each specimen was defined as the point when 50 percent of the initial flexural stiffness was reached. Specimens were tested at various strain levels in order to develop a strain-cycles fatigue curve. The fatigue regressions form a linear log-log plot defined by Equation 1:

$$N = K\,(1/\varepsilon)^n \qquad \text{[Eq. 1]}$$

where

N = number of cycles to failure
K = constant
n = constant
ε = strain.

The endurance limit was estimated for each mix using the fatigue life and strain level for each of approximately 10 specimens. The endurance limit is defined as the strain at which asphalt concrete can endure an infinite number of load cycles.[8] In a practical sense, for this study, it was defined as the strain level at which asphalt concrete survives at least 50 million cycles, and it was projected from the regression of the test results for each mix. This endurance limit equates to approximately 500 million load cycles on an in-service pavement, i.e., 40 to 50 years of traffic on a heavily trafficked road. The endurance limit was roughly estimated from the 95 percent confidence one-sided lower prediction limit for a fatigue life of 50 million cycles (Figure 1).

Binder Recovery and Grading

Binder was recovered from mix samples by extraction (AASHTO T164, Method A) and Abson recovery (AASHTO T170).[6] Then, the recovered binder was graded in accordance with AASHTO M320. Multiple temperatures were used in order to determine an exact grade rather than just the passing grade, which is normally obtained for acceptance testing.

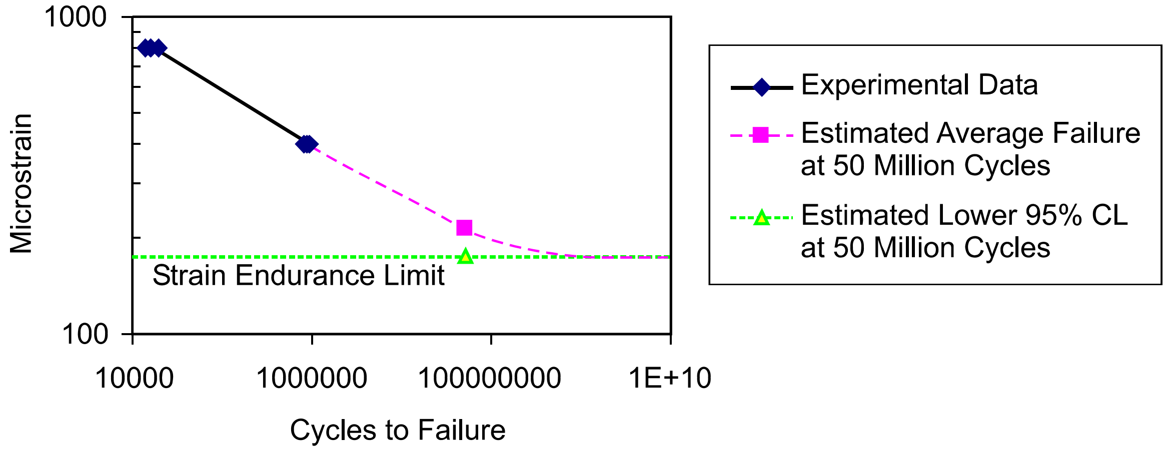

Figure 1. Example of Fatigue Endurance Limit. CL = confidence level.

Test Methods Required for Miscellaneous Additional Testing

Shingle Binder Content

Samples of recycled shingles were split and tested by extraction (AASHTO T164, Method B) and the ignition furnace method (AASHTO T308, Method A).[6] The extraction method is considered to determine directly an accurate value for binder content; the ignition furnace method requires a correction to be applied because of aggregate loss and loss of combustible materials other than asphalt binder under the high test temperature. An accurate correction factor is necessary in order for the quality control and acceptance tests to indicate the actual binder content of the asphalt concrete mixture.

Indirect Tension Tests

Indirect tension tests were performed on specimens 64 mm by 102 mm in diameter at 20°C as described for unconditioned specimens in the AASHTO T283[6] test method normally used for determining moisture susceptibility. This test was used to estimate how well the binder of the shingles combined with the virgin binder.

RESULTS AND DISCUSSION

Test Section Installations

A summary of the asphalt mixes and contractors involved in the field installations is provided in Table 1.

Superior Paving Corp., Stevensburg, Virginia

The BM-25.0 base mix was sampled twice as it was placed on two VDOT paving projects. The first sample was taken by the contractor's personnel on April 28, 2009, for a widening paving project on Route 230. Only volumetric properties and a binder recovery/grading were obtained on this sample. The same base mix was sampled on May 14, 2009, as it was being used to pave a section on Route 15 near a shopping center north of Culpeper, Virginia. For both projects, the mix was produced through a double drum plant at an average production temperature of 295°F to 300°F. The ground shingles were added through a RAP bin. Paving took place normally with no problems.

W-L Construction & Paving Inc., Strasburg, Virginia

The BM-25.0 base mix was sampled and placed on a small subdivision street on June 22, 2009. The mix was produced through a batch plant at an average temperature of 300°F. The shingles were pre-blended in a 50-50 blend with No. 10 aggregate and stockpiled before being fed into the drum through the RAP collar in proper portions resulting in 4 percent shingles in the asphalt mix. Paving took place normally with no problems, although the mix did exhibit a tender zone that necessitated a delay of rolling during compaction.

Branscome Inc., Richmond, Virginia

The SM-12.5 surface mix was sampled and placed on Route 460 west of Petersburg, Virginia, on July 30, 2009. The mix was produced with a double drum plant at an average temperature of 300°F. The mix contained a combination of recycled materials consisting of 18 percent RAP and 2 percent shingles. The two materials were added concurrently to the RAP conveyor belt in the proper proportions and entered the plant drum through the conventional RAP collar. No problems were encountered with the paving process.

W-L Construction & Paving Inc., Clear Brook, Virginia

The SM-12.5 surface mix was sampled and placed on the shoulder of Route 522 south of Winchester, Virginia, on October 7, 2009. The HMA and WMA were produced through the same double drum plant at average temperatures of 300°F and 270°F, respectively. The WMA was produced using the green plant foaming system that used a very small amount of water to cause a foaming action of the asphalt. The shingles were pre-blended in a 50-50 blend with No. 10 aggregate before being entered into the drum through the RAP collar. The target shingle content was 5 percent. Paving proceeded with no observed problems.

Laboratory Tests

Volumetric Properties and Ignition Furnace Results

Volumetric properties and gradation results for the field samples from each project are provided in Tables 2 and 3, respectively. The volumetric properties, air voids, and VFA were all within acceptable production limits. VMA was greater or very close to the minimum design values. The property values for the samples from Superior Paving Corp. projects were very close, which indicates consistency in the product from day to day. Similarly, the asphalt contents and gradations representing fine sieve sizes that might be affected by shingles were very close for the samples from Superior Paving Corp., further verifying consistency in the product. The

Table 2. Volumetric Properties of Field Samples

Contractor	Mix	Air Voids, %	VMA, %	VFA, %
Superior Paving Corp., Stevensburg	BM-25.0	2.3	13.2	82.5
		2.4	14.8	83.6
W-L Construction & Paving Inc., Strasburg	BM-25.0	1.5	11.8	87.3
Branscome Inc., Richmond	SM-12.5	3.5	15.2	77.3
W-L Construction & Paving Inc., Clear Brook	SM-12.5 HMA	3.2	16.1	80.1
	SM-12.5 WMA	3.0	16.3	81.5
Design (D) / Production (P) Limits	BM-25.0	1.0-4.0P	>12.0D	67.0-92.0P
Design (D) / Production (P) Limits	SM-12.5	2.0-5.0P	>14.0D	65.0-83.0P

VMA = voids in mineral aggregate; VFA = voids filled with asphalt; HMA = hot mix asphalt, WMA = warm mix asphalt.

Table 3. Gradation and Asphalt Content

Sieve, mm	Superior BM-25.0	Superior BM-25.0	W-L BM-25.0	Branscome SM-12.5	W-L SM-12.5 HMA	W-L SM-12.5 WMA	Design Range BM-25.0	Design Range SM-12.5
25.0	99.5	100.0	99.3				90-100	
19.0	92.4	94.0	94.7	100.0	100.0	100.0	< 90	100
12.5	71.5	77.1	81.2	96.8	95.5	95.1		95-100
9.5	59.8	64.9	74.1	88.7	83.8	83.5		<90
4.75	38.8	41.5	56.6	59.4	58.8	58.8		
2.36	30.5	32.7	36.7	43.8	42.1	41.6	19-38	34-50
1.18	25.5	26.7	23.8	33.8	26.8	26.8		
0.6	20.1	20.5	16.9	23.6	17.8	18.4		
0.3	14.3	14.5	13.0	14.8	13.1	13.7		
0.15	9.5	9.6	10.3	9.0	10.4	10.4		
0.075	6.2	6.3	8.3	5.7	8.1	7.2	1-7	2-10
% AC[a]	4.9 (5.0)	5.2 (5.0)	5.0 (5.0)	5.3 (5.5)	5.9 (5.9)	6.1 (5.9)		

Superior = Superior Paving Corp., Stevensburg, Virginia; W-L = W-L Construction & Paving Inc., Strasburg, Virginia; Branscome = Branscome Inc., Richmond, Virginia; W-L = W-L Construction & Paving Inc., Clear Brook, Virginia; HMA = hot mix asphalt; WMA = warm mix asphalt.
[a] Asphalt content design values are in parentheses.

asphalt contents of single samples for all projects were well within production limits, i.e., ±0.3 percent for the average of four samples.

W-L Construction & Paving Inc. indicated that the shingles were pre-blended with the No. 10 aggregate in a 50-50 ratio. Samples of the blended material were tested for asphalt binder content with the ignition furnace method for their base mix and surface mix projects. With the ignition furnace it was determined that the blend contained shingle / No. 10 aggregate ratios of 33/67 and 37/65 for the base mix and surface mix projects, respectively. However, the contractor apparently adjusted the amount of the blended material entering the plant to yield the proper mix binder content, as evidenced by the production mix binder contents being very close to the target job mix values.

Rut Tests

The rut test results are provided in Table 4. According to VDOT's maximum allowable limits, the test results indicated that the mixes would be satisfactory for heavy traffic situations from a rutting resistance standpoint. In addition, the rut depths were comparable to those reported for conventional Virginia D surface mixes containing PG 70-22 binder that were tested in an earlier high-RAP study.[9]

Table 4. Rut Test Results

Contractor	Mix	Air Voids, %	Rut Depth, mm
Superior Paving Corp., Stevensburg	BM-25.0	7.3	1.5
W-L Construction & Paving Inc., Strasburg	BM-25.0	7.9	1.3
Branscome Inc., Richmond	SM-12.5	7.6	1.3
W-L Construction & Paving Inc., Clear Brook	SM-12.5 HMA	7.5	0.9
	SM-12.5 WMA	7.4	0.9
VDOT allowable maximum for surface mixes	Low traffic: PG 64-22		7.0
	Medium traffic: PG 70-22		5.5
	High-traffic: Modified binder		3.5

HMA = hot mix asphalt; WMA = warm mix asphalt; VDOT = Virginia Department of Transportation.

Fatigue Tests

The fatigue regression constants and endurance limits as described previously are provided in Table 5. The fatigue regression log-log plots are shown in Figure 2. A previous high-RAP study tested eight mixes containing 21 to 30 percent RAP that yielded endurance limits ranging from 83 to 130 microstrain.[9] Those mixes contained considerable RAP and are used routinely by VDOT. The fatigue endurance limits of the mixes containing shingles were within the range of values for endurance limits of mixes currently allowed by VDOT.

Table 5. Fatigue Test Results

Contractor	Mix	Average Air Voids, %	Strain Endurance Limit, με	Fatigue Constant, K	Fatigue Constant, n
Superior Paving Corp., Stevensburg	BM-25.0	6.8	148	1.42988×10^{-22}	7.8076
W-L Construction & Paving Inc., Strasburg	BM-25.0	7.1	111	2.34744×10^{-16}	6.1336
Branscome Inc., Richmond	SM-12.5	7.2	75	3.22881×10^{-10}	4.3159
W-L Construction & Paving Inc., Clear Brook	SM-12.5 HMA	6.9	140	4.50120×10^{-14}	5.5666
	SM-12.5 WMA	7.0	184	2.23152×10^{-19}	7.1704

HMA = hot-mix asphalt; WMA = warm-mix asphalt.

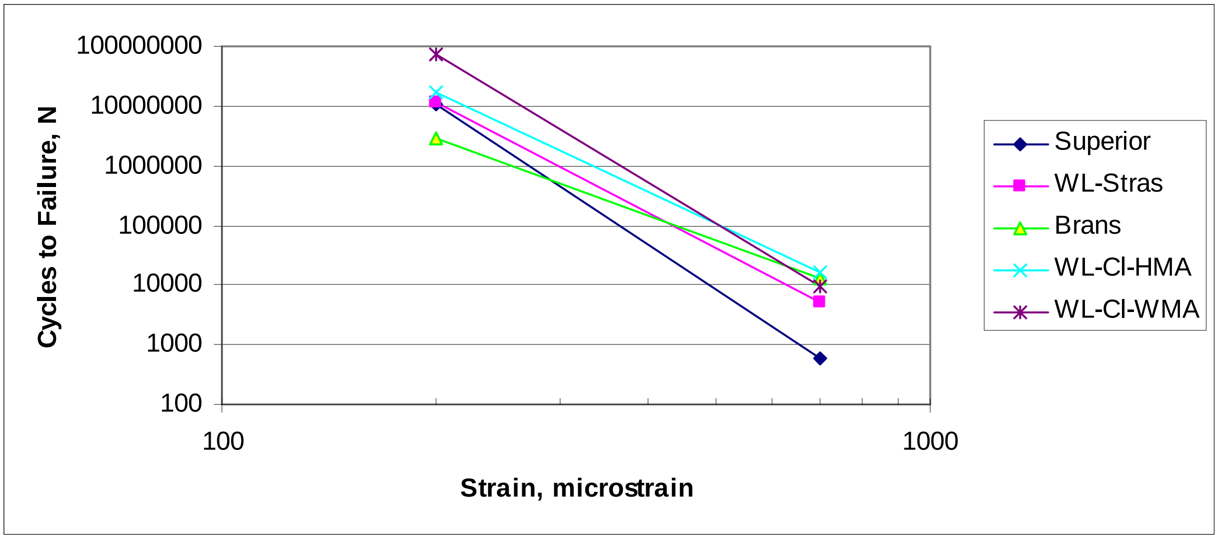

Figure 2. Laboratory Fatigue Life Regressions. Superior = Superior Paving Corp., Stevensburg, Virginia; WL-Stras = W-L Construction & Paving Inc., Strasburg, Virginia; Brans = Branscome Inc., Richmond, Virginia; WL-Cl-HMA = W-L Construction & Paving Inc., Clear Brook, Virginia, Hot-Mix Asphalt; WL-Cl-WMA = W-L Construction & Paving Inc., Clear Brook, Virginia, Warm-Mix Asphalt.

Binder Recoveries and Grading

The performance gradings of the binders recovered from field samples of the projects are listed in Table 6. In reference to the virgin PG 64-22 binder, the high-temperature grade was increased one grade on three of the projects, two grades on two of the projects, and three grades on one of the projects. The low-temperature grade deteriorated one grade on five of the cases and stayed the same in the sixth case. However, in all cases, the binders were a -16 low-temperature grade or better, which passed VDOT specifications. Bonaquist reported at the 4th Asphalt Shingle Recycling Forum in Chicago that the addition of 25 percent roofing shingle binder improves the high-temperature grade two levels and makes the low-temperature grade one grade poorer, further supporting the results of the present study. There was no apparent difference in the properties of the binder recovered from the HMA and WMA samples for the W-L Construction & Paving Inc. project on Route 522. Perhaps the temperature difference of 30°F for the production of these mixes was not sufficient to cause stiffening of the binder.

Table 6. Grading of Asphalt Binder Recoveries of Field Samples

Contractor	Mix ID	Route	PG Grading	
			Exact	**Passing**
Superior Paving Corp., Stevensburg	BM-25.0	230	PG 83-18	PG 82-16
Superior Paving Corp., Stevensburg	BM-25.0	15	PG 81-19	PG 76-16
W-L Construction & Paving Inc., Strasburg	BM-25.0	Subdivision	PG 81-20	PG 76-16
Branscome Inc., Richmond	SM-12.5	460	PG 74-25	PG 70-22
W-L Construction & Paving Inc., Clear Brook	SM-12.5 HMA	522	PG 74-20	PG 70-16
	SM-12.5 WMA	522	PG 74-21	PG 70-16

HMA = hot-mix asphalt; WMA = warm-mix asphalt.

Additional Laboratory Testing

Shingle Material Properties

Samples of shingles were subjected to binder removal by solvent extraction and by the ignition furnace, which is the generally accepted method for asphalt content determination. The solvent extraction would be considered to yield the "true" binder content, whereas the ignition furnace also burns some foreign material and possibly aggregate. The purpose was to determine an ignition furnace correction factor that should be applied when quality control / quality acceptance tests are performed.

Two samples of ground shingles were tested by solvent extraction, yielding 24.3 percent binder; companion samples yielded 29.2 percent binder by the ignition furnace test. In other words, the ignition furnace test indicated that the shingles contained about 5 percent more binder than they actually contained. A similar determination by South Carolina found that the difference between extraction and ignition testing was 2 percent for its shingles.[9] Assuming a correction of 5 percent for shingles, the correction for an ignition furnace test that should be applied to the binder content of mix containing shingles would be:

[(% shingles) x (% difference between binder determined by extraction and ignition furnace)] / 100

Therefore, an approximate 0.05 percent shingle correction factor for each 1 percent of shingles would need to be applied to the ignition furnace results for binder content of a mix. A mix containing 4 percent shingles would need to have a 0.2 percent correction applied in addition to the normal aggregate correction. This factor was determined only from a limited sampling and could vary somewhat for other sources of shingles.

Binder Blending for Warm Mix

An SM-9.5D surface mix containing PG 70-22 binder was tested in indirect tension. The tests were performed on specimens containing shingle contents ranging from 0 to 5 percent that had been mixed at two temperatures: 250°F and 300°F. The specimens were mixed at 300°F to simulate HMA and at 250°F to simulate WMA. The idea was to determine how mix stiffness was affected by the mixing temperature. If the shingle binder and virgin binder combined to the same degree at both mixing temperatures, the mix stiffness should have displayed the same differential increase at both temperatures as shingle content was increased.

Table 7 lists the strengths and Figure 3 shows graphically the strength difference attributable to inadequate blending of the virgin and shingle binders. The 300°F curve was shifted down to the 250°F curve to eliminate the additional aging effects. The strength difference between the shifted curve and 250°F curve can then be attributed to inadequate blending. With 5 percent shingles, the strength of the WMA mix increased only about 50 percent as much as that of the HMA mix [(190-155) / (245-183)] = 0.56. It is difficult to duplicate field conditions in the laboratory, and perhaps better binder blending would normally occur in a hot-mix plant than in a laboratory experiment because of more vigorous mixing.

Table 7. Tensile Strength (psi)

% Shingles	Mixed at 250°F (HMA)	Mixed at 300°F (WMA)
0	155	183
2	165	210
3	168	220
4	173	240
5	190	245

HMA = hot mix asphalt; WMA = warm mix asphalt.

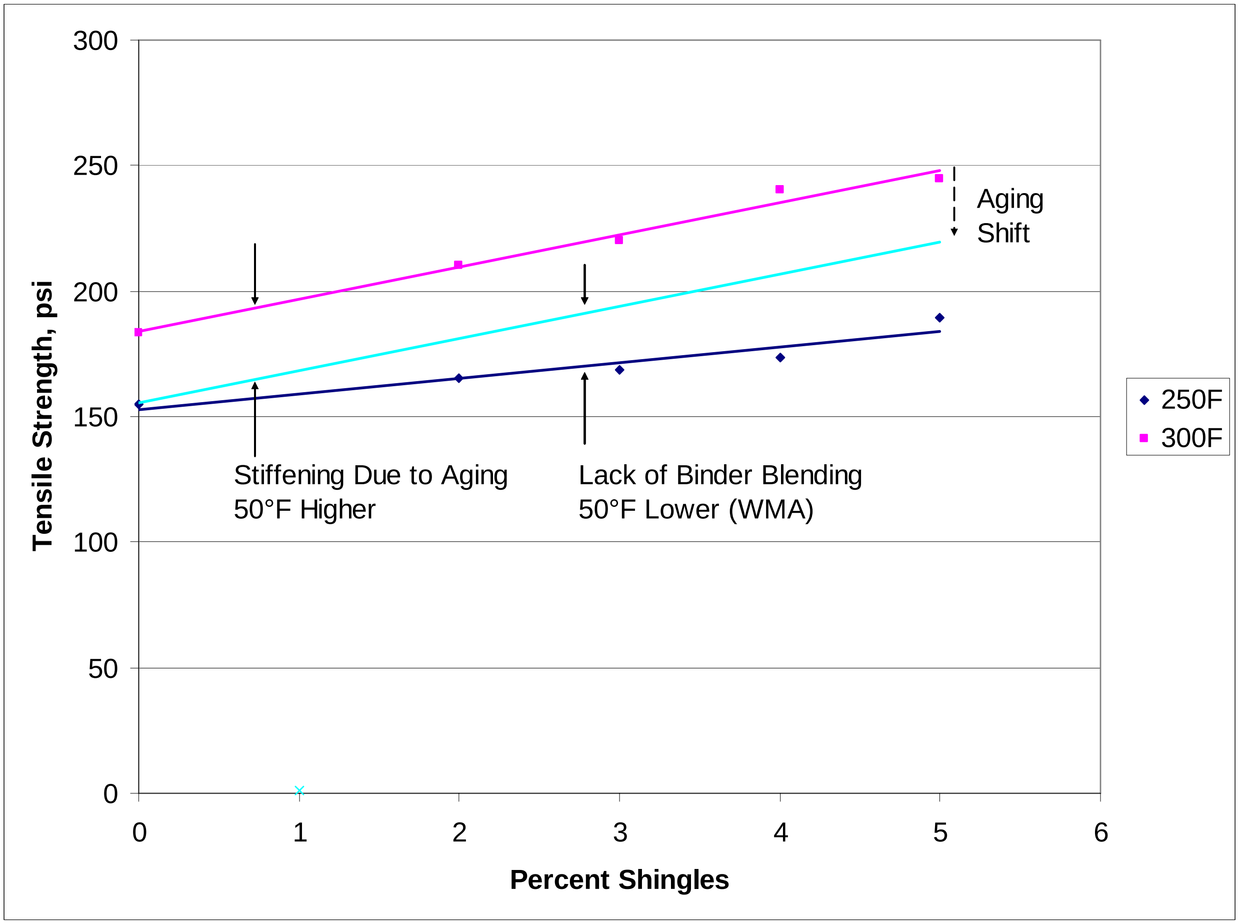

Figure 3. Effect of Mixing Temperature on Shingle and Virgin Binder Blending. WMA = warm mix asphalt.

Summary

The construction experience of contractors with tear-off shingles was satisfactory with no problems. The volumetric properties of mix from each project were within VDOT specifications. Rut tests indicated that the mixes containing shingles can be used in situations involving heavy traffic where rutting is a concern. Fatigue test results indicated that fatigue durability is comparable to that being provided by current mixes. Binder recoveries indicated an improvement of high-temperature grading, and the low-temperature grading was within VDOT specifications. Limited indirect tensile testing indicated that blending of the virgin and shingle binder was less for WMA than for HMA. This is an area for possible research.

MoDOT allows up to 30 percent of the shingle binder to be used without a change in the virgin binder grade, and it has used a considerable amount of shingles in its hot mix since 2005 with satisfactory performance (J. Schroer, unpublished data). MoDOT used approximately 53,000 tons of shingles in 2009, of which about 90 percent was tear-off shingles. Considering Missouri's good pavement performance, the current VDOT special provision allowing a maximum of 25 percent aged shingle binder versus MoDOT's 30 percent shingle binder with no change in virgin binder grade should be conservative.

CONCLUSIONS

- *The use of tear-off roofing shingles in asphalt mixes should produce satisfactory mixes.*
- *Routine mix properties during construction should be satisfactory.*
- *Rutting resistance complies with the requirements for VDOT mixes used in heavy traffic.*
- *Shingle mixes perform as well as conventional high-RAP mixes.*
- *The high-temperature grading of binders was improved, and the low-temperature grading was within VDOT specifications.*
- *The ignition furnace correction factor should be based not only on aggregate correction but also on the combustibility of non-asphalt materials contained in the shingle waste.*

RECOMMENDATIONS

1. *VDOT's Materials Division should develop a modified specification stating that recycled shingles must be certified to be free of asbestos-containing material as defined by the National Emission Standards for Hazardous Air Pollutants (i.e., a material containing less than 1.0 percent asbestos) and that the source of recycled shingles must be residential homes with no more than four units per structure.* Such shingles have very little chance of containing asbestos. Such specifications would possibly minimize the amount of required asbestos testing but would necessitate certification by the recycler concerning the source of the product.

2. *With the changes noted in Recommendation 1, VDOT's Materials Division should continue the use of the current special provision allowing tear-off shingle waste for general usage.*

COSTS AND BENEFITS ASSESSMENT

A representative of Oldcastle Materials, Inc., of Atlanta, Georgia, reported at the 4th Asphalt Shingle Recycling Forum held in 2009 that the cost savings per ton of plant mix is approximately \$3 to \$5 when reclaimed shingles are used. The source of the shingles used in

HMA in Virginia is Asphalt Roof Recycling Co., Mt. Airy, Maryland. Assuming an average cost of virgin binder for VDOT's 2009 construction season of approximately $400 per ton and the FOB price of reclaimed shingles from Mt. Airy, a savings of approximately $3.40 per ton of HMA would be realized with the use of reclaimed shingles. If the transportation costs of hauling the shingles to the asphalt plants of the contractors involved in this study is also considered, the savings would be reduced by $0.40 to $1.00 per ton. If the process is approved by VDOT for general usage, shingle recyclers will be located near the facilities of asphalt contractors, resulting in lower shingle costs. If a savings of $3 per ton could have been realized on one-half of the 400,000 tons of HMA produced last year for VDOT, VDOT would have saved approximately $600,000. Potential cost savings is further evidenced by the fact that contractors were willing to try the process with no additional compensation from VDOT and some contractors continued to use the shingles on private work.

As already mentioned, a considerable amount of shingles in Virginia is currently being disposed of in waste facilities. The use of recycled shingles would not only provide cost savings for VDOT but would also be an environmental plus for Virginians since waste material that would otherwise go to a landfill would be used. The use of shingle waste in asphalt concrete would also create possible business opportunities in recycling and processing the shingles.

ACKNOWLEDGMENTS

The author acknowledges those who made this research successful. Personnel from VDOT's Materials Division—Bill Bailey, Trenton Clark, and Todd Rorrer—helped arrange the paving and were responsible for performing some of the tests. Materials personnel from VDOT's Staunton, Culpeper, and Richmond districts were helpful in coordinating sampling and observing the paving processes. Personnel from Superior Paving Corp., W-L Construction & Paving Inc., and Branscome Inc. were especially helpful in providing paving information and facilitating sampling at the hot-mix plants. Thanks also go to the Asphalt Roof Recycling Company in Mt. Airy, Maryland, for providing numerous samples of recycled shingles for testing. VTRC personnel—Troy Deeds, Donnie Dodds, and Aaron Dupont—were especially diligent in project coordination, sampling and the extensive testing that was required. Appreciation is also expressed to the people who reviewed the report and offered comments: Alex Apeagyei, Bill Bailey, Trenton Clark, Stacey Diefenderfer, Haroon Shami, and David Shiells.

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APPENDIX A

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
RECLAIMED ASPHALT SHINGLES (RAS) (TEAR OFFS) IN HOT MIX ASPHALT CONCRETE

June 24, 2008

I. DESCRIPTION

This specification covers reclaimed asphalt shingles (RAS) tear-offs used in hot mix asphalt (HMA) concrete. These requirements are to be met in addition to those contained in Section 211. The Contractor shall receive approval by the Engineer to use RAS tear-offs in the HMA concrete.

II. MATERIALS

(a) **Tear-off RAS materials** shall be discarded shingle scrap from the re-roofing of domestic buildings. These tear-offs shall have been produced by the manufacturing process for roofing shingles. Blending or mixing of Tear-offs with Tabs shall not be permitted.

Tear-off RAS materials shall be free from foreign materials such as paper, roofing nails, wood, or metal flashing. Materials shall be shredded prior to being incorporated in the HMA mixture so that one hundred percent of the shredded pieces are less than 1/2 inches (12. 5 mm) in any dimension.

Tear-off RAS materials shall not contain asbestos fibers. If tear-off shingles are to be used, the Contactor shall furnish test results of RAS sample analysis for Polarized Light Microscopy (PLM) on the tear-off shingles which certify the material to be used is free of asbestos. Testing is required at the specified rate of 1 per 100 tons of RAS prior to processing and results shall be submitted prior to or during the stockpile approval process.

(b) **Asphalt Binder shall be** Performance Grade (PG) of asphalt conforming to the requirements specified in Section 211 and Table II-14A, Asphalt Concrete Mixtures (Superpave). The selection of the PG of asphalt from Table II-14A shall be governed by the combined amount of RAS and RAP. (For estimation purposes only, it may be assumed that 1 percent RAS is equivalent to 4 percent RAP.)

III. DETAIL REQUIREMENTS

RAS tear-offs in hot mix asphalt concrete shall be mixed mechanically in a plant specifically designed for producing hot mix asphalt for HMA production.

IV. JOB-MIX FORMULA

The Contractor shall submit a job mix formula in accordance to section 211.03. The Contractor shall submit material samples to include the RAS stockpiled tear-off shingles, reclaimed asphalt pavement (RAP) and PG Binder.

The amount of RAS material used in the recycled mixture shall be no more than five percent of the total mixture weight. The combined percentages of RAS and RAP shall not contribute more than twenty- five percent of the total asphalt content of the mixture, according to the following equation:

$$\frac{\left(\%RAS_{mix} \times {}^{\%AC_{RAS}}\!/_{100}\right) + \left(\%RAP_{mix} \times {}^{\%AC_{RAP}}\!/_{100}\right)}{\%AC_{JMF}} \leq 25.0\% \qquad \text{[Eq. 2]}$$

Where:

$\% RAS_{mix} =$ Percent RAS in the Job Mix Formula
$\% AC_{RAS} =$ Average Percent AC in the RAS
$\% RAP_{mix} =$ Percent RAP in the Job Mix Formula
$\% AC_{RAP} =$ Average Percent AC in the RAP
$\% AC_{JMF} =$ Design AC content of the JMF

The Contractor shall determine the asphalt content of the RAS using AASHTO T-164, Method B, or AASHTO T-308 and report the average results to the nearest 0.1 percent.

V. STORING MATERIALS

Contractors shall store tear-off RAS by stockpiling either whole or as partial shingles which have not been shredded or shredded shingles that meet the maximum size requirements. Stockpiled RAS shall not be contaminated by dirt or other objectionable foreign materials. Blending of the shingles with fine aggregate may be necessary to prevent conglomeration of shingle particles. When fine aggregate is used for this purpose, this material shall be accounted for in the mix design. Tabs shall be stockpiled separately.

APPENDIX B

JOB MIX DESIGNS

Superior Paving Corp., Stevensburg, Virginia: BM-25.0A

Percentage	*Material*	*Source and Location*
36%	No. 56	Luck Stone, Stevensburg, Virginia
27%	No. 60	Luck Stone, Stevensburg, Virginia
13%	Natural Sand	Ennstone-Morie, Fredericksburg, Virginia
4%	Shingles	Asphalt Roof Recycling Co., Mt. Airy, Maryland
5.0%*	PG 64-22	Nu Star, Baltimore, Maryland, and Dumfries, Virginia Associated Asphalt, Martinsburg, West Virginia
0.5% More Life 3300		Rohm-Haas, Cincinnati, Ohio

*Includes binder from shingles.

Sieve, mm	% Passing
37.5	100
25.0	96
19.0	90
2.36	33
0.075	5.4

Branscome, Inc., Richmond, Virginia: SM 12.5A

Percentage	*Material*	*Source and Location*
45%	No. 78	Luck Stone, Richmond, Virginia
15%	No. 10	Luck Stone, Richmond, Virginia
20%	Natural Sand	Branscome Inc., Richmond, Virginia
18%	RAP	Branscome Inc., Richmond, Virginia
2%	Shingles	Asphalt Roof Recycling Co., Mt. Airy, Maryland
5.5%*	PG 64-22	Valero, Hopewell, Virginia
0.5%	Adhere HP+	ARR-MAZ Products, Winter Haven, Florida

* Includes binder from shingles.

Sieve, mm	% Passing
19.0	100
12.5	96
9.5	90
2.36	46
0.075	6.0

W-L Construction & Paving Inc., Strasburg, Virginia: BM-25.0A

Percentage	*Material*	*Source and Location*
49%	No. 57	Carmeuse Lime & Stone, Strasburg, Virginia
10%	No. 8	Carmeuse Lime & Stone, Strasburg, Virginia
37%	No. 10	Carmeuse Lime & Stone, Strasburg, Virginia
4%	Shingles	Asphalt Roof Recycling Co., Mt. Airy, Maryland
5.0%*	PG 64-22	Associated Asphalt, Martinsburg, West Virginia
0.5%	Adhere 77-00	ARR-MAZ Products, Winter Haven, Florida

* Includes binder from shingles.

Sieve, mm	% Passing
37.5	100
25.0	96
19.0	82
2.36	30
0.075	6.0

W-L Construction & Paving Inc., Clear Brook, Virginia: SM-12.5A (HMA and WMA)

Percentage	*Material*	*Source and Location*
50%	#78	Vulcan Materials, Warrenton, Virginia
30%	#10	Vulcan Materials, Warrenton, Virginia
10%	Manufactured Sand	Carmeuse Lime & Stone, Clear Brook, Virginia
5%	#10	Carmeuse Lime & Stone, Clear Brook, Virginia
5%	Shingles	Asphalt Roof Recycling Co., Mt. Airy, Maryland
5.9%*	PG 64-22	Citgo, Dumfries, Virginia
0.5%	Adhere 77-00	ARR-MAZ Products, Winter Haven, Florida

* Includes binder from shingles.

Sieve, mm	% Passing
19.0	100
12.5	95
9.5	84
2.36	43
0.075	8.4

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