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research report

Use of Manufactured Waste Shingles in a Hot-Mix Asphalt Field Project

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Abstract

The Virginia Department of Transportation (VDOT) is faced with trying to maintain its roads with materials whose cost is increasing at an alarming rate. The significant cost increase for asphalt concrete, which is used to pave a majority of Virginia's roads, is primarily linked to the cost increase for the petroleum products from which asphalt binder is produced. In the 1990s, VDOT developed a special provision to allow contractors, upon request, to use waste shingles in asphalt concrete. These shingles contain approximately 20 percent asphalt, which replaces part of the expensive virgin binder in the mix. In 2006, a contractor requested that the manufactured waste shingles be allowed on an overlay paving project in southeast Virginia.

The 4.1-mile two-lane section was paved using a surface mix containing 5 percent shingle waste and a surface mix containing 10 percent recycled asphalt pavement for comparison. Density tests were performed on the pavement, and various laboratory tests such as permeability, fatigue, tensile strength ratio, rut, and binder recoveries were performed on samples of mix collected during the construction of the section. Both the field and laboratory test results indicate that the behavior and performance of the two mixes should be similar.

The study recommends that VDOT's Materials Division prepare a permanent special provision to allow the manufactured waste to be used in asphalt. Because of the success of using manufactured waste, tear-off shingle waste resulting from replacing home shingles should also be investigated.

Although manufactured waste shingles are available only in the northeastern part of North Carolina, several Virginia counties near the North Carolina border may be able to realize a cost reduction if shingles are used in the future. There is potential for approximately 50,000 tons of hot-mix plant mix containing waste shingles to be supplied to VDOT's Hampton Roads District per year. It was estimated that as much as $2.69 could be saved for every ton of asphalt that uses the waste shingles.

FINAL REPORT

USE OF MANUFACTURED WASTE SHINGLES IN A HOT-MIX ASPHALT FIELD PROJECT

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

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ABSTRACT

The Virginia Department of Transportation (VDOT) is faced with trying to maintain its roads with materials whose cost is increasing at an alarming rate. The significant cost increase for asphalt concrete, which is used to pave a majority of Virginia's roads, is primarily linked to the cost increase for the petroleum products from which asphalt binder is produced. In the 1990s, VDOT developed a special provision to allow contractors, upon request, to use waste shingles in asphalt concrete. These shingles contain approximately 20 percent asphalt, which replaces part of the expensive virgin binder in the mix. In 2006, a contractor requested that the manufactured waste shingles be allowed on an overlay paving project in southeast Virginia.

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INTRODUCTION

Virginia has been active in the evaluation of techniques to utilize waste materials in highway construction. In the 1990s, Virginia Senate Bill 469 asked the Virginia Department of Transportation (VDOT) to form a "Recycled Materials in Highway Construction Advisory Committee" to make recommendations to VDOT regarding the use of recycled materials in highway construction. The materials found to have the most potential were glass; tires; plastics; aggregate fines; roofing material; bituminous concrete; and miscellaneous items such as yard waste, wood waste, concrete, and newspaper. Efforts were made to use waste automobile tire rubber[1] and waste glass[2] in asphalt, but with little success. The tire rubber did not appear to be cost beneficial, and the glass presented safety problems in the residential area where it was used.

The committee also recommended that research be conducted in the use of recycled roofing material. As a result, VDOT developed a draft specification for its use in asphalt concrete in 1999.[3] The specification allowed either tear-offs, i.e., roofing removed from buildings, or manufacturing waste. The manufacturing waste tends to be more consistent in material characteristics than do tear-offs and does not contain deleterious materials such as asbestos. VDOT wanted to gain experience and verify that the process would produce mixes that were equal to or better than those without shingles and intended that the draft specification be used to place trial sections upon requests from contractors before providing blanket approval for a specific source and process. Although there had been inquiries prior to 2006, no contractors had followed through with a request to place asphalt concrete containing roofing material.

In 2006, a North Carolina contractor requested approval to use asphalt concrete containing manufactured shingle waste. Although the source of the waste was in North Carolina, there was a potential advantage in decreasing the cost of the asphalt concrete in this geographic area in the southeastern corner of Virginia. The cost of asphalt binder has recently increased considerably, and shingles contain an appreciable amount of asphalt binder; therefore, the future savings in the cost of mix binder could be substantial. Numerous investigators have reported on the use of waste shingles, which is allowed in several states, including North Carolina. The asphalt pavements in North Carolina that have used manufacturing shingle waste have performed well. The Construction Materials Recycling Organization et al. developed a comprehensive list of references, including technical articles, magazine articles, and presentations, concerning recycling shingles.[4]

PURPOSE AND SCOPE

The purpose of this investigation was to evaluate the placement and early performance of a test section of asphalt concrete containing manufacturing waste shingles in southeastern Virginia. The mix containing shingle material had been proposed to the VDOT district materials engineer in that region by an asphalt contractor who obtained the shingles from a shingle manufacturing facility in North Carolina.

METHODS

Overview

This investigation evaluated a 9.5 mm Superpave asphalt surface mixture containing 5 percent manufactured waste roofing shingles. The same mixture containing 10 percent recycled asphalt pavement (RAP) but no shingles was used for comparison. Observations were made and tests were performed during the paving of a field project, and tests were subsequently performed in the laboratory on mixture that was sampled during the construction. Future performance evaluations of the pavement sections will be made to detect any detrimental or beneficial long-term effects caused by use of the shingles.

Test Sections

Rose Brothers Paving Co., Inc., produced and paved the project that was the subject of this study with the 9.5 mm surface mix at a rate of 165 psy (1.5 in). Figure 1 shows the layout of

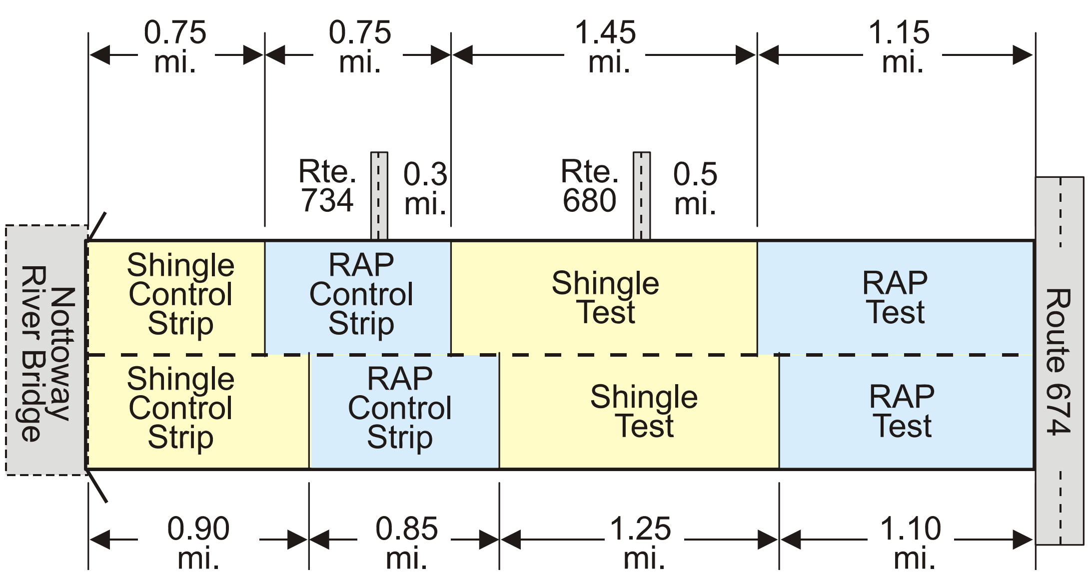

Figure 1. Location of Field Sections

the field project, which was paved July 24 through 28, 2006. The asphalt plant was located near Murfreesboro, North Carolina, and the paving site was approximately 2.5 mi southwest of Franklin, Virginia, on Route 671 in the southeastern corner of the state.

The roadway was a rural two-lane pavement 24 ft wide with light automobile traffic and a few tractor-trailers. The existing surface showed considerable distress such as alligator cracking and patching of badly cracked areas, as shown in Figure 2. Although the severity of the distress varied within the 4.1-mi section, the surface condition led the researcher to believe that the section of mix containing shingles and the section of mix with no shingles were generally placed on pavements having a similar structural capacity. A visual record with many digital photos was made of the condition of the pavement before it was paved in case anomalies in performance occurred. Approximately 4.4 lane-miles requiring 2,500 tons of mix containing shingles and 3.8 lane-miles requiring 2,200 tons of mix containing no shingles were paved. None of the mix used in the two roller pattern/control strips that were paved the first 2 days in an approval process was used for the evaluation. The high ambient temperature during the week of paving was generally in the upper 80s to upper 90s. The mix temperature at the asphalt plant was approximately 315 °F for both mixes.

Figure 2. Typical Pavement Condition Before Paving

Materials

The basic mix was a Virginia SM-9.5A surface mix containing PG 64-22 binder with 10 percent RAP; it was designed at a compactive effort of 65 gyrations (see Table 1). The shingle mix, also designed at 65 gyrations, contained PG 64-22 binder and 5 percent shingles. The manufactured waste shingles (Figure 3) were shredded/ground (Figure 4) at one of the Rose Brothers Paving Co., Inc., plants near Gaston, North Carolina, and transported by truck approximately 40 mi to the Murfreesboro plant site. Although no routine sizing tests were performed, the VDOT special provision required the shingles to be ground to a maximum size of 0.5 in, which appeared to be achieved. A spot check of one sample of ground shingles demonstrated that 98 percent passed the ½ in sieve and 68 percent passed the No. 4 sieve.

An AASHTO Provisional Standard, i.e., "Standard Recommended Practice for Design Considerations When Using Reclaimed Asphalt Shingles in New Hot Mix Asphalt," indicated that only 20 to 40 percent of the binder is available if the shingle particles are larger than 0.5 in and 95 percent is available for particles smaller than the No. 4 sieve (American Association of State Highway and Transportation Officials, unpublished data). There was no sign of unmelted asphalt particles in the asphalt concrete mixture during manufacture and paving. The shingle composition was cited by a consultant to be approximately 18 percent asphalt, 34 percent filler, 38 percent granules, 7 percent sand, 2 percent fiber glass, and 1 percent tape and water (Ross, B.B., Jr., personal communication, March 6, 2006).

Table 1. Materials in the Two Mixtures

Mix	Percentage	Material	Source
RAP mix	42	78M	Vulcan Materials, Skippers, Va.
	10	Fine RAP	Rose Brothers, Murfreesboro, N.C.
	19	Coarse Sand	Rose Brothers, Grit Pit, Rich Square, N.C.
	29	Regular screenings	Vulcan Materials, Skippers, Va.
	5.5[a]	PG 64-22 binder	Koch Materials, Newport News, Va.
	0.25	Adhere HP+	Armaz, Vanceboro, N.C.
Shingle mix	45	78M	Vulcan Materials, Skippers, VA
	5	Recycled shingles	Certain Teed Corporation, Oxford, N.C.
	27	Coarse sand	Rose Brothers, Grit Pit, Rich Square, N.C.
	23	Regular screenings	Vulcan Materials, Skippers, Va.
	5.8[a]	PG 64-22 binder	Koch Materials, Newport News, Va.
	0.25	Adhere HP+	Armaz, Vanceboro, N.C.

[a]Includes binder from RAP and shingles

Field Testing

Nuclear density tests were performed with a thin-lift nuclear gauge using a single 60-sec reading at each location. VDOT requires that a roller pattern be established with a nuclear gauge for each new mix and that 10 randomly selected nuclear density tests be performed on an adjacent control strip to establish the target density. Ten nuclear density tests per 1,000 lane-feet were also planned on each experimental section in a random manner for both the conventional mix containing RAP and the mixture containing shingles using a nuclear gauge from the Virginia Transportation Research Council (VTRC). These tests were in addition to the regular specified tests by the contractor. However, because of a battery failure on the VTRC nuclear device, the

Figure 3. Grinding Waste Shingles

Figure 4. Ground Shingles

last day, nuclear density tests could not be performed on the test section paved with the mixture containing RAP. One 6-in core was removed from each 1,000 lane-feet at a randomly selected location on all sections for testing later in the laboratory.

Laboratory Testing

Samples of both mixtures were taken at the asphalt plant and transported to the VTRC laboratory, where tests were performed at a later date. Samples were taken twice during the production of each type of mixture: once in the morning and once in the afternoon.

Gradation and Gyratory Volumetric Properties

The ignition furnace was used to remove the asphalt from samples of mixture that were taken during construction, after which asphalt content and gradation were determined. Volumetric properties were determined on samples of mixture compacted at an effort of 65 gyrations, which is the gyration compactive effort for all VDOT mixes.

Core Specific Gravity Tests and Permeability Tests

Specific gravity tests on the cores were performed in accordance with AASHTO T 166-05.[5] Subsequently, falling head permeability tests were performed in accordance with Virginia Test Method (VTM) 120.[6]

Fatigue Tests

Beam fatigue tests were performed in accordance with AASHTO T 321[5] using the apparatus shown in Figure 5. Three fatigue tests were performed at both 400 $\mu\varepsilon$ and 800 $\mu\varepsilon$, and *failure* was defined as a reduction of flexural stiffness by 50 percent. The *endurance limit* is defined as the strain at which the specimen can endure an infinite number of load cycles. In a practical sense for this experiment, the endurance limit was defined as the strain level that a laboratory specimen could survive for at least 50 million cycles, and it was projected from the six experimental test results. 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. A method of analysis associated with NCHRP Study 9-38 indicated that the endurance limit can be roughly estimated from the 95 percent confidence one-sided lower prediction limit for a fatigue life of 50 million cycles (Prowell, B.D., personal communication, January 4, 2007); that estimation was used to compute the endurance limit in this study (see Figure 6).

Rut Tests

Rut tests were performed on beams with the Asphalt Pavement Analyzer in accordance with VTM 110.[6] The method tests three beams simultaneously through 8,000 cycles at a load of 120 lb, a hose pressure of 120 psi, and a test temperature of 120 °F.

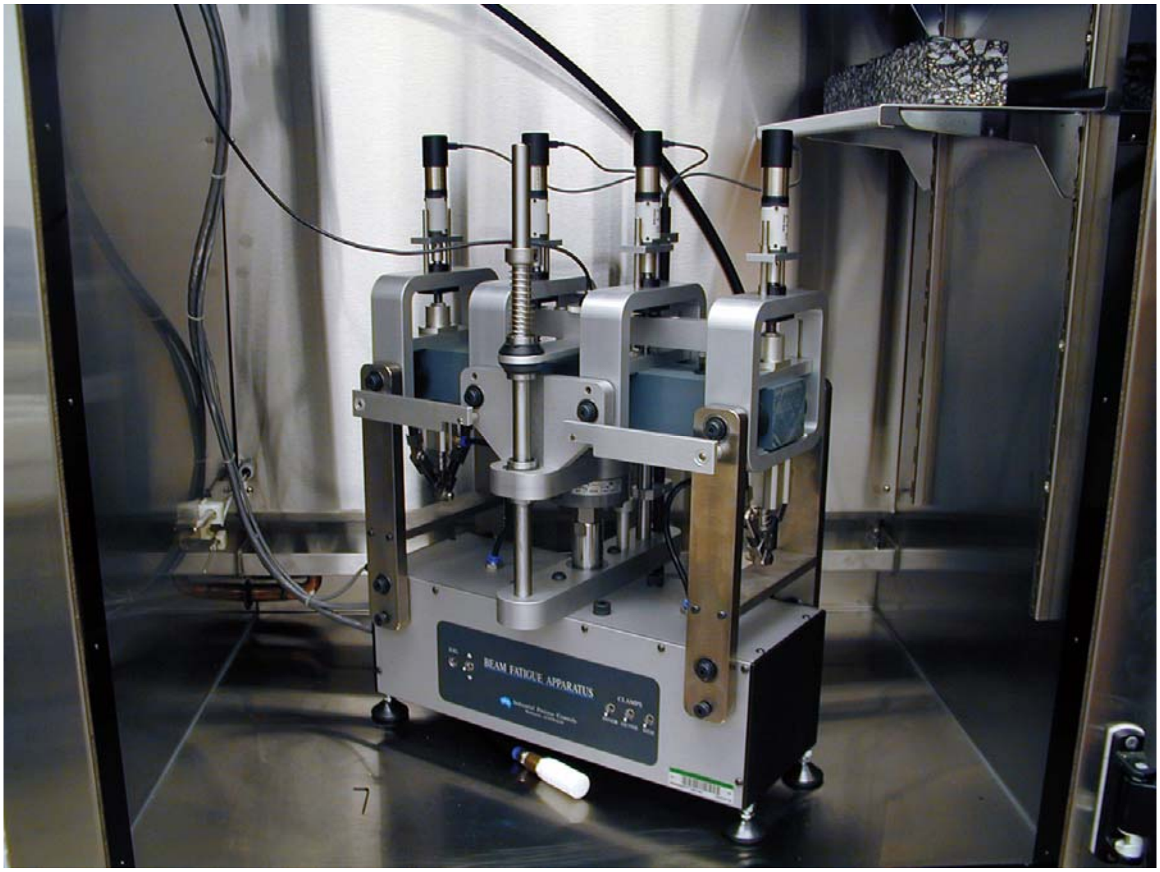

Figure 5. Beam Fatigue Testing Equipment

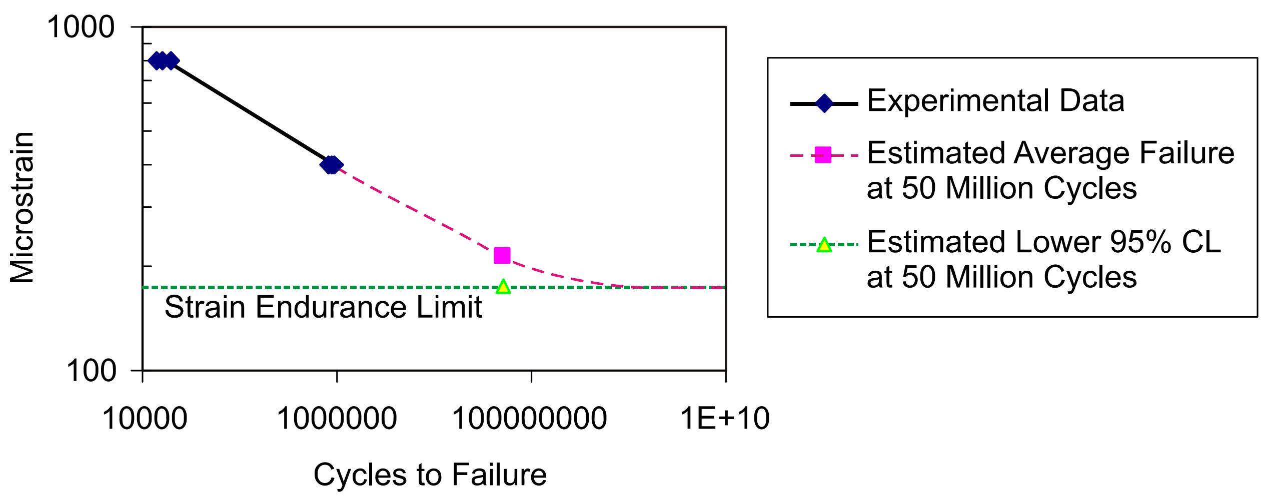

Figure 6. Example of Estimated Endurance Limit. CL = Confidence limit

Tensile Strength Ratio Stripping Tests

Tensile strength ratio (TSR) moisture susceptibility tests were performed in accordance with AASHTO T 283.[5] Two groups of specimens were made at 7.5 percent air void content.

One group was tested in indirect tension in a dry condition, and the other group was saturated to 70 to 80 percent, subjected to a freezing overnight, conditioned in a 140 °F water bath, and then tested in indirect tension at 70 °F. The ratio of the saturated-specimen strength to the dry-specimen strength indicates stripping susceptibility.

Abson Binder Recoveries

The binder was recovered in accordance with AASHTO T 170[5] for both mixes. The recovered binder was graded in accordance with Superpave performance grading after undergoing only aging with the pressure aging vessel since it had already undergone aging during production usually simulated by including aging with the rolling thin-film oven, which is normally required when testing virgin binders.

RESULTS

Field Testing and Observations

According to Section 315.05 of the VDOT specifications,[7] the adequacy of each new mixture must be proven by establishing a roller pattern and control strip on which core density is measured to make sure that the specified density of 92.5 percent of maximum theoretical density can be achieved. Since this study was the first time that these mixtures had been used, the contractor was required to construct trial sections the first day for both mixtures. Both slightly failed the density requirements; therefore, additional sections were constructed the second day, and these passed the density requirement. The shingle mixture achieved an average nuclear density of 137.7 pcf during the trial on the first day and 140.9 pcf during the passing trial on the second day. The RAP mixture achieved an average density of 139.9 pcf during the trial on the first day and 140.9 pcf during the passing trial on the second day.

The average air void contents of approximately 12 cores removed from each experimental section paved the third and fourth days are shown in Table 2. The average air void contents of the sections containing shingles and RAP were statistically equal at a 95 percent confidence level.

Both mixtures were slightly tender during rolling. The rolling by the finish roller had to be delayed until the mixture had cooled enough to prevent pushing under the roller.

Table 2. Volumetric Properties: Mix Samples and Pavement Cores

Property	Recycled Asphalt Pavement Mix	Shingle Mix
65 Gyrations		
VTM, %	3.6	3.6
VMA, %	16.1	15.9
VFA, %	77.8	77.5
Roadway, Post-construction		
Air voids, %	7.9	8.0

VTM = voids in total mix; VMA = voids in mineral aggregate; VFA = voids filled with asphalt.

Laboratory Testing

Mixtures was sampled during construction and burned in the ignition oven to remove the binder. Table 3 indicates that the average gradation and binder content of the mixture containing 5 percent shingles and the control mixture containing 10 percent RAP were similar. Similarly, the gyratory volumetric properties on companion samples were almost identical for the two mixtures (Table 2). These tests indicate that the two mixtures should have behaved similarly in the field from a density standpoint, which they did.

The permeability results of field cores from the two mixtures are shown in Figures 7 and 8. The mixtures containing RAP and shingles had average permeability values of 83 x 10^{-5} cm/sec and 98 x 10^{-5} cm/sec, respectively. The mixture containing RAP had 2 of 10 cores with a permeability value above the maximum allowable initial mix design limit of 150 x 10^{-5} cm/sec, and the mixture containing shingles had 4 of 12 cores with a permeability value above 150 x 10^{-5} cm/sec. As expected, in both cases, the high permeability values were associated with high air voids. Even though the average air voids in the mixes were less than the specified average maximum air voids of 8.8 percent, some individual values were high, resulting in high permeability. As observed from the permeability plots, the air voids must be less than approximately 9.0 percent in order for the permeability value to remain under 150 x 10^{-5} cm/sec for in-place pavement.

Table 3. Gradation of Mixtures

Sieve, mm	10% Recycled Asphalt Pavement Mix		5% Shingle Mix	
	Job Mix	2-Sample Average	Job Mix	2-Sample Average
12.5	100	100	100	100
9.5	96	96	95	96
4.75	67	67	66	65
2.36	48	47	48	46
1.18		36		35
0.6		26		25
0.3		16		15
0.15		9		9
0.075	6.0	6.0	6.2	6.1
% AC	5.5	5.6	5.8	5.6
Film thickness, µm		8.7		8.7

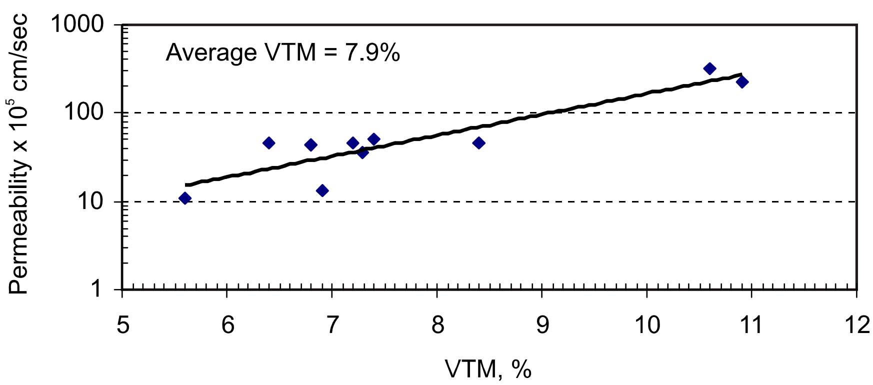

Figure 7. Permeability vs. Air Voids of RAP Mix Field Cores. VTM = Voids in total mix

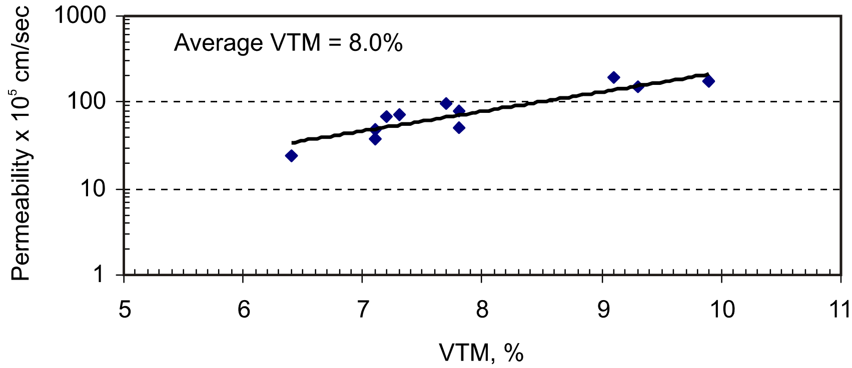

Figure 8. Permeability vs. Air Voids of Shingle Mix Field Cores. VTM = Voids in total mix

As noted earlier, the endurance limit, which is the strain level allowing 50 million cycles in the laboratory, was calculated from the regression formed by the testing of three beams at both the 400 με and 800 με levels. The endurance limit was estimated from the regression by calculating the lower 95 percent confidence limit for strain at 50 million cycles. The endurance limits for the four samples taken during construction of the field sections are given in Table 4. The results ranged from 152 με to 222 με. There was overlap and no practical difference between results from the control mix containing RAP and the experimental mix containing shingles.

The rut depths of samples of mixture taken in the morning and afternoon for both mixtures are shown in Table 5. The maximum specification limit for an SM-9.5A mixture is 7.0 mm; therefore, the results for the mixtures containing RAP were borderline and the results for the shingle mixture were satisfactory. A statistical analysis using analysis of variance at a 95 percent confidence level showed a difference between the shingle mixture taken in the afternoon and both of the RAP mixtures.

The binder recovery test results are provided in Table 6. The binder recovered from both mixtures graded as a PG 70-22 binder. The virgin binder sampled during construction of each mixture was from the same source and was graded as a PG 64-22 binder. When the results were interpolated to determine the exact grading, the shingle mixture contained a PG 74-24 binder and

Table 4. Fatigue Test Results

Mix	Sampling Time	Endurance Limit @ 50 x 10^6 cycles, με
Recycled asphalt pavement	Morning	182
	Afternoon	167
Shingle	Morning	152
	Afternoon	222

Table 5. Rut Test Results

Mix	Sampling Time	Rut Depth, mm
Recycled asphalt pavement	Morning	7.0
	Afternoon	7.2
Shingle	Morning	6.3
	Afternoon	5.1

Table 6, Dynamic Shear Rheometer (DSR) and Bending Beam Test Results of Virgin Binder and Abson Binder Recoveries

Binder Properties	Virgin Binders		Mix with 10% RAP (Recovered)	Mix with 5% Shingles (Recovered)
	RAP Mix	Shingle Mix		
No Lab Aging				
$G^*/\sin\delta$, kPa > 1.0	1.282 @ 64 °C 0.630 @ 70 °C[a]	1.333 @ 64 °C 0.663 @ 70 °C[a]		
Rolling Thin-Film Oven				
$G^*/\sin\delta$, kPa > 2.20	4.014 @ 64 °C 1.884 @ 70 °C[a]	3.648 @ 64 °C 1.710 @ 70 °C[a]	4.546 @ 64 °C 2.252 @ 70 °C 1.145 @ 76 °C[a]	6.943 @ 64 °C 3.447 @ 70 °C 1.758 @ 76 °C[a]
Pressure aging vessel				
$G^*\sin\delta$, kPa < 5000	3026 @ 22 °C 2113 @ 25 °C	3255 @ 22 °C 2259 @ 25 °C	2413 @ 25 °C 1682 @ 28 °C	2298 @ 25 °C 1647 @ 28 °C
Creep Stiffness, MPa < 300	128 @ -12 °C	129 @ -12 °C	126 @ -12 °C 257 @ -18 °C	113 @ -12 °C 243 @ -18 °C
m-value > 0.300	0.319 @ -12 °C	0.314 @ -12 °C	0.322 @ -12 °C 0.287 @ -18 °C[a]	0.312 @ -12 °C 0.283 @ -18 °C[a]

RAP = recycled asphalt pavement.
[a]Failed the criteria.

the RAP mixture contained a PG 70-25 binder. A slightly stiffer shingle mix binder could account for less rutting in the shingle mix, as reported earlier. There was apparently little difference in the cold temperature grading, but there was an almost a full PG grade difference on the high temperature end between the two mixtures. The binder was also recovered from a sample of waste shingles, which produced a high temperature grading of approximately 90. The resultant high temperature grading of the shingle-virgin binder combination was calculated based on the properties of the shingle binder and virgin binder. The high temperature grading was calculated to be PG 71 compared to the actual recovered grading of PG 74-24.

Both mixes contained approximately 70 percent crushed granite that was known to be susceptible to stripping and 25 percent sand with no known stripping history. Both mixes contained 0.25 percent chemical anti-stripping additive that had proven to be effective through TSR tests during the mix design. The TSR stripping test result for one sample of mix containing shingle was 0.95. The TSR test results for two samples of mix containing RAP were 0.93 and 1.03. Considering the variability of the test method, there was no practical difference between the results for the two mixtures. VDOT requires a minimum value of 0.80. Both mixtures should be resistant to stripping and moisture damage.

Performance Observations

A visual examination of the sections was conducted approximately 18 months after construction. Both sections were performing well, with negligible cracking distress. There was less than 100 ft of longitudinal cracking near the right wheelpath in each section, and it was unclear whether the cracking was caused by the finish roller during construction or by reflection of underlying cracks. Periodic visual pavement evaluations will continue to be made after the formal end of this study.

CONCLUSIONS

- Conventional RAP and shingle mixes behave in a similar manner during placement and compaction.
- The two mixes have similar gradation and volume, nearly identical permeability, the same endurance limits, and an excellent TSR.
- Conventional RAP mixes have borderline rutting characteristics; rutting characteristics for the shingle mix are satisfactory.
- The binder gradings for both mixes increase from PG 64-22 to PG 70-22 upon the addition of RAP and shingles; the shingle mix is slightly stiffer than the RAP mix.
- The performance of both mixes should be satisfactory.
- Both mixes are performing well in the pavement after 18 months of service.

RECOMMENDATIONS

1. *VDOT's Materials Division should develop a permanent provisional specification to allow manufacturing shingle waste to be used in asphalt concrete.*
2. *VTRC should conduct additional research regarding the possible use of tear-off shingles in the future, although there are potential problems associated with their use.*

COSTS AND BENEFITS ASSESSMENT

There should be monetary savings since shingles contain considerable asphalt, which is selling at a premium price. For example: Assume a typical mix contains 5.5 percent binder and 5 percent shingles. Since shingles typically contain 20 percent of asphalt, the shingles in the mix would contribute approximately one-fifth of the total binder content. Binder in January 2008 was costing approximately $340 per liquid ton.[8] In 1997, a cost estimate for shingle acquisition and processing costs of approximately $0.55 per ton of mix was given by Ross.[9] If it is assumed that the cost has increased to $0.71 per ton at the present time based on inflation,[10] in this case there would be savings of $2.69 per ton of mix due to the use of the shingle waste. Disposal fees may be accrued by the contractor, i.e., the contractor may be paid to dispose of the shingle waste, which may possibly balance the shingle processing costs and increase cost savings. Considering that the average cost of this type of mix in 2007 year in the district where shingle usage is possible was approximately $55 per ton, there is the potential for a $2.69/$55.00 = 4.9% savings in hot plant mix when shingle waste is used. It was estimated from 2008 bids on asphalt overlays that approximately 50,000 tons of asphalt mix containing shingle waste could be supplied to VDOT's Hampton Roads District per year, yielding a potential saving of $134,500.

- Shingle asphalt binder provided per ton of hot mix = 5% x 2,000 lb x 20% = 20 lb.
- Asphalt binder cost per lb = $340/2000 = $0.17.
- Therefore, the value of binder contained in shingles = 20 lb x $0.17 = $3.40 per ton of HMA
- Consider that $0.71 is the cost to process shingles, then the value of the binder = $3.40 - $0.71 = $2.69.

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REFERENCES

1. Maupin, G.W., Jr. *Field Trials of Asphalt Rubber Hot Mix in Virginia.* VTRC 95-R16. Virginia Transportation Research Council, Charlottesville, 1965.

2. Maupin, G.W., Jr. *Glasphalt Test Sections in Virginia.* VTRC 98-R6. Virginia Transportation Research Council, Charlottesville, 1997.

3. Virginia Department of Transportation. *Special Provision: Reclaimed Asphalt Shingles in Hot Mix Asphalt.* Richmond, September 1999.

4. Construction Materials Recycling Association, U.S. EPA Region 5, and University of Florida. www.shinglerecycling.org. Accessed March 5, 2008.

5. American Association of State Highway and Transportation Officials. *Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part 2B:Tests*. Washington, D.C., 2006.

6. Virginia Department of Transportation. *Virginia Test Methods*. http://www.virginiadot.org/business/resources/bu-mat-VTMs070704.pdf. Accessed May 16, 2007.

7. Virginia Department of Transportation. *Road and Bridge Specifications.* Richmond, 2007.

8. Virginia Department of Transportation. *Asphalt Price and Fuel Adjustments.* http://www.virginiadot.org/business/const/indices-asphalt.asp. Accessed January 8, 2008.

9. Ross, B.B., Jr. *An Evaluation of the Use of Hot Mixed Asphalt Pavements Containing Roofing Shingles Material in North Carolina.* Paper presented to the North Carolina Department of Environmental, Health, and Natural Resources. Raleigh, N.C., March 1997.

10. U.S. Department of Labor, Bureau of Labor Statistics. Overview of BLS Statistics on Inflation and Consumer Spending. http://www.bls.gov/bls/inflation.htm. Accessed January, 23, 2008.