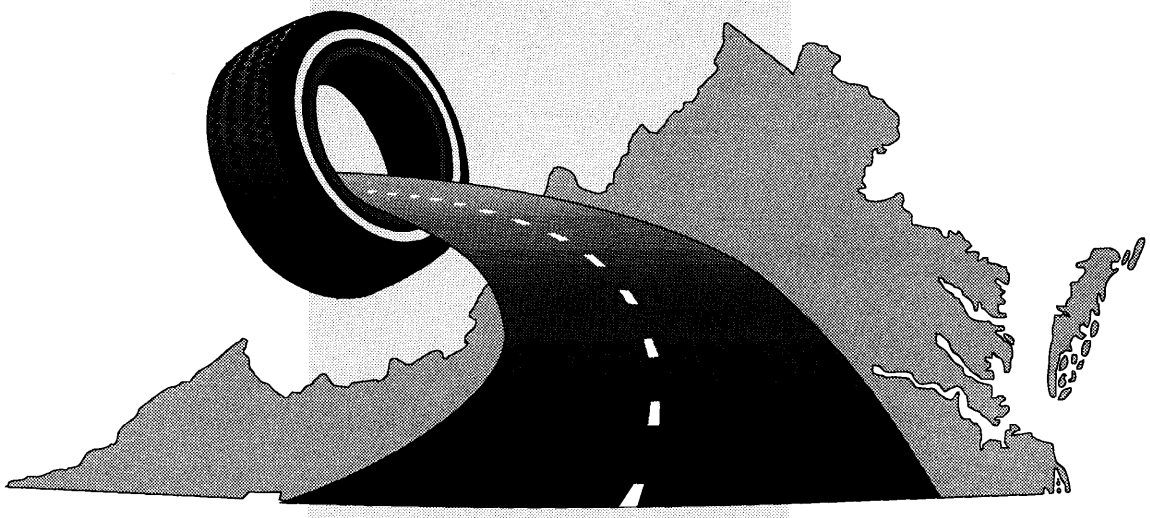
FINAL REPORT

FIELD TRIALS OF ASPHALT RUBBER HOT MIX IN VIRGINIA



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Supplementary Notes

Abstract

Four test sections using asphalt rubber hot mix were placed in Virginia during the period of 1990 through 1993. The purpose of these installations was to familiarize both contractors and Virginia Department of Transportation (VDOT) personnel with the construction process and compare the performance of different types of mixes containing ground tire rubber.

The MacDonald and Rouse processes, both wet processes, were used successfully. Dense-graded surface mixes, a gap-graded surface mix, and a base mix were manufactured. A stress absorbing membrane interlayer was also used on one project in an attempt to deter or eliminate a variety of types of cracking.

The asphalt rubber mixes have performed as well as the conventional mixes over the short term. More evaluation time is needed to determine if the long-term performance of the asphalt rubber mixes is superior to that of the conventional mixes. The cost of the asphalt rubber mixes was 64 to 102 percent more than that of the conventional mixes; however, this cost would probably decrease if substantial quantities were placed.

VDOT has the necessary experience to contract placement of asphalt rubber mixes if the suspended ISTEA mandate is effected.

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Four test sections using asphalt rubber hot mix were placed in Virginia during the period of 1990 through 1993. The purpose of these installations was to familiarize both contractors and Virginia Department of Transportation (VDOT) personnel with the construction process and compare the performance of different types of mixes containing ground tire rubber.

The MacDonald and Rouse processes, both wet processes, were used successfully. Dense-graded surface mixes, a gap-graded surface mix, and a base mix were manufactured. A stress absorbing membrane interlayer was also used on one project in an attempt to deter or eliminate a variety of types of cracking.

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INTRODUCTION

Approximately 285 million tires are discarded annually in the United States,[1] and approximately 75 percent of these tires are disposed of in landfills, illegal dumps, and stockpiles.[2] In 1991, it was estimated that 2 to 3 billion tires were stored in stockpiles.[3]

Two major potential uses for scrap tires are as energy sources and in civil engineering applications. Industries that are using tires as an energy source are cement manufacturing, pulp and paper manufacturing, and electricity production. Shredded tires have been used in several lightweight embankments in several states, and the Virginia Department of Transportation (VDOT) recently installed a lightweight fill as an experimental project. Other civil engineering applications have included drainage layers, slope stabilization, and retaining walls.

Another civil engineering use is to incorporate ground tires into asphalt as a crumb rubber modifier. Charles McDonald, a materials engineer for the City of Phoenix, Arizona, began to work on using crumb rubber in asphalt applications for highway construction in the early 1960s.[1] Surface treatments called stress absorbing membranes were developed in the 1960s, and crumb rubber was used in an open-graded plant mix in 1975. Two types of technologies have evolved: the wet process where crumb rubber is reacted with hot asphalt cement, and the dry process where the rubber is added to the asphalt hot mix as an aggregate. Various patents have been obtained on both processes, some of which have expired.

The reports of performance are mixed. California and Arizona reported cost-effective applications, but other states reported failures.[4] Presently, it does not appear that economics justify the use of rubber since hot mix containing rubber generally costs 50 to 100 percent more than conventional mixes and additional service life is questionable. The Florida Department of Transportation believes that crumb rubber improves the durability and pavement life of their open-graded surface mixes and that the benefits of adding rubber outweigh the 10 percent increase in the cost of the mixes.[5]

Many states have instructed their department of transportation to investigate the use of scrap tires in construction applications and in some cases have mandated that they be used. Because of interest by the Virginia legislature, a review of potential uses of scrap tire rubber and the problems and potential advantages was conducted.[6] In addition, a test section of dense-graded surface mix overlay containing rubber was constructed on Route 1 in Fairfax County.[7] Three additional sections were placed in 1992 and 1993 in order to gain experience in the construction and performance of asphalt rubber mixes.

The acquisition of experience was very wise considering the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 requiring the use of rubber in asphalt. The legislation mandated that states use rubber on a specified percentage of their projects receiving federal aid. Even though the enactment of the legislation has been delayed 2 years, states will have to begin using some crumb rubber in 1996 unless Congress decides to amend the legislation.

PURPOSE AND SCOPE

The purpose of this project was to gain experience in the use of crumb rubber modified asphalt and determine whether the addition of rubber enhances performance. Since construction details of the first section placed were reported in an interim report,[7] only construction of the final sections is described here. The performance of all sections with the exception of the one using base mix is also reported. Detectable differences in the performance of base mix will take many years to ascertain.

METHODOLOGY

General

It was hoped that experience would be gained through this project that would allow VDOT to specify and contract asphalt rubber applications that perform as well as or better than standard asphalt paving materials. The experience was obtained by using a variety of applications, including three types of mixes (two surface and one base) and a stress absorbing membrane interlayer (SAMI). It was believed that by conducting these trial projects state contractors would become familiar with the operation through direct and indirect association and that construction of asphalt rubber pavement would not be thrust on them suddenly, resulting in dissatisfaction and poor-quality pavements.

As projects were constructed and the work was observed, any problems were noted and an attempt was made to eliminate the problems on jobs that followed. Samples of mix were taken on several of the projects and tested by various methods in the laboratory to attempt prediction of performance. Although the projects were monitored for pavement distresses in order to gauge actual performance, several projects are relatively young and performance evaluations will have to be continued in the future.

On one of the jobs, environmental testing by a consultant was included to determine whether the use of rubber produced harmful effects on the environment or workers. The paving industry is concerned that the inclusion of rubber may affect the health of their workers.[3] The basic results of the consultant's testing are included in this report.

Tests and Measurements

Several types or variations of tests were performed to try to predict the performance of the mixes, and more routine tests were performed during and after construction to determine if the mixes met specifications. Not all of the tests were performed on each project, and some of the procedures changed slightly since it was approximately 3 years between the paving of the first project and the last project and testing technology changed somewhat during this time.

Gyratory Shear Test

The gyratory shear test was performed in accordance with ASTM D 3387 with the exception of the number of total revolutions.[8] Although readings were taken periodically throughout the compaction process, the compaction was ended when the change of density decreased to 16 kg/m^3 per 100 revolutions.

Resilient Modulus Test

The indirect tensile resilient modulus test was performed at 40 C in accordance with ASTM D 4123 with a Mark II Retsina device.[8]

Indirect Tensile Test

The indirect tensile test was performed with the loading head and deformation measuring equipment described in ASTM D 4123. A closed-loop hydraulic load system was used to apply the load to produce a tensile horizontal deformation rate of 1.5 mm/min at test temperatures of 2 C, 7 C, and 13 C.

Creep Test

Uniaxial creep tests were performed at 40 C on specimens 64 mm by 100 mm in diameter, which were constructed on the gyratory testing machine (GTM). The specimens were preloaded for 2 min at 207 kPa, unloaded, allowed to rest for 5 min, and reloaded for 60 min at 207 kPa. Axial deformation was recorded at set intervals after the load was being applied and again for 60 min after the load had been released. The permanent deformation remaining after the load was released was the primary property used to evaluate the mixes.

Rut Depth Measurements

Transverse profile measurements were taken on two of the projects with an electronic leveling device (Dipstick), and the rut depths were estimated from the profiles. The device, which was walked across the pavement, measures the difference in elevation of the two attached "walking" supports. A computer attachment was available to record each reading automatically and plot a profile. However, because of the long time required for each measurement and computation, the measurements were recorded manually and put into the spreadsheet where the profile could be graphed. An improved version of the device that records the data quickly is now available.

Friction Tests

Friction tests were performed with a full-scale skid trailer at 64 km/hr (ASTM E 274-90) using a standard smooth tire (E 524-88).[8]

Routine Tests

Density and air void determinations on pavement plugs and cores were made in accordance with ASTM D 2726 and D 3203, respectively.[8]

Mix Design

The mixes were designed by the Marshall method in accordance with Virginia Test Method (VTM) 57.[9]

Fairfax County Project

The asphalt cement and extender oil were heated to 177 C and blended with the ground tire rubber. The asphalt rubber mixture was kept at this temperature for 60 min (known as reacting) before being mixed with the aggregate, which was maintained at 163 C. The mix was then brought to 149 C before being compacted with a compactive effort of 75 blows. The specimens were allowed to cool to room temperature before they were extracted from the molds to prevent the rubber from expanding and yielding inaccurate density values.

Wytheville Surface Mix

The asphalt cement and ground tire rubber were heated for 20 min at 177 C before they were mixed with the aggregate, which had been heated to 154 C. The mix was then brought to 140 C

and compacted at the specified number of blows (75 blows). The specimens were allowed to cool to room temperature before they were extracted from the molds.

Wytheville Base Mix

The asphalt cement and extender oil were heated to 204 C, mixed with the ground rubber, and reacted at 177 C for 60 min. The reaction time was longer than that used with the Wytheville surface mix in order to match the reaction time achieved in the field process for the base mix. The aggregate was heated to 149 C and mixed with the asphalt rubber binder. The specimens were compacted at 141 C using 112 blows and allowed to cool to room temperature before they were removed from the mold.

Ashland Project

The asphalt cement and extender oil were heated to 204 C, mixed with the ground rubber, and reacted at 190 C for 60 min. The aggregate was heated to 154 C and mixed with the asphalt rubber binder. The specimens were compacted at 149 C using 75 blows and allowed to cool to room temperature before they were removed from the mold.

TEST SECTIONS

Route 1, Fairfax County

In this project, the wet process was used in which the crumb rubber is mixed with asphalt cement and reacted for approximately 1 hr before it is mixed with aggregate. This was the first crumb rubber modified mix placed by VDOT, and the construction was carried out with only one problem: the asphalt mixture stuck to the breakdown roller. This problem was minimized, however, by the application of a generous supply of water to the wheels. Since the installation of this test section was reported in 1991,[7] the details are not repeated here. Because of the manner in which the results are presented in the current report, it may be helpful to note that there were two sections constructed several miles apart; the sections are designated as northern and southern sections in the 1991 report.

Field Tests and Observations

The results of void determinations performed on cores and rut-depth measurements estimated from the Dipstick profiles at 4 years are shown in Table 1. The voids decreased to the 6 to 8 percent range. There is no danger of permanent deformation at this void level, but excessive aging

Table 1. Evaluation of Fairfax Sections at Four Years

Section	Pavement Voids (%)		Rut Depth (mm)	
	Postconstruction	4 Years	Average	Range
South Rubber	9.5	7.8	0	0-2
South Control	13.3	7.6	1	0-4
North Rubber	12.1	5.9	2	0-8
North Control	12.2	7.8	3	0-8

resulting from oxidation is certainly a possibility. It is generally agreed that voids below 3 percent do not ensure adequate stability and voids above 6 percent may lead to excessive air exposure and aging.

The rut depth for all sections was negligible. Since the level of air voids was still above 3 percent, any rutting caused by instability would be unexpected. The small amount of rutting was probably caused by consolidation.

Figures 1 and 2 show friction test results at 4 years. The friction values for the rubber sections at both the northern and southern locations tended to be slightly higher than those for the control sections. Although the friction averages for the rubber and control mixes were significantly different at a 95 percent confidence level for the northern section, they were not different for the southern section. With the exception of three tests on the northern section, all of the val-

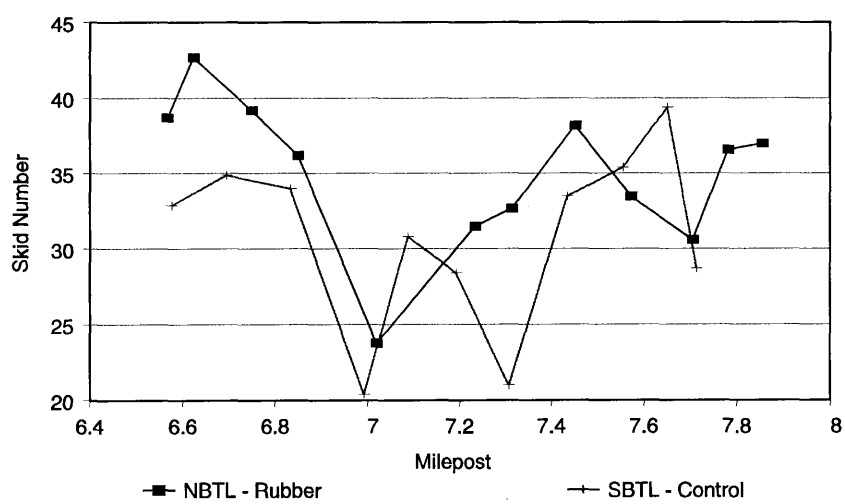

Figure 1. Friction Tests for Northern Fairfax Section

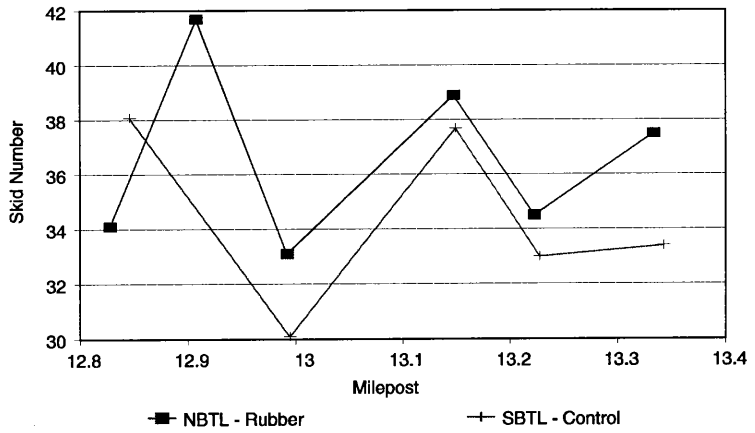

Figure 2. Friction Tests for Southern Fairfax Section

ues were above 25. The three tests were taken near stoplights where there were excessive oil drippings, which may have caused the low values.

All sections had considerably more cracking than was observed during the last field measurements in 1992, and there was no noticeable difference between the amount of cracking in the different sections. The types of cracking present were transverse, longitudinal, and fatigue. Most of the cracks probably reflected through from cracks in the old surface, and a dense-graded mix containing rubber could not be expected to deter the large strains causing reflection cracks. There was a small area of raveling in the northern end of the traffic lane for the southern rubber section that appeared to be confined to one truckload of mix; the cause is unknown.

I-81, Wythe County, SM-2C Surface Mix

On August 3 and 4, 1992, approximately 2.5 lane-km of crumb rubber modified overlay surface mix was placed in the southbound lanes of I-81, 1.8 km south of Route 52 in Wythe County (see Figure 3). The mix was produced and placed by APAC-Virginia Inc. of Wytheville, Virginia. Although it was planned that 1,800 metric tons of asphalt rubber mix would be placed, only 1,120 metric tons were placed because the asphalt rubber blending equipment burned. The paving was completed with the normal SM-2C control mix.

Materials

The materials used in the mixes are listed in Table 2. The mix gradation was the same as that of the control mix (Table 3). GF-80 ultrafine ground crumb rubber having a mean particle size of 74 μm was blended with an AC-30 asphalt cement in continuous blending equipment furnished by Rouse Rubber Industries, Inc., Vicksburg, Mississippi. Two mixes were placed containing rubber: one with the asphalt rubber binder containing 5 percent rubber by the weight of

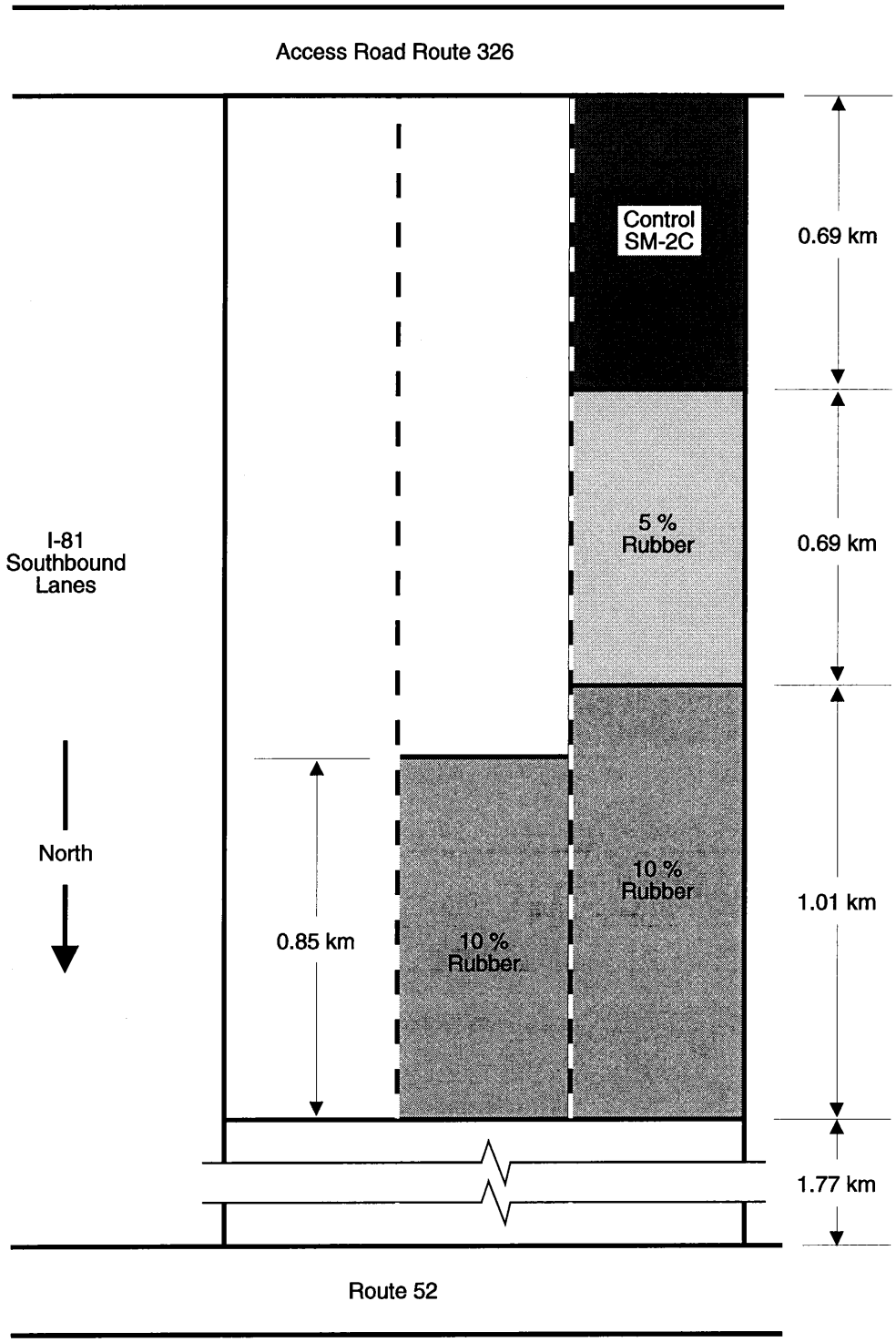

Figure 3. Location of Surface Mix Text Sections in Wythe County

Table 2. Sources of Materials for I-81 Surface Mix Project in Wythe County

Aggregates	
60% No. 8	Salem Stone, Syvatus, Va.
15% Pit Sand	Wythe Stone, Wytheville, Va.
15% No. 10	Wythe Stone, Wytheville, Va.
10% RAP	APAC stockpile, Wytheville, Va.
Binders	
SM-2C control	AC-30, Shell Oil, Bristol, Va.
SM-2C (5% rubber)	AC-30, Shell Oil, Bristol, Va. 5% GF-80 rubber, Rouse Rubber Industries, Vicksburg, Miss.
SM-2C (10% rubber)	AC-30, Shell Oil, Bristol, Va. 10% GF-80 rubber, Rouse Rubber Industries, Vicksburg, Miss.
0.5% Ad-Here HP Plus	Arr-Maz Products, Washington, N.C.

Table 3. Gradations of Mix Samples Taken During Construction of I-81 Surface Mix Project in Wythe County (% Passing)

Sieve (mm)	Control		5% Rubber		10% Rubber Traffic Lane		10% Rubber Center Lane		JM
	APAC	VTRC	APAC	VTRC	APAC	VTRC	APAC	VTRC	
19	100.0	100.0	100.0		100.0	100.0	100.0		100
12.5	99.9	99.4	99.8	100.0	99.8	99.8	99.6	100.0	97
9.5	91.3	90.0	90.9	91.1	91.3	87.0	91.1	94.2	90
4.75	54.0	54.0	53.8	48.0	54.1	41.8	54.2	50.4	58
2.36	29.9	32.8	32.4	29.5	33.5	24.7	32.2	30.2	
0.600	18.1	19.3	18.5	18.5	21.0	16.2	22.0	19.5	21
0.300	11.5	13.0	11.9	12.4	13.9	10.9	15.0	12.8	
0.150	7.2	8.7	8.1	7.4	8.0	6.2	8.9	7.1	
0.075	5.0	6.2	4.8	4.9	5.1	3.8	5.6	4.4	5
AC (%)	5.4	4.9	5.5	5.5	5.5	5.1	5.3	5.2	*

APAC = contractor; VTRC = Virginia Transportation Research Council; JM = job mix; AC = asphalt content.
*Design AC = 5.3%, 5.5%, and 5.6% for control mix, 5% rubber mix, and 10% rubber mix, respectively.

binder and the other containing 10 percent rubber. Mixes were designed by both the Virginia Transportation Research Council (VTRC) and the VDOT State Materials Laboratory.

Mixing and Paving Operation

A 2.7-metric ton standard batch plant was used to produce the asphalt mixes. The blending unit was attached to the paving contractor's asphalt storage tank and the pipe line supplying asphalt cement to the pug mill. The pipe lines between the blending unit and the contractor's plant were 50-mm lines, although the rubber blending company recommended that 75-mm lines be used. These lines, which were approximately 9 m to 12 m in length and not insulated, tended to restrict the flow of binder and slow production. The temperature of the asphalt cement was typically 175 C to 180 C before blending with the crumb rubber. When the temperature of the asphalt rubber binder dropped below 155 C one day, the binder clogged the line and production had to be stopped. There were continual problems with the booster heater on the blending unit, and it failed to produce the binder at a satisfactory temperature. When the pumping of the asphalt rubber binder was slowed because of low temperature, plant production dropped from a normal 140 metric tons per hour to 90 metric tons per hour. The mixing times were 3 sec dry and 30 sec wet for both the control and asphalt rubber mixes.

The blender transfer heater oil overheated while being stored one night and caught fire, which necessitated extensive repairs to the blender unit; therefore, the asphalt rubber phase of the project was terminated when only about two-thirds of the tonnage had been placed.

The mixes were placed with a normal asphalt hot-mix paver and compacted with a 9,000-kg tandem vibratory roller using the vibratory mode on only one pass. A 5,000-kg tandem finish roller followed. Paving temperatures averaged 160 C for the mix with 10 percent rubber and 145 C for the mix with 5 percent rubber placed on the first day of paving and 155 C for the mix with 10 percent rubber placed on the second day of paving. A significant amount of blue smoke coming from the mix during the paving operation on the first day was found to be caused by an overdose of antistripping additive. The overdose that resulted from the reduced flow of asphalt rubber binder was corrected, virtually eliminating the smoke. Also, as paving progressed, it was found that the temperature of the mix could be decreased and the required pavement density could still be achieved.

Test Results

The extraction results using samples of plant mix obtained during construction by the contractor (APAC) and research lab (VTRC) showed differences between labs (see Table 3). The research lab results tended to be coarser for the rubber modified mixes. Some of the difference may be explained by the fact that the samples were taken at different times; however, some of the differences were larger than expected, particularly for the mix with 10 percent rubber that was

Table 4. Marshall and Road Plug Properties for I-81 Surface Mix Project in Wythe County

	Control		5% Rubber		10% Rubber Traffic Lane		10% Rubber Center Lane	
	APAC	VTRC	APAC	VTRC	APAC	VTRC	APAC	VTRC
75-Blow Marshall								
VTM (%)	4.4	5.3	4.5	4.8	4.5	7.2	4.3	6.4
VMA (%)	15.4	16.9	15.4	17.4	15.5	18.7	15.0	18.3
VFA (%)	71.2	68.8	70.8	72.7	71.2	61.2	71.4	65.3
STAB (kN)		13.6		12.0		12.7		15.0
Road Plugs After Construction								
VTM (%)		9.9		7.0		7.8		---
Road Cores at 24 Months								
VTM (%)		6.6		4.7		4.5		---

APAC = contractor; VTRC = Virginia Transportation Research Council; VTM = voids total mix; VMA = voids mineral aggregates; VFA = voids filled with asphalt; STAB = stability.

placed in the traffic lane. The Marshall results in Table 4 tend to verify that results for the mix with 10 percent rubber sampled from the traffic lane differed significantly between the two laboratories. Total voids (VTM) were significantly higher for the coarser research lab samples than for the contractor samples. These differences are probably attributable to the techniques used to collect the samples. The voids of the plugs removed from the compacted pavement were significantly higher for the control mix than for the mixes with rubber. The lesser voids for the mixes with rubber should result in improved performance because of less aging due to oxidation and possibly increased strength.

Specimens were made in the U.S. Corps of Engineers gyratory shear device and tested with the Retsina resilient modulus device in indirect tension at a vertical deformation rate of 50 mm/min at 40 C. The results presented in Table 5 indicate that the rubber tends to increase shear strength and resilient modulus. An increase in these properties indicates that the mixes with rubber should be more resistant to deformation caused by wheel loads. The tensile strength values do not show a similar trend.

Table 5. GTM, Resilient Modulus, and Indirect Tensile Strength Test Results for I-81 Surface Mix Project in Wythe County

Mix	GTM Shear Strength (kPa)	GSI	VTM (%)	Resilient Modulus (MPa)	Tensile Strength (kPa)
Control	480	0.89	4.6	720	772
5% Rubber	500	0.88	4.4	1250	606
10% Rubber Traffic Lane	590	0.85	6.6	900	462
10% Rubber Center Lane	730	0.87	5.3	1230	751

GTM = gyratory test machine; GSI = gyratory shear index; VTM = voids total mix.

Table 6. Creep Test Results (104 F, 30 psi) for I-81 Surface Mix Project in Wythe County

Mix	Total Strain (%)	Permanent Strain (%)	VTM (%)
Control	0.293	0.152	7.1
5% Rubber	0.246	0.101	5.9
10% Rubber Traffic Lane	0.213	0.079	6.1
10% Rubber Center Lane	0.228	0.086	6.1

VTM = voids total mix.

The uniaxial creep tests revealed an advantage that mixes with rubber have in resisting permanent deformation (Table 6). Mixes were compacted to a VTM of 1 to 2 percent less than those measured in the pavement immediately after construction in order to simulate testing of the pavement material after it was exposed to some traffic. The permanent strain, which is the strain remaining after the load has been released for 1 hr, was the important property to consider. The permanent strain of the control mix was reduced approximately 30 percent by adding 5 percent rubber and approximately 50 percent by adding 10 percent rubber. These results predict that the mixes with rubber will deform less under traffic loading than the mix with no rubber.

Field Tests and Observations After Two Years

Cores were taken, and voids were determined after 24 months (see Table 4). The voids have decreased approximately 2 to 3 percent since construction. Chehovits[10] reported that asphalt rubber mixes tend to densify less under traffic than mixes containing normal binders, but that did not appear to hold true in this instance or for the Fairfax test sections. The asphalt rubber mixes densified at approximately the same rate as the control mixes. If the void levels of the asphalt rubber mixes do not drop below 3 percent, the mixes should be more durable than the control mix since their void level is lower and oxidation will be less.

The rut depths estimated from the Dipstick profiles are given in Table 7. Although none of the rut depths was excessive, there was a trend for the mixes with less rubber to have more rutting. The *t* test indicated a statistically significant difference at a 95 percent confidence level between the rutting of the control mix and both mixes containing rubber.

Table 7. Rut Depths for I-81 Surface Mix Project in Wythe County

Section	Average (mm)	Range (mm)
Control	6	4-7
5% Rubber	4	3-6
10% Rubber	3	2-6

Note: The values in this table have already been corrected for a 1-mm hump left by the paver screed during construction.

I-81, Wythe County, BM-3 Base Mix

Approximately 3,600 metric tons of asphalt rubber modified BM-3 base mix was placed on a reconstruction project in both the northbound and southbound lanes of I-81 from 5.18 km E. of Route 52 to 5.64 km E. of Route 52. The mix was produced and placed by APAC-Virginia, Inc. of Wytheville, Virginia. The project was undertaken to lower the grade to obtain adequate clearance at a bridge over I-81. This project was contracted requiring asphalt rubber modification in order to gain experience with the use of rubber in a base mix. Although there was no experimental evaluation performed as was done for the other jobs, some of the observations and test results are worthy of mention.

Materials

The materials used are listed in Table 8. The limestone aggregate from Wythe Stone was composed of 40 percent No. 357, 25 percent No. 68, and 35 percent No. 10. The binder con-

Table 8. Sources of Materials for I-81 Base Mix Project in Wythe County

Aggregates	
40% No. 357	Wythe Stone, Wytheville, Va.
25% No. 68	Wythe Stone, Wytheville, Va.
35% No. 10	Wythe Stone, Wytheville, Va.
Binder	
82% AC-10	Shell Oil, Wood River, Ill.
4% Sundex 790 Oil	Sun Oil Co., Bay Village, Ohio
0.5% HP Plus	ARR-MAZ Products, Washington, N.C.
15% TR-24 Rubber	Baker Rubber Co., South Bend, Ind.
3% TBS-20 Rubber	Baker Rubber Co., South Bend, Ind.

tained AC-10 from Shell Oil Company with 0.5 percent HP-PLUS antistripping additive, 4 percent extender oil from Sun Oil Company, and 18 percent rubber. The minus 1-mm rubber was 1 part recycled tennis balls (TBS-20) and 5 parts recycled tires (TR-24) furnished by Baker Rubber Company.

Mix Design

As required in the contract, the asphalt contractor hired a consultant to design the mix using a 152-mm Marshall device. VTRC attempted to run checks on the consultant's design. The design curves shown in Figure 4 indicate a major difference between the consultant's design and the VTRC design. The VTRC design failed to achieve as much density. Both the VTM and voids in the mineral aggregate (VMA) were higher in the VTRC design. There was also a vast difference in the stability values. The VTRC stability values were much higher and probably more reasonable for a base mix. A great deal of time was spent talking with the consultant to determine why there were major differences, but the reasons could not be ascertained. Therefore, a decision was made to use the consultant's design since the consultant had a great deal of experience with asphalt rubber mix design. The suggested asphalt rubber binder content was 4.6 percent, and the design gradation is shown in Table 9.

Mixing and Paving Operation

Able Contractors, Inc., of Riverside, Rhode Island, was contracted by APAC to blend the ground rubber and asphalt cement. Blending of the asphalt rubber binder and production of several trial batches of mix were done on May 3, 1993. The trial batches had binder contents of

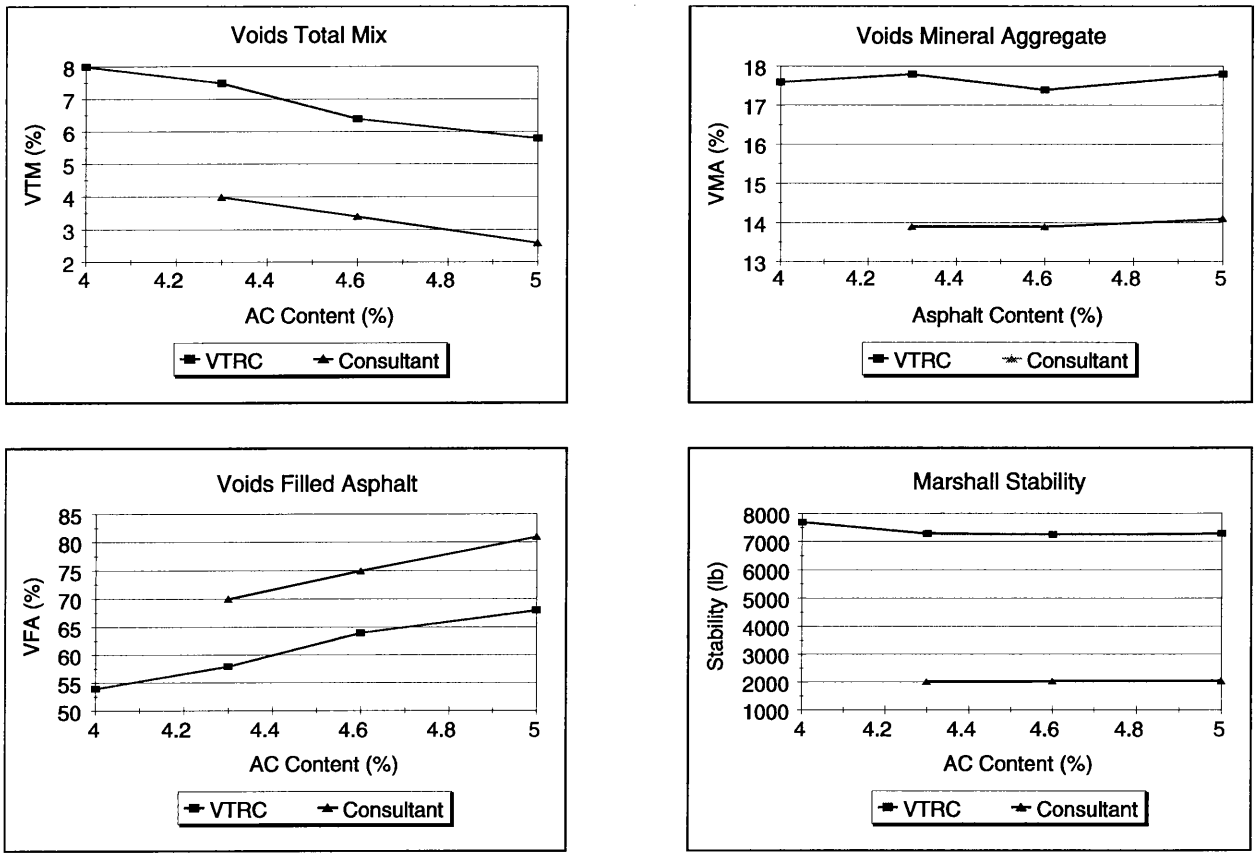

Figure 4. Comparison of Mix Designs for Base Mix in Wythe County

Table 9. Design Gradation for I-81 Base Mix Project in Wythe County

Sieve (mm)	Design Gradation (% Passing)
50	100
37.5	96
25.0	80
12.5	53
4.75	38
0.600	10
0.075	4

4.3, 4.6, and 4.9 percent. The batches were dumped on the ground and inspected, and Marshall specimens were made from the batch containing 4.6 percent binder, the recommended design

binder content. The Marshall VTM was 11.0 percent, and the aggregate gradation from a belt sample was coarse; therefore, it was decided to add No. 8 stone to the aggregate blend and increase the binder content to 4.8 percent. Because of the length of time needed to determine asphalt content by reflux extraction and the possible lack of accuracy due to the insoluble rubber, it was decided to use the nuclear asphalt content gauge to determine the asphalt content and belt samples to determine the aggregate gradation. The contractor had a nuclear asphalt content gauge at the asphalt plant, and the VDOT Bristol District Lab also ran some duplicate tests.

When production started on May 4, 1993, some uncoated particles were noticed; therefore, the wet mixing time was increased from 35 to 38 sec, which appeared to remedy the problem. The blending used to produce the asphalt rubber binder went well, and there were no problems encountered with the production of the plant mix. However, the release agent used in the truck bodies to prevent the mix from sticking had to be changed because it was ineffective.

District personnel observed that the mix handled well and appeared to segregate less than the same mix without rubber. This phenomenon may be due to the sticky nature of the binder, which prevents the particles from rolling and segregating during handling. The mix was stable and did not deform under the paver or haul trucks when the second layer was placed later during the same day. Cores and nuclear density tests showed that the pavement had in-place voids in the vicinity of 7 to 8 percent.

Placement of the base mix in the southbound lanes was completed on May 6, 1993. The other half of the asphalt rubber mix was placed in the northbound lanes on June 2-3, 1993, with no problems.

Test Results

The gradation results of belt samples, asphalt contents by nuclear method, and VTM from the 112-blow 152-mm Marshall tests are given in Table 10. The tests were performed by the contractor with the exception of the asphalt content comparison tests, which were performed by VDOT's Bristol materials lab. Even with belt samples, the gradation test results were within specifications, and there was excellent agreement between VDOT's and the contractor's results for binder content using the nuclear asphalt content gauge.

Route 1, Ashland

A four-lane 7.2-km section of Route 1, south of Ashland, was overlaid September 1-10, 1993, with several types of applications using recycled tire rubber (Figure 5). Three hot mixes were used: approximately 3,700 metric tons of dense-graded mix (ARHM-DG), 3,700 metric tons of gap-graded mix (ARHM-GG) containing crumb rubber, and approximately 1,000 metric tons of a dense-graded control mix with conventional AC-30 asphalt cement binder. A SAMI

Table 10. Production Tests for I-81 Base Mix Project in Wythe County

Date Sample No.	5/4/93 1	5/5/93 1	5/5/93 2	5/6/93 1	Acceptance Range (Average of 4 Tests)
Sieve (mm)	% Passing				
50			100.0	100.0	100
37.5		100.0	96.6	95.7	92-100
25.0		83.4	78.4	79.6	76-84
19.0		74.1	68.1	70.0	
12.5		52.3	50.5	53.1	49-57
9.5		45.7	43.9	46.2	
4.75		36.8	32.1	36.8	34-42
2.36		18.7	18.4	19.1	
0.600		12.0	7.4	9.3	7-13
0.300		5.8	5.2	6.6	
0.075		3.4	3.3	3.8	3-5
AC (%)	4.8 / 4.8*	4.7 / 4.7*		4.8	4.5-5.1
VTM (%)	5.8	4.4		4.1	

AC = asphalt content; VTM = voids total mix.
* VDOT tests on split samples.

using an asphalt rubber binder was placed under one-half of each mix on the southern end of the project.

Environmental testing was done by a consultant to determine if emissions during the production and paving process were harmful to the environment or workers. This testing was reported in separate reports cited in later discussion and only the basic findings are reported here.

Distress Survey

Three weeks before paving, a visual distress survey was conducted to determine the types and amounts of distresses present in the old pavement, and the distresses were mapped in accordance with SHRP manual P-338.[11] The pavement, which was composed of concrete with several overlays of asphalt, had transverse cracks, longitudinal cracks, fatigue cracks, edge cracking, block

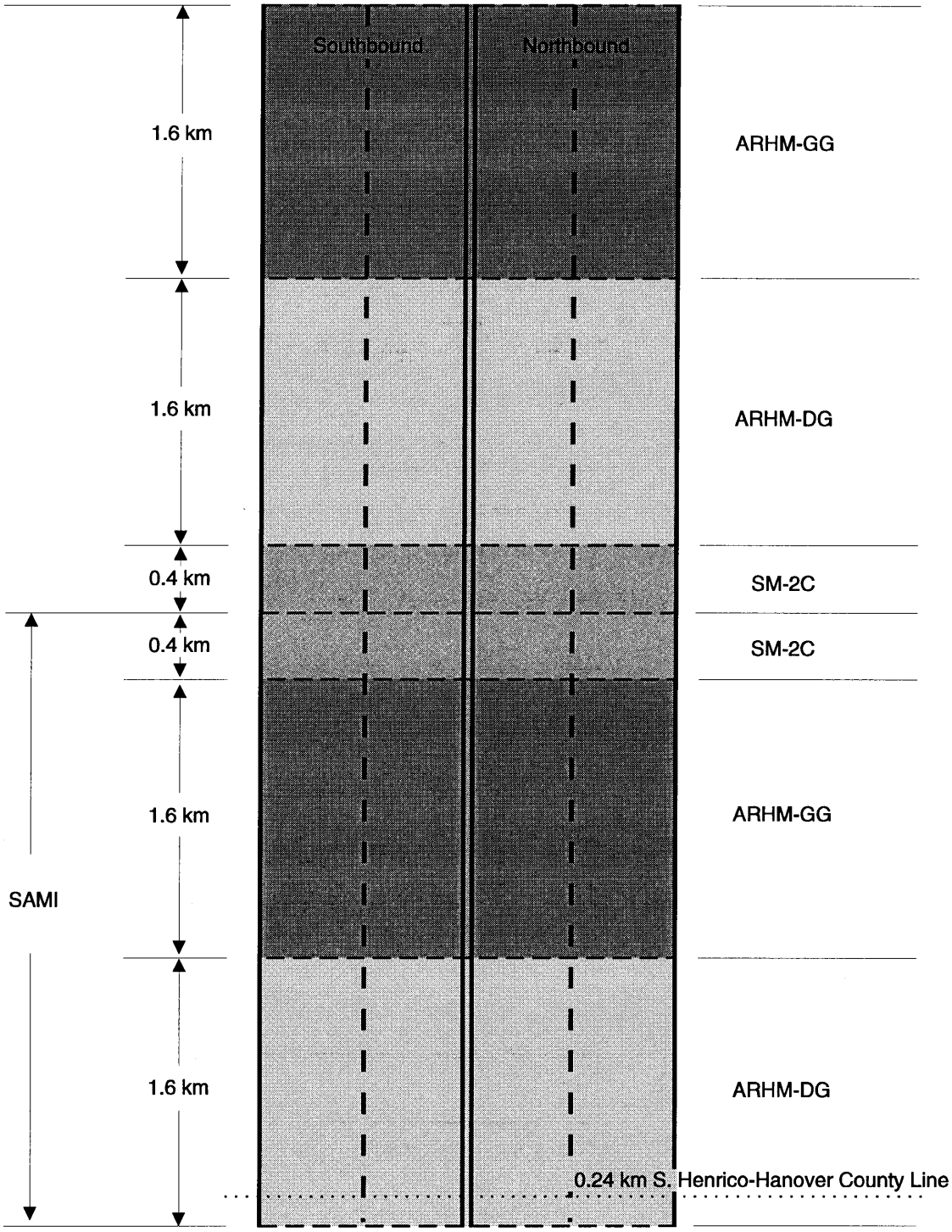

Figure 5. Location of Test Section on Route 1 Near Ashland

cracking, alligator cracking, and some patches. Crack severity ranged from light to heavy. Heaved transverse cracks were spot milled before construction.

It is planned that randomly selected portions of each section will be monitored for distresses at periodic intervals and compared to the evaluations before paving to determine the percentage of cracks that have reflected through the overlay.

Materials

The sources of materials for the mixes are listed in Table 11, and the design gradation and binder contents are listed in Table 12. The binder for both rubber modified mixes contained AC-20 asphalt cement, 4 percent extender oil, and 18 percent ground tire rubber expressed as a percentage of the total binder content. The ingredients were mixed and reacted for 1 hr before being used. The same ingredients were used in the binders for both the hot plant mixes and SAMI.

Table 11. Sources of Materials for Ashland Project

Aggregates	
SM-2C and ARHM-DG	
80% No. 28	Luck Stone Corp., Rockville, Va.
20% Grade A sand	Smith Sand and Gravel, Bowling Green, Va.
ARHM-GG	
65% No. 360	Luck Stone Corp., Rockville, Va.
35% No. 10	Luck Stone Corp., Rockville, Va.
Binder Materials	
AC-20	Citgo Asphalt Refining Co., Hopewell, Va.
790 Extender Oil	Sun Company Inc., Marcus Hook, Penn.
TR-24 Rubber	Baker Rubber Co. (Phone 219-237-6200 for address)
Kling Beta 2700	Scanroad, Incorp., Waco, Tex.

Table 12. Plant Mix Designs for Ashland Project (% Passing)

Sieve (mm)	SM-2C Control	ARHM-DG	ARHM-GG
19.0	100	100	100
12.5	99	99	99
9.5	88	88	86
4.75	59	59	37
2.36	41	41	23
0.600	20	20	9
0.300	11	11	6
0.150	7	7	4
0.075	5.5	5.5	3.5
AC (%)	5.4	6.8	7.8

AC = asphalt content.

Mix Design

The asphalt rubber binder supplier responsible for the hot-mix design obtained the services of Western Technologies, Inc., which has extensive experience in the design of asphalt rubber mixes. VTRC attempted to check the designs submitted by the consultant, but just as in the previous project, there was considerable disagreement. Table 13 shows the differences in Marshall properties, which were especially large for the ARHM-GG mix. Considerable communication between the labs and retesting by VTRC failed to ascertain the reason for the disagreement. The VTRC designs were duplicated very closely by the VDOT materials lab, and a design using the hand-held hammer substantiated the original VTRC designs using the mechanical hammer. The inability to achieve reasonable designs for the asphalt rubber mixes continues to be a concern for possible future projects.

Mixing and Paving Operation

The plant mix was produced by MEGA Contractors, Inc., Rockville, Virginia, in a CMI drum plant in Rockville, Virginia, with a capacity of 180 to 360 metric tons per hour. Able Contractors Inc., Riverside, Rhode Island, was retained by MEGA to supply the rubber-modified binder material at the hot-mix plant. Able Contractors was also responsible for applying the binder to the pavement for the SAMI construction. An attempt was made to use the plant's as-

Table 13. Marshall Properties at Optimum Design Asphalt Content for Ashland Rubber Project

Property	ARHM-DG		ARHM-GG		
	Consultant	VTRC	Consultant	VTRC Mechanical Hammer	VTRC Hand Hammer
AC (%)	6.8	6.8	7.8	7.8	7.8
VTM (%)	3.5	4.5	3.9	7.8	6.7
VMA (%)	17.6	20	20	25	24
VFA (%)	80	78	83	68	72

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

phalt cement pump, but the metering system would not work with the viscous binder. MEGA was given permission by VDOT to use Able Contractors' pump and metering system, but they had to calibrate the plant to yield the correct binder content. The binder content was monitored with a nuclear asphalt content gauge since extractions are especially slow with mixes containing rubber.

The contractor was required to complete both the northbound and southbound lanes in each section on the same day. Two pavers were used, one operating in the northbound lanes and one in the southbound lanes. This type of operation ensured that a full 1.6-km section could be completed in 1 day if no complications such as bad weather interfered. It also enabled the contractor to complete the work quickly and save money by not having to pay the daily mobilization fee charged by the binder supplier.

The ARHM-DG mix with no SAMI was the first to be paved. The traffic lanes were paved first, and then traffic was switched to the traffic lanes and the passing lanes were paved. It appeared that the traffic was causing the traffic lane to bleed when traffic was switched. Surface temperature measurements indicated that the overlay was still 75 C, and the contractor was warned to delay opening to traffic in the future until the surface temperature of the overlay had reached the allowable maximum temperature of 65 C. The pavement was watered on some of the following sections to accelerate cooling. Although the first section of pavement appeared to be in danger of bleeding, it did not.

The northernmost section of ARHM-GG mix was paved next, and the following sections were done in sequence from a north to south progression. No paving problems were encountered that were attributable to the use of the asphalt rubber.

The asphalt rubber binder supplier applied the binder for the SAMI, and the paving contractor applied the chips and swept and vacuumed the excess chips before paving with the overlay. A special Bearcat distributor designed for applying asphalt rubber binder was used. The temperature of the binder was approximately 190 C when it was applied. The excessive blue smoke during application presented a possible safety problem concerning visibility for passing traffic. The chips that were applied hot had been precoated with 0.5 percent AC-20 to increase the chance of forming a good bond with the binder and negating any adverse effect of dust that might have been present on the aggregate. Quantity checks revealed an average rate of 2.7 l/m^2 for binder and 14 kg/m^2 for chips. The roller operator had to be careful not to expose the tires of the pneumatic roller to uncovered binder since it tended to stick to the tires and track worse than a normal binder.

Test Results

Gradation and Asphalt Content Test

The gradation and asphalt content of the production samples are listed in Tables 14 through 16. The contractor determined gradation from extracted samples by the reflux method and asphalt content by the nuclear device for both mixes containing rubber. VTRC subsequently determined both gradation and asphalt content by the reflux method for all mixtures. It was expedient for the contractor to use the nuclear device because the reflux was extremely slow in extracting the binder for the asphalt rubber mixes.

The contractor's results were the average of four samples randomly selected from each section, and the VTRC results were for only the single sample on which the laboratory tests were performed; therefore, it is understandable that the results did not agree precisely. The samples tested by VTRC for the control mix and ARHM-DG mix were slightly finer than the average of the production samples tested by the contractor. The production results of the control mix were slightly finer than the design values on the 4.75-mm and 0.600-mm sieves.

The asphalt contents agreed remarkably well with the design values considering that the nuclear asphalt content gauge was used by the contractor for the asphalt rubber mixes.

Marshall Tests and Pavement Voids

The results of 75-blow Marshall tests on production samples are listed in Table 17. The values are the average of test results for two samples. It is obvious that the design 3.5 percent void level for the asphalt rubber mixes was not achieved, especially for the gap-graded mix. Possibly, the binder content could have been increased slightly to decrease the voids and increase the durability.

Table 14. Production Gradation and Asphalt Content for ARHM-DG Mix for Ashland Rubber Project

Sieve (mm)	MEGA		VTRC
	SAMI	No SAMI	No SAMI
19.0	100.0	100.0	100.0
12.5	99.4	99.5	99.2
9.5	90.0	88.2	92.6
4.75	62.2	59.8	70.2
0.600	22.7	21.7	26.2
0.300	12.1	12.1	14.8
0.075	5.2	4.8	6.0
AC (%)	7.0	6.8	7.2

SAMI = stress absorbing membrane interlayer; AC = asphalt content.

Table 15. Production Gradation and Asphalt Content for ARHM-GG Mix for Ashland Rubber Project

Sieve (mm)	MEGA		VTRC
	SAMI	No SAMI	No SAMI
19.0	100.0		
12.5	99.5	100.0	100.0
9.5	84.1	82.5	85.7
4.75	38.9	38.7	39.6
2.36	21.6	22.0	22.0
0.600	9.7	10.0	10.0
0.300	6.8	7.6	7.7
0.075	3.7	4.0	5.0
AC (%)	7.6	7.7	7.5

MEGA = contractor; VTRC = Virginia Transportation Research Council; SAMI = stress absorbing membrane interlayer; AC = asphalt content.

Table 16. Production Gradation and Asphalt Content for SM-2C Mix for Ashland Rubber Project

Sieve (mm)	MEGA		VTRC
	SAMI	No SAMI	No SAMI
19.0	100.0		
12.5	99.7	100.0	100.0
9.5	89.7	91.6	93.6
4.75	61.4	63.9	70.0
0.600	22.4	23.5	26.3
0.300	12.5	11.9	14.1
0.075	5.4	5.5	6.0
AC (%)	5.5	5.5	5.6

MEGA = contractor; VTRC = Virginia Transportation Research Council; SAMI = stress absorbing membrane interlayer; AC = asphalt content.

Table 17. 75-Blow Marshall Voids Total Mix and Pavement Voids for Ashland Rubber Project

Type of Mix	MEGA (%)	VTRC (%)	Pavement Voids (%)
SM-2C (No SAMI)	4.3	4.7	7.6
SM-2C (SAMI)			6.3
ARHM-DG (No SAMI)	4.2	5.1	9.9
ARHM-DG (SAMI)	4.5	6.4	8.9
ARHM-GG (No SAMI)	6.2	6.5	10.6
ARHM-GG (SAMI)	6.8	6.4	11.7

MEGA = contractor; VTRC = Virginia Transportation Research Council; SAMI = stress absorbing membrane interlayer.

Pavement void values also indicated that the binder content could have been increased. Approximately 11 percent voids in the gap-graded mix will allow the entrance of water, possibly causing stripping and the entrance of air resulting in accelerated oxidation.

Gyratory Shear Tests

The gyratory shear test results are listed in Table 18. There was no significant difference in shear strengths among the three mixes: all of which were greater than the minimum desirable strength of 260 kPa. The gyratory shear index (GSI) values were low, i.e., considerably less than 1.0, which may indicate that the mixes were deficient in binder. The VTM tends to parallel those obtained with the Marshall test. A high VMA for the ARHM-DG mix may indicate that the rubber particles are tending to push the aggregate particles apart, preventing close packing. A low VFA for the ARHM-GG mix possibly indicates that more binder could have been used.

Table 18. Gyratory Shear Test Results for Production Samples for Ashland Rubber Project

Type of Mix	Shear Strength (kPa)	GSI	VTM (%)	VMA (%)	VFA (%)
SM-2C (No SAMI)	320	0.94	5.0	17.6	71.8
ARHM-DG (No SAMI)	300	0.91	5.3	21.5	75.4
ARHM-DG (SAMI)	340	0.90	5.7	21.8	74.0
ARHM-GG (No SAMI)	340	0.89	6.7	23.2	71.3
ARHM-GG (SAMI)	47	0.88	8.0	24.3	67.2

GSI = gyratory shear index; VTM = voids total mix; VMA = voids mineral aggregate; VFA = voids filled with asphalt; SAMI = stress absorbing membrane interlayer.

Indirect Tensile Tests

Indirect tensile tests were conducted at three temperatures in an attempt to determine whether the asphalt rubber binder tended to make the mix more ductile and possibly able to resist cracking at low temperatures. Each mix was tested at 2 C, 7 C, and 13 C at a horizontal deformation rate of 1.5 mm/min.

Figure 6 illustrates the failure strains for each mix based on the average of eight samples at each point. The failure strain of the ARHM-GG mix is statistically greater than the failure strains of the ARHM-DG mix and the control mix at 2 C at a 99 percent confidence level. The failure strain of the gap-graded mix is statistically greater than that of the dense-graded mix at

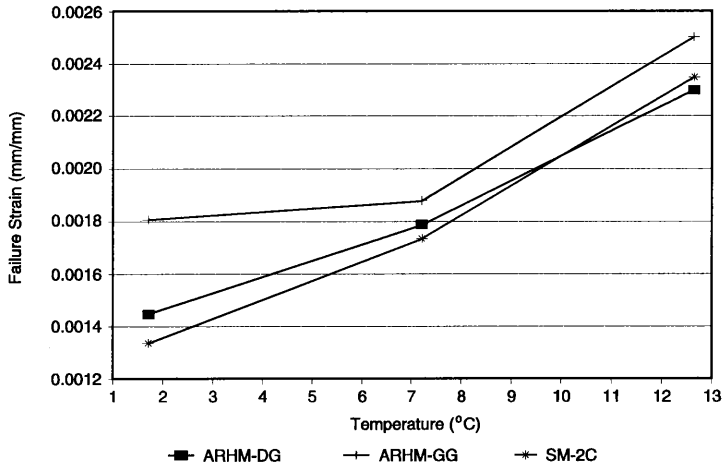

Figure 6. Failure Strain for Indirect Tensile Tests

7 C and 13 C at a 90 percent confidence level. These results indicate that the gap-graded mix should tolerate higher strains before failing, especially at low temperatures.

Environmental Testing

The asphalt plant stack emissions were tested by KTA Environmental of Pittsburgh, Pennsylvania. Emissions for the ARHM-DG mix were tested on September 1, and those for the control mix were tested on September 3. Industrial hygiene air samples collected from the worker breathing zones were also tested for the ARHM-DG, ARHM-GG, and control mixes produced on September 1, 2, and 3, 1994, respectively. The report of the testing of stack emissions by KTA stated ". . . it is our judgment that the analytical results of the pollutants sampled support the notion that HMA crumb rubber mixture does not materially impair air quality in the state as measured by comparison to federal and state requirements."[12]

Although the worker hygiene air quality testing did not reveal any exposure beyond permissible levels, permissible exposure limits do not exist for some of the materials identified.[13] Higher levels of some chemicals components such as polycyclic aromatic hydrocarbons (PAHs), sulfur heterocyclics, and benzene soluble fractions (BSF) were recorded during paving with the rubber mixes than during paving with the control mix. The BSF was thought to be a long-chain saturated aliphatic with low toxicity.

Lists of specific compounds identified and the amounts present are given in the two reports cited.

Field Observations After Eight Months

After 8 months, samples were sawed from the pavement at several locations where the SAMI was not used and examined visually. Moisture was detected in the ARHM-GG mix and at the pavement interface immediately beneath the mix. No moisture was detected in the ARHM-DG mix. The gap-graded mix had more voids than the dense-graded mix immediately after construction, possibly allowing more rain water to enter. The entrance of water could promote stripping.

A detailed crack analysis has not been done, but transverse cracks have reflected through the new mix in all sections. Because of the large strains involved in creating this type of cracking, it was not thought that the addition of rubber would mitigate the cracking. Future examinations may indicate that the rubber will slow or eliminate some of the less severe cracking.

Friction Tests at Ten Months

The results of friction tests performed with the smooth tire are plotted in Figure 7. It was evident that the values for the control mix and the ARHM-DG mix that was paved first (mileposts 1.8 to 3.3) were considerably lower than for the other ARHM-DG mix and either gap-graded mix. Usually, one would suspect a change of gradation or asphalt content to influence the density and surface texture and thus the friction values, but an examination of these mix characteristics did not reveal a reason for the difference in friction values. The ambient temperature was slightly higher on the days the sections were paved that had low friction values. The high temperature recorded on days on which the control and first ARHM-DG mix were paved were 34 C and 33 C, respectively, compared with 32 C for the ARHM-DG mix with high friction values. It was also observed that traffic was allowed on the first ARHM-DG mix before it had cooled

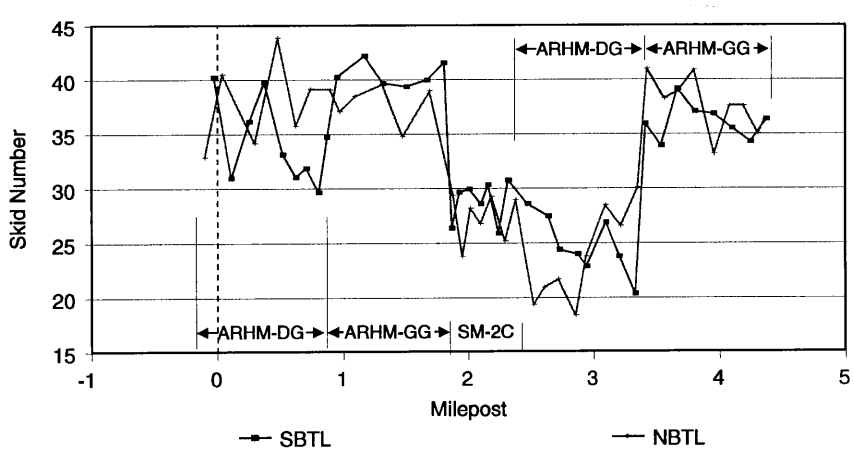

Figure 7. Friction Test Results on Ashland Project

sufficiently, which may have caused the binder to be drawn to the surface. A combination of these two conditions, high ambient temperatures and the mix being hot when opened to traffic, could certainly have caused some loss of surface texture and lowering of friction resistance.

COST SUMMARY

The cost of the mixes containing rubber ranged from 64 to 102 percent more than that of the control mixes on the same projects (Table 19). This cost is comparable to what other states have encountered for the same types of applications.

One reason for the extremely high cost is that the jobs were relatively small and the asphalt contractors were probably adding a cushion to cover unexpected costs associated with producing and paving using a new material. The binder suppliers, who had to travel considerable distances in all cases, charged a mobilization fee per day or per week that had to be written off for the entire job. If the estimate of time required to complete a job is short, the contractor has to absorb the extra costs; therefore, most contractors will add some cost to the bid price to cover extra time that may required because of bad weather or breakdowns. If asphalt rubber were

Table 19. Mix Costs

Project	Mix Type	Cost per HM-GG Metric Ton	Cost Increase (%)
Rte. 1 Fairfax	SM-2C Control	$29.00	
	Asphalt Rubber	$52.90	82
I-81 Wythe Co.	SM-2C Control	$25.08	
	5% Rubber	$50.72	102
	10% Rubber	$50.72	102
I-81 Wythe Co.	BM-3 Control	$28.32	
	BM-3 Asphalt Rubber	$50.72	79
Rte. 1 Ashland	SM-2C Control	$34.62	
	Dense-Graded Rubber	$56.78	64
	Gap-Graded Rubber	$56.78	64
	SAMI	$1.93 per m^2	

HM-GG = hot mix-gap graded; SAMI = stress absorbing membrane interlayer.

placed in Virginia in large quantities, the unit price would very likely decrease. However, it would probably never decrease enough to be competitive with the price of other asphalt modifiers such as polymers, and it is unlikely that the higher cost would be justified by a longer service life.

SUMMARY

Although the test pavements containing asphalt rubber are performing as well as the pavements containing normal mixes, several sections have been in service only a short time. Currently, none of the pavements containing asphalt rubber shows superior performance and probably will not be cost-effective. More time will be required to evaluate the different mixes and types of construction used on the last project near Ashland and the surface mix used near Wytheville.

Shear strength and resilient modulus were increased for the surface mixes containing the fine 80-mesh ground rubber used near Wytheville, and the creep permanent strain was reduced. The rutting potential of these mixes should thus be less than that of the control mixes. On the other hand, the shear strength of the asphalt rubber mixes placed near Ashland did not differ from that of the control mix. Quite possibly, a repeated load triaxial test may better simulate the actual performance under moving traffic, but the equipment was not available for this study. The mixes in Ashland had low GSI values under the gyratory shear test, which may mean that they were low in binder. The indirect tensile test indicated that the gap-graded mix used at Ashland may not crack as easily as regular mixes at low temperatures.

Good agreement was obtained with the nuclear asphalt content gauge and extraction tests used to determine the binder content on two of the projects.

Mix design appears to be a problem. There was not good agreement between the consultant and VDOT labs in two cases, and more work needs to be done to resolve these differences.

Some changes were made in the specifications from the first project to the last project placed. It is felt that only minor changes in the present specifications will be required when it becomes necessary or desirable to place more asphalt rubber mix.

CONCLUSIONS

1. Both the MacDonald and Rouse processes are viable options in the use of ground tire rubber in asphalt pavement.

2. More rubber can be used in the MacDonald process than in the Rouse process.

3. Based on lab tests, the Rouse process offers rutting resistance and the MacDonald process using gap-graded mixes offers cracking resistance at low temperatures.

4. Based on the limited time of evaluation, asphalt rubber mixes were found to perform at least as well as regular mixes. The Rouse process seems to confirm lab results, and its use offers some resistance to rutting.

5. The addition of rubber will probably add approximately 50 to 100 percent to the cost of conventional mixes, and it is unlikely that its addition will be cost-effective.

RECOMMENDATIONS

1. Projects should continue to be evaluated periodically to determine long-term performance.

2. An effort should be made to resolve questions about mix design.

3. The nuclear asphalt content gauge should be used to monitor binder content of asphalt rubber mixes.

4. The latest specifications used by VDOT on the experimental projects may be used with minor modifications for future contracts when needed.

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