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research report

Evaluation of Using Higher Percentages of Recycled Asphalt Pavement in Asphalt Mixes in Virginia

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Supplementary Notes

Abstract

In 2007, the Virginia Department of Transportation (VDOT) decided to allow higher percentages of recycled asphalt pavement (RAP), i.e., more than 20 percent, in hot-mix asphalt with no change in binder grade. Because of this increase, one section of the contract provisions in certain plant-mix overlay schedules around the state had to be rewritten to raise the limit on the proportion of recycled material to 30 percent from the customary 20 percent. The allowance of higher RAP percentages should result in a lower cost of asphalt mix per ton, especially given the recent rising cost of asphalt cement and virgin aggregates.

The purpose of this study was to estimate the effect of increased RAP percentages on performance and relative mixture cost on specific VDOT paving projects in 2007. Projects using more than 20 percent RAP were conducted in three VDOT districts. In addition, several value engineering proposals for using increased percentages of RAP submitted by contractors were accepted and carried out in another district. Six contractors produced a total of 129,277 tons of mix containing 21 to 30 percent RAP from seven asphalt plants in four VDOT districts. Mix containing less than 20 percent RAP was also sampled and tested for comparison purposes.

Laboratory tests performed on samples collected during production revealed no significant difference between the higher RAP mixes and the control mixes for fatigue, rutting, and susceptibility to moisture. Binder was recovered from asphalt mix sampled during construction and graded to determine the effect of adding higher percentages of RAP.

There were no construction problems attributed to the use of the mix with the higher RAP percentage. Only slight price adjustments were applied to 2 of the 10 high-RAP projects, and these adjustments were not due to the higher RAP percentage.

Analysis of bid data found that the inclusion of a contract specification that allowed the higher RAP percentages had a small, statistically insignificant impact on the bid prices for surface mix items. However, value engineering proposals received for jobs that were not advertised with the high-RAP specification showed that the use of over 20 percent RAP could reduce costs in at least some cases.

FINAL REPORT

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(A partnership of the Virginia Department of Transportation
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ABSTRACT

In 2007, the Virginia Department of Transportation (VDOT) decided to allow higher percentages of recycled asphalt pavement (RAP), i.e., more than 20 percent, in hot-mix asphalt with no change in binder grade. Because of this increase, one section of the contract provisions in certain plant-mix overlay schedules around the state had to be rewritten to raise the limit on the proportion of recycled material to 30 percent from the customary 20 percent. The allowance of higher RAP percentages should result in a lower cost of asphalt mix per ton, especially given the recent rising cost of asphalt cement and virgin aggregates.

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INTRODUCTION

Escalation of materials prices has resulted in a significant rise in the cost of asphalt paving in recent years. Therefore, there is a statewide and national effort to use recycled asphalt pavement (RAP) to lower the cost of paving. RAP contains approximately 95 percent aggregate and 5 percent asphalt binder, both valuable resources. Brock, of Astec Industries, Inc., has been quoted as saying: "Today, however, with liquid AC at $330 to $350 per ton and rock at $8 to $25 per ton, the economics of using RAP is attractive to both producers and paving contractors."[1] According to Schreck of the Virginia Asphalt Association, in 2006, there was potential for a savings of $3.72 per ton of hot mix for each 10 percent of RAP that could be incorporated.[2]

The Virginia Department of Transportation (VDOT) first used RAP in an experimental project in 1979, and two subsequent RAP projects were completed in 1980 and 1981. These projects used 40 to 45 percent RAP through batch-type asphalt plants.[2] Because of the successful completion of these projects, VDOT adopted a specification in 1984 that allowed up to 25 percent RAP unless otherwise approved by the project engineer.[2]

In 1997, with the adoption of Superpave, VDOT changed its specification to allow up to 20 percent RAP for surface and intermediate mixes before the virgin binder grade had to be changed.[2] This value was midway between the 15 percent recommended by Federal Highway Administration guidelines for Superpave and the VDOT limit of 25 percent for pre-Superpave mixes mentioned previously. Since Superpave was being implemented as a new mix design procedure, VDOT exercised caution not to set specification limits for RAP that had the potential to influence performance negatively. In NCHRP Study No. 253, McDaniel and Anderson, of Purdue University, found that RAP could be used in Superpave mixes if the binder contained in the RAP was considered during the binder selection.[3] In a subsequent pooled fund study, McDaniel et al. found that mixes can be designed properly with up to 40 or 50 percent RAP.[4]

As mentioned previously, states were reluctant to allow high percentages of RAP when the use of Superpave commenced. Some states allowed no RAP in surface mixes, and those that

RAP generally allowed from 10 to 30 percent.[5] A national RAP expert task group has been formed to encourage greater use of RAP, primarily through using RAP contents greater than those currently being used. The National Asphalt Pavement Association recently published a guide for designing asphalt mixtures containing up to 40 percent RAP.[6] Newcomb, the association's vice-president of research and technology, indicated that it is time for industry to look at increasing the amount of RAP in mixes.[7]

A joint committee composed of Virginia asphalt industry representatives and personnel from VDOT's Asset Management Division decided to increase the percentage of RAP for specific maintenance overlay schedules in Virginia in 2007. The special provision developed for these projects is provided in Appendix A. Although there was a general expectation that mixes containing more than 20 percent RAP could be economical, VDOT wanted to document the construction and verify that performance would be acceptable with the possible cost reduction.

VDOT may experience the impact of allowing over 20 percent RAP in either or both of two ways. First, VDOT may realize a cost impact up front if the change of specifications induces some contractors to submit different bid prices on plant mix items or affects the frequency of price adjustments and delays. Second, VDOT may realize a cost impact "down the road," if higher-RAP pavement proves to have different life cycle properties than pavement containing 20 percent or less RAP. The cost-effectiveness of higher-RAP mixes therefore depends on the unit cost of these mixes and on their performance during and after placement.

PURPOSE AND SCOPE

The purpose of this study was to estimate the effect of increased RAP percentages on performance and relative mixture cost for specific VDOT paving projects in 2007. Projects using a high percentage of RAP (i.e., projects where the RAP percentage was above 20) were planned in four VDOT districts but were conducted in only three. In addition, several value engineering proposals (VEPs) for using increased percentages of RAP submitted by contractors were accepted and carried out in another district.

This study reports only the results of tests that could be conducted within 1 year of advertisement of the resurfacing contracts. Long-term performance evaluations of the pavements will continue.

METHODOLOGY

This project was conducted jointly by the Virginia Transportation Research Council (VTRC) and VDOT's Materials Division. Staff from both entities collected samples for laboratory testing. The performance of the mixes was predicted by performing laboratory tests. The Materials Division also accumulated information regarding the production and construction of the hot-mix asphalt (HMA) used in this study such as type of equipment, temperatures, materials, quality control production results, etc., to document construction variables should the performance be affected detrimentally. The Materials Division performed Abson recoveries for the binder testing and conducted rut testing. VTRC performed the remaining laboratory tests and tested the properties of the virgin and recovered binders. Each high-RAP mix was tested to predict performance and document its properties. Mixture was also sampled and tested from three projects that used low-RAP (mixes with less than 20 percent RAP) for comparison. In addition, some laboratory test results that were obtained previously through other research projects were included for the low-RAP projects.

One of the aims of this investigation was to determine the effect on cost of using mixes containing a higher RAP content. The bid price data from the 2007 plant mix schedules were analyzed to estimate this effect of the higher-RAP specification (see Appendix A) on the price per ton of mix.

Locations of Projects

High-Rap Projects

Several maintenance overlay schedules in Dinwiddie and Goochland counties (Richmond District) could be bid with either low-RAP or high-RAP mixes. All maintenance schedules in the Hampton Roads District could be bid with either the low-RAP or high-RAP option, but high-RAP mixes were bid only in Chesapeake City and Surry County. Another district (Northern Virginia) had a schedule allowing this option, but the contractor chose not to use high-RAP mixes because of design difficulties with the high fines/asphalt ratio. The projects in Carroll and Floyd counties (Salem District) were required to be high-RAP. Although not originally planned, two contractors performing the HMA work in Appomattox, Campbell, and Pittsylvania counties (Lynchburg District) chose to submit VEPs to use high-RAP mixes in order to lower costs. The computed savings were split between VDOT and the contractor when the VEPs were accepted.

Table 1 shows the construction of VDOT's high-RAP mixtures in 2007. Most of the work involved asphalt overlays with the exception of the Goochland County job where an

Table 1. Summary of Construction of High-RAP Mixes

Route(s)	County or City	Mix Type	% RAP	Contractor	Tonnage
SR 40, CR 703	Dinwiddie	SM-12.5D	25	B.P. Short	12,007
CR 611	Surry	SM-9.5D	25	B.P. Short	3,169
I-664	Chesapeake	SM-12.5D	30	Branscome, Inc.	7,092
SR 6	Goochland	SM-12.5D	25	Branscome Richmond	5,250
SR 6	Goochland	IM-19.0D	30	Branscome Richmond	2,584
US 58	Carroll	SM-9.5D	30	Adams Construction	10,042
US 221	Floyd	SM-9.5D	30	Adams Construction	7,544
US 29	Nelson	SM-9.5D	25	Marvin V. Templeton & Sons	24,898
SR 24, CR 691	Appomattox	SM-9.5D	25	Marvin V. Templeton & Sons	24,841
US 29, SR 57, CR 729, CR 988	Pittsylvania	SM-9.5D	21	W-L Construction and Paving	31,940
Total					129,277

intermediate mix (IM-19.0D) was covered with an SM-12.5D surface mix. D mixes require a PG 70-22 or a PG 64-22 binder when more than 20 percent RAP is used in the HMA. All of these mixes contained PG 64-22 binder with the high-RAP contents. All of the mixes were designed with the Superpave gyratory compactor using 65 gyrations. Design and production criteria are provided in Table 2.

Table 2. Mix Design and Production Criteria

	Mix		
	SM-9.5D	**SM-12.5D**	**IM-19.0D**
Sieve (mm)	**Gradation design (% passing)**		
25.0			100
19.0		100	90-100
12.5	100	95-100	90 max.
9.5	90-100	90 max.	
4.75	80 max.		
2.36	38-67	34-50	28-49
75µm	2-10	2-10	2-8
Volumetric properties (%)			
Design air voids	4.0	4.0	4.0
Production air voids	2.0-5.0	2.0-5.0	2.0-5.0
Design voids filled with asphalt	68-84	65-83	64-81
Minimum design voids in mineral aggregate	15.0	14.0	13.0

Low-Rap Projects

Some control sections of pavement with low-RAP mixes were identified for use for performance comparison. Although it was not possible to locate those sections adjacent to the high-RAP sections, an effort was made to match the conditions that would affect performance to those of the high-RAP sections.

Sampling and Testing

At least one sample of mixture was taken from a single truck at the hot-mix plant for each paving project for subsequent laboratory testing. Samples of RAP were taken at the same time. Mixture was sampled from some projects more than once to repeat the Abson recovery test and obtain binder properties. VTRC performed all tests except rut tests, which were performed by VDOT's Central Office Asphalt Lab. The lab also recovered the binder by the Abson procedure from mixture and RAP samples, and VTRC subsequently graded the recovered binder.

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.

Fatigue Tests

Beam fatigue tests were performed in accordance with AASHTO T 321[8] using the apparatus shown in Figure 1. At least three fatigue tests were performed at a high, low, and intermediate strain level, 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 it was defined as the strain level that a lab specimen could survive at least 50 million cycles, and it was projected from the regression of the 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. The endurance limit was roughly estimated from the 95 percent confidence one-sided lower prediction limit for a fatigue life of 50 million cycles, and that estimation was used in this study (see Figure 2).

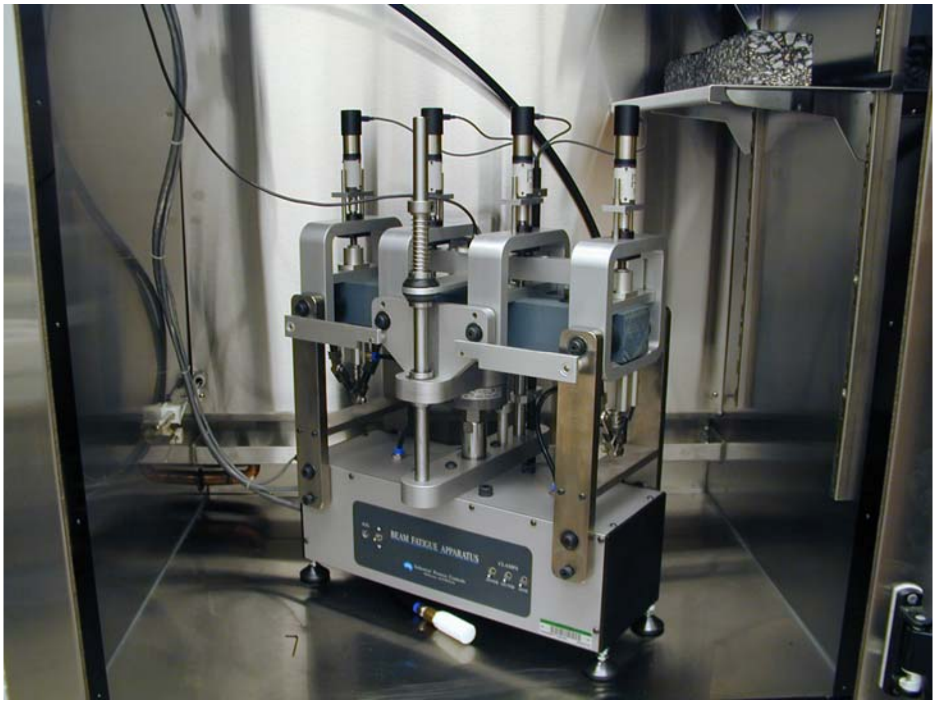

Figure 1. Beam Fatigue Testing Equipment

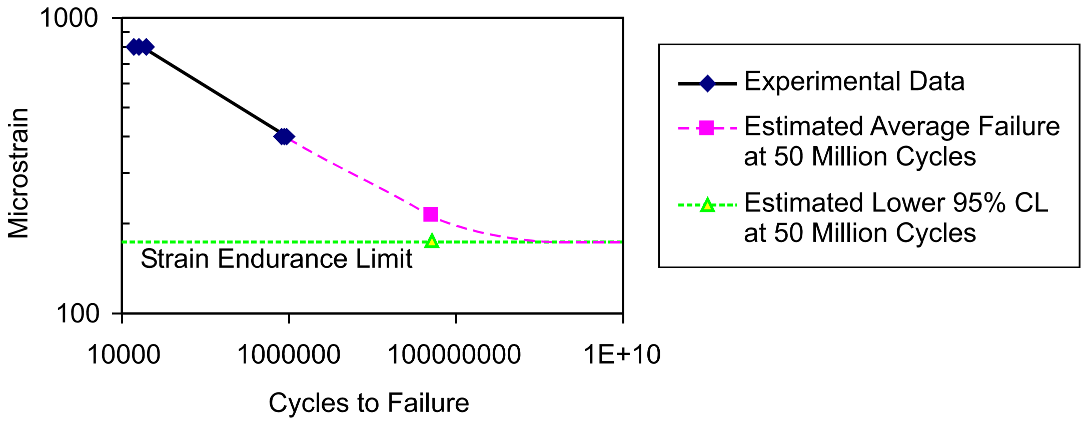

Figure 2. Example of Estimated Endurance Limit

Rut Tests

Rut tests were performed on beams with the Asphalt Pavement Analyzer (APA) in accordance with VTM 110.[9] 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.

Tensile Strength Ratio Stripping Tests

Tensile strength ratio (TSR) moisture susceptibility tests were performed in accordance with AASHTO T 283.[8] 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 Recoveries

The binder was recovered from all mixes and RAP samples in accordance with AASHTO T 170.[8] The recovered binder was graded in accordance with Superpave performance grading (PG) after aging in the pressure aging vessel (PAV) since it had already undergone aging during production, usually simulated by including aging with the rolling thin-film oven (RTFO). RTFO aging is normally required when testing virgin binders.

2007 Plant Mix Schedule Price Bid Data

The price analysis compared the prices of the plant mixes where the advertised provision allowed or required over 20 percent RAP with those of the mixes where the advertised provision limited RAP content to the standard 20 percent or less.

Bid Price Data

A cross-sectional database consisting of all of the surface mix (SM) line items in the 2007 plant mix schedules was compiled. The data of principal interest were (1) the winning contractor's bid price for each surface mix line item and (2) a pair of 0/1 variables (dummy variables) that indicated whether that surface mix line item was subject to an optional high-RAP provision, to a required high-RAP provision, or to no high-RAP provision. To control for other factors believed to influence the price of plant mix, several additional pieces of information were tabulated: (1) the number of tons of plant mix in that line item; (2) the total number of tons of plant mix, of any type, in the schedule that contained that line item; (3) the number of contractors who submitted bids for the schedule that contained that line item; (4) the asphalt mix designation (9.0, 9.5, 12.5, or 19.0) in that line item; and (5) the binder grade (A, D, or E) in that line item. Table 3 provides a breakdown of the surface mix bid items in the 2007 plant mix schedule.

The difference between the number of high-RAP bid items in Table 3 and the number of high-RAP mixes in Table 1 reflects the fact that in half-a-dozen of the jobs that included the

Table 3. Surface Mix Items in VDOT 2007 Plant Mix Schedule

Mix Type	Number of Bid Items	Number of Bid Items with High-RAP Spec
9.0A	2	0
9.5A	26	9
9.5D	24	3
9.5E	1	0
12.5A	24	0
12.5D	26	4
12.5E	8	0
19.0A	9	0
19.0D	2	0
Total	122	16

high-RAP provision, the contractors chose to produce plant mix that contained no more than 20 percent RAP.

Value Engineering Proposals

VDOT procurement policies and procedures give the contractor an opportunity to propose changes in design that will reduce cost or add value: if the proposal is approved, VDOT and the contractor divide the calculated savings equally. Two contractors chose to submit VEPs for high-RAP mix designs on projects not subject to the high-RAP provision. These VEPs covered 3 of the 105 non–high-RAP items in the regression database. As cost savings were the fundamental basis of these VEPs, they provide an additional perspective on the potential cost savings from using over 20 percent RAP. Although this sample of three was too small to allow meaningful statistical analysis, it was possible to describe and compare the three cases.

RESULTS AND DISCUSSION

Laboratory Tests

Gradation and Volumetrics

Gradation and asphalt content was determined for samples of high-RAP mix taken by VDOT/VTRC during construction that had been subjected to the ignition furnace. The results of those tests are listed in Table 4. There were three 9.5 mm, three 12.5 mm, and two 19.0 mm mixes. All were D mixes, i.e., contained a PG 64-22 virgin binder with more than 20 percent RAP. The asphalt contents of the 9.5 mm, 12.5 mm, and 19.0 mm mixes ranged from 5.6 to 5.8, 5.6 to 5.7, and 5.5 to 6.0, respectively.

Table 5 shows the gradation and asphalt content of samples of mixture containing 20 percent or less RAP, which served as a control comparison. There were five 9.5 mm and two 12.5 mm mixes. One-half of each sized mix was designated as an A mix, i.e., contained PG 64-22 binder, and one-half was designated as a D mix, i.e., contained a PG 70-22 binder. The asphalt contents of the 9.5 mm and 12.5 mm mixes ranged from 5.5 to 5.8 and 5.2 to 5.4, respectively.

Table 4. Gradation and Asphalt Content Performed on Lab Samples of High-RAP Mixes

Mix ID	% Passing							
	07-1023 SM-9.5D	**07-1025 SM-9.5D**	**07-1026 SM-9.5D**	**07-1027 SM-12.5D**	**07-1045 SM-12.5D**	**07-1046 SM-12.5D**	**07-1047 IM-19.0D**	**07-1056 SM-9.5D**
% RAP	**25**	**30**	**25**	**30**	**25**	**25**	**25**	**21**
Sieve (mm)								
19.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	99.7	99.9	99.9	98.3	98.8	97.4	95.2	99.5
9.5	94.8	91.1	95.8	91.1	90.6	87.0	85.7	93.9
4.75	60.0	55.2	63.0	64.8	57.5	58.6	59.7	63.7
2.36	43.9	41.6	44.2	48.2	41.6	44.0	43.0	47.6
1.18	34.6	33.5	32.1	38.3	31.0	32.1	31.1	36.0
600μm	25.1	25.3	22.7	29.1	21.9	22.4	21.5	26.0
300μm	14.1	14.4	15.2	17.8	14.4	14.4	12.7	15.4
150μm	6.6	8.8	9.4	8.7	9.1	9.2	8.0	10.2
75μm	4.4	6.1	5.2	5.4	5.3	6.2	5.7	6.4
% AC	5.6	5.8	5.7	5.6	5.5	5.7	5.5	6.0

AC = asphalt content.

Table 5. Gradation and Asphalt Content Performed on Lab Samples of Control Mixes

Mix ID	% Passing						
	06-1035 SM-9.5A	**06-1041 SM-9.5A**	**06-1047 SM-12.5A**	**06-1055 SM-9.5A**	**07-1060 SM-9.5D**	**07-1063 SM-12.5D**	**07-1064 SM-9.5D**
% RAP	**10**	**20**	**10**	**20**	**15**	**20**	**0**
Sieve (mm)							
19.0		100.0	100.0	100.0	100.0	100.0	100.0
12.5	100.0	99.9	95.8	99.2	99.9	93.3	99.7
9.5	96.4	93.6	84.1	90.9	93.5	77.3	94.2
4.75	67.5	60.6	48.3	60.2	55.4	49.1	57.7
2.36	47.2	42.6	32.7	46.5	38.7	37.4	42.7
1.18	36.1	32.5	24.7	37.1	30.4	28.9	30.6
600μm	26.7	23.9	19.7	27.5	22.5	20.4	20.7
300μm	16.2	15.4	13.4	15.6	13.0	12.5	12.4
150μm	9.2	9.7	8.6	7.8	8.8	8.0	7.9
75μm	6.2	5.9	6.5	5.3	6.8	5.4	5.4
% AC	5.7	5.5	5.4	5.8	5.7	5.2	5.5

AC = asphalt content.

Fatigue Tests

As previously discussed in the "Methods" section, at least nine fatigue tests at different strain levels were performed on each mix, and the endurance strain limit, i.e., the maximum strain that can be tolerated for nearly an infinite fatigue life, was calculated. Table 6 lists the estimated strain endurance limits for each mix. Using the *t*-test at a 95 percent confidence limit, one cannot conclude that the average endurance limits of 104 με and 121 με for high-RAP and control mixes, respectively, are different.

Table 6. Estimated Fatigue Strain Endurance Limits From Regressions

Mix	Mix ID		% RAP	% Air Voids	Regression R-square	Number of Specimens	Endurance Microstrain
High RAP	07-1023	SM-9.5D	25	6.5	0.941	8	113
	07-1025	SM-9.5D	30	6.6	0.972	11	97
	07-1026	SM-9.5D	25	7.1	0.639	11	83
	07-1027	SM-12.5D	30	7.1	0.960	11	93
	07-1045	SM-12.5D	25	7.2	0.957	11	118
	07-1046	SM-12.5D	25	7.2	0.806	11	111
	07-1047	IM-19.0D	25	7.2	0.979	11	93
	07-1056	SM-9.5D	21	8.3	0.969	9	130
				7.0	**0.903**		**104**
Control	06-1041	SM-9.5A	10	7.8	0.996	7	117
	06-1047	SM-12.5A	20	8.9	0.876	8	80
	06-1055	SM-9.5A	20	8.2	0.884	11	123
	06-1035	SM-9.5A	10	7.8	0.996	6	177
	07-1060	SM-9.5D	15	7.0	0.975	11	158
	07-1063	SM-12.5D	20	7.0	0.926	11	110
	07-1064	SM-12.5D	0	8.3	0.932	11	79
				7.8	**0.919**		**111.631**

Values in bold indicate average.

Table 7. Rut Test Results Using the APA

Mix	Mix ID		% RAP	% VTM	Rut Depth (mm)
High RAP	07-1023	SM-9.5D	25	8.5	4.8
	07-1025	SM-9.5D	30	8.1	4.6
	07-1026	SM-9.5D	25	8.0	3.8
	07-1027	SM-12.5D	30	7.7	4.8
	07-1045	SM-12.5D	25	7.8	3.5
	07-1046	SM-12.5D	25	8.3	2.1
	07-1047	IM-19.0D	25	8.0	2.4
	07-1056	SM-9.5D	21	8.2	1.8
					3.5
Control	06-1041	SM-9.5A	10	7.1	3.8
	06-1047	SM-12.5A	20	8.6	2.7
	06-1055	SM-9.5A	20	8.6	4.6
	06-1035	SM-9.5A	10	7.8	7.0
	07-1060	SM-9.5D	15	8.2	3.1
	07-1063	SM-12.5D	20	8.5	1.4
	07-1064	SM-12.5D	0	8.0	2.4
					3.6

Values in bold indicate average.

Tensile Strength Ratio Tests

The results of tensile strength ratio (TSR) tests are shown in Table 8. Similarly, it is obvious from the test results that there is no significant difference between the average TSR for the high-RAP and control groups. It might be noted that three mixes from the high-RAP group and one mix from the control group had values lower than the minimum acceptable design value of 0.8.

Table 8. Tensile Strength Ratio (TSR) Test Results

Mix	Mix ID		% RAP	TSR
High RAP	07-1023	SM-9.5D	25	0.85
	07-1025	SM-9.5D	30	0.86
	07-1026	SM-9.5D	25	0.69
	07-1027	SM-12.5D	30	0.74
	07-1045	SM-12.5D	25	0.84
	07-1046	SM-12.5D	25	0.88
	07-1047	IM-19.0D	25	0.77
	07-1056	SM-9.5D	21	0.91
				0.82
Control	06-1041	SM-9.5A	10	0.72
	06-1047	SM-12.5A	20	0.85
	06-1055	SM-9.5A	20	0.82
	06-1035	SM-9.5A	10	0.93
	07-1060	SM-9.5D	15	0.89
	07-1063	SM-12.5D	20	0.82
	07-1064	SM-12.5D	0	0.87
				0.83

Shading indicates values failing design specifications. Values in bold indicate average.

Binder Tests Results

The results of tests performed on the recovered binder from mixture and RAP samples are shown in Table 9. In some cases, multiple samples of the same mix were taken at different times in order to recover the binder for performance grading testing. A total of 12 samples of binder were recovered from the high-RAP mixes, and 4 samples of binder were recovered from the low-RAP mixes. The binder grades recovered from 12 samples containing various percentages of RAP greater than 20 percent were seven PG 70-22, two PG 76-22, two PG 76-16, and one PG 64-22. In 2 of 12 cases for the high-RAP mixes, the low temperature grading was –16; therefore, it appears that it will be necessary to keep a –16 low temperature grading as required in the 2007 high-RAP special provision (see Appendix A) rather than a conventional –22. Using a low temperature grading of –16 should not affect performance since cold temperature cracking does not appear to be a problem in Virginia. Even one of the control mixes with 20 percent RAP yielded a low temperature grading of –16.

In one case, the high-temperature grading of recovered binder from a D mix containing 25 percent RAP graded to a 64; however, the exact high temperature grading was 69. It very nearly graded to a 70 high temperature grading. It appears that a temperature bump of one grade for both high temperature and low temperature for mixes containing 20 to 30 percent RAP is justified.

The grading of the binder in the high-RAP mix was also calculated from the grading of the virgin PG 64-22 binder and RAP binder recovery by a simple proportioning exercise. The calculated high temperature grading averaged 1.1°C less than the recovered mix binder value; however, the standard deviation of the difference between the two methods was high at 3.1°C. In other words, individual values for the high-temperature grading could differ as much as 3°C 32 percent of the time. The calculated low temperature averaged 0.5°C more than the recovered mix value; for example, –21.5°C instead of –22.0°C. The standard deviation of the difference of the low-temperature values between the methods was 1.5°C.

Table 9. Performance Grading Test Results on Virgin and Recovered Binder

Mix ID		% RAP	Virgin Binder	Abson Recovery		Calculated From Virgin and RAP Binders
				100% RAP	Mix	
07-1023	SM-9.5D	25	6/19/07	6/19/07	6/19/07	
			PG 66-24* *PG 64-22*	PG 90-18 *PG 82-16*	PG 71-22 *PG 70-22*	PG 72-22
07-1025	SM-9.5D	30	6/27/07	6/27/07	6/27/07	
			PG 64-24 *PG 64-22*	PG 83-18 *PG 82-28*	PG 76-20 *PG 76-16*	PG 70-22
07-1026	SM-9.5D	25	7/10/07	7/10/07	7/10/07	
			PG 67-24 *PG 64-22*	PG 96-13 *PG 82-10*	PG 71-23 *PG 70-22*	PG 74-21
07-1027	SM-12.5D	30	7/17/07	7/17/07	7/17/07	
			PG 67-26 *PG 64-22*	PG 93-17 *PG 82-16*	PG 76-25 *PG 76-22*	PG 75-23
07-1045	SM-12.5D	25	8/24/07	8/24/07	8/24/07	
			PG 67-24 *PG 64-22*	PG 88-13 *PG 82-10*	PG 76-22 PG 76-22	PG 72-21
07-1046	SM-12.5D	25	8/28/07	8/28/07	8/28/07	
			PG 65-24 *PG 64-22*	PG 94-17 *PG 82-16*	PG 73-23 *PG 70-22*	PG 72-22
07-1046	SM-12.5D	25	9/18/07	8/28/07	9/18/07	
			PG 64-24 *PG 64-22*	PG 94-17 *PG 82-16*	PG 69-25 *PG 64-22*	PG 72-22
07-1046	SM-12.5D	25	10/03/07	8/28/07	10/03/07	
			PG 65-24 *PG 64-22*	PG 94-17 *PG 82-16*	PG 74-22 *PG 70-22*	PG 72-22
07-1047	IM-19.0D	30	8/28/07	8/28/07	8/28/07	
			PG 67-25 *PG 64-22*	PG 93-16 *PG 82-16*	PG 73-23 *PG 70-22*	PG 75-22
07-1056	SM-9.5D	21	9/12/07	9/12/07	9/12/07	
			PG 65-24 *PG 64-22*	PG 95-14 *PG 82-10*	PG 77-21 *PG 76-16*	PG 71-22
07-1056	SM-9.5D	21	9/17/07	9/12/07	9/17/07	
			PG 66-24 *PG 64-22*	PG 95-14 *PG 82-10*	PG 72-22 *PG 70-22*	PG 72-22
07-1056	SM-9.5D	21	11/09/07	9/12/07	11/09/07	
			PG 66-25 *PG 64-22*	PG 95-14 *PG 82-10*	PG 74-22 *PG 70-22*	PG 72-23
07-1060	SM-12.5D	15	10/01/07	10/03/07	10/01/07	
			PG 71-24 *PG 70-22*	PG 85-27 *PG 82-22*	PG 73-23 *PG 70-22*	PG 73-24
07-1060	SM-12.5D	15	10/03/07	10/03/07	10/03/07	
			PG 71-23 *PG 70-22*	PG 85-27 *PG 82-22*	PG 76-22 *PG 76-22*	PG 73-24
07-1063	SM-9.5D	20	10/11/07	10/11/07	10/11/07	
			PG 72-24 *PG 70-22*	PG 94-16 *PG 82-16*	PG 79-16 *PG 76-16*	PG 76-22
07-1064	SM-12.5D	0	PG 72-23 *PG 70-22*	NA	PG 73-25 *PG 70-22*	NA
06-1035	NA					
06-1041	NA					
06-1047	NA					
06-1055	NA					

Numbers in roman indicate the tested failure point grading; numbers in italics indicate the MP-1 PG grading designation.

Analysis of Bid Price Data

Regression Analysis

The regression model believed to be the most economically sound was a linear equation in which the dependent variable was the winning bid price for each surface mix line item. The independent variables were (1) a set of three dummy variables, A_i, that indicated the aggregate gradation (9.0, 9.5, 12.5, or 19.0) in that line item; (2) a set of three dummy variables, B_i, that indicated the binder grade (A, D, or E) in that line item; (3) the reciprocal, $1/T_{item}$ (i.e., the inverse), of the number of tons of plant mix in that line item; (4) the reciprocal, $1/T_{total}$, of the total number of tons of plant mix, of any type, in the schedule that contained that line item; (5) the reciprocal, 1/N, of the number of contractors who submitted bids for the schedule that contained that line item; and (6) a pair of dummy variables, D_i, that indicated whether that surface mix line item was subject to an optional high-RAP provision, to a required high-RAP provision, or to no high-RAP provision. An error term, e, represented the independently and identically distributed random element that ordinary least squares regression assumes to exist. The three binder grade dummies, exactly one of which always took a value of 1 rather than 0, captured the intercept term in the regression. Equation 1 shows the mathematical form of the regression model.

Equation 1: Regression Model

$$P = \sum a_iA_i + \sum b_iB_i + c_1(1/T_{item}) + c_2(1/T_{total}) + c_3(1/N) + \sum d_iD_i + e$$

Table 10 presents the numerical results of the regression analysis.

The regression analysis was also run using two alternative models: first, a linear model that used the natural values of the tonnage variables and the number of bidders, rather than their reciprocals; second, a log-linear model in which the price and quantity variables were expressed as logarithms and the number of bidders carried its natural value. Equations 2 and 3 show the mathematical forms of the alternative models.

Equation 2: Alternative Linear Regression Model

$$P = \sum a_iA_i + \sum b_iB_i + c_1T_{item} + c_2(T_{total} - T_{item}) + c_3N + \sum d_iD_i + e$$

Equation 3: Loglinear Regression Model

$$\ln P = \sum a_iA_i + \sum b_iB_i + c_1\ln T_{item} + c_2\ln(T_{total} / T_{item}) + c_3\ln N + \sum d_iD_i + e$$

The results of these regressions were generally similar to the results of the original regression. These results are not tabulated but they will be noted when they corroborate, or contradict, the results of the original regression.

Further, regressions under all three specifications were run on otherwise identical datasets in which a single high-RAP dummy variable indicated merely the presence or absence of a high-RAP provision but did not indicate whether a high-RAP mix was permitted or required. The

Table 10. Regression of Award Price on a Set of Explanatory Variables

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.9147					
R Square	0.8368					
Adj. R Square	0.8131					
Standard Error	32.0141					
Observations	122					
ANOVA						
	df	*SS*	*MS*	*F*	*Signif. of F*	
Regression	11	583181	53016	51.728	2.4682E-38	
Residual	111	113795	1025			
Total	122	696945				
	Coefficients	*Standard Error*	*t Stat*	*P-value (Significance Level)*	*Lower 95% Conf. Limit*	*Upper 95% Conf. Limit*
Intercept	N/A	N/A	N/A	N/A	N/A	N/A
(Item Tons) $^{-1}$	2692.694	424.104	6.3491	4.494E-09	1852.305	3533.084
(Total Tons) $^{-1}$	73574.084	43795.921	1.6799	0.0958	-13210.454	160358.622
(# of Bids) $^{-1}$	22.391	11.313	1.9792	0.0503	0.026	44.809
> 20% RAP (allowed)	-7.553	10.957	-0.6893	0.4921	-29.264	14.159
> 20% RAP (required)	-2.975	20.026	-0.1486	0.8822	-42.657	36.707
9.5 aggregate	-13.786	23.536	-0.5857	0.5592	-60.424	32.852
12.5 aggregate	-6.840	23.662	-0.2891	0.7731	-53.727	40.048
19.0 aggregate	-21.980	25.017	-0.8786	0.3815	-71.553	27.593
A binder	58.287	23.348	2.4965	0.0140	12.022	104.552
D binder	51.986	23.970	2.1687	0.0322	4.487	99.485
E binder	48.665	26.028	1.8697	0.0642	-2.912	100.242

results of these alternative regressions did not differ fundamentally from the results of the principal regression. They are not tabulated, but the general pattern is described here.

As a last variation, regressions under all three specifications were run on three slightly smaller data sets: (1) one set of 120 observations from which the two SM-9.0A items, i.e., the only two items calling for a 9.0 aggregate gradation, were removed; (2) one set of 120 from which the item of highest tonnage and the item of lowest tonnage were removed; and (3) one set of 118 from which both were removed. The results of these variant regressions differed negligibly from the results of the regressions on the full dataset, and they are not described further.

Impact of High-RAP Provision on Unit Price

Allowing a high-RAP mix as an additional design option should not increase the unit cost to VDOT, and it could decrease it. A contractor who bids on a job where a high-RAP mix design is permitted retains the option of ignoring the special provision and using one of his or her existing mix designs, so at worst the cost should be unaffected. *Requiring* the use of a high-RAP mix could, in theory, raise the cost to VDOT. It might preclude the cheapest mix design for certain contractors, namely, those who lack stockpiles of RAP. Whether this possibility exists in reality is an empirical question.

The impact of the high-RAP provision did not prove to be statistically significant. As shown in Table 10, regression using the main equation produced negative point estimates of the coefficients on both high-RAP dummies: the first coefficient implies that allowing high-RAP mixes was associated with a $7.55/ton reduction in unit price; the second implies that requiring high-RAP mixes was associated with a $2.98/ton reduction in price. The estimates, however, did not differ significantly from 0 or from one another.

Regression using the other linear equation also produced negative, but statistically insignificant, point estimates. Regression using the log-linear equation produced positive, but statistically insignificant, point estimates. Regression on a dataset that included only one high-RAP dummy variable, representing both high-RAP specifications, produced in all models a coefficient whose value was an average of the coefficients on the two separate high-RAP dummies. Regression using the main specification, for example, produced for the coefficient on the single high-RAP dummy a point estimate of –6.533 (that is, a price reduction of $6.53/ton). Under every specification, the point estimates remained statistically insignificant.

Impact of Tonnage on Unit Price

There is reason to suppose that the unit cost to the agency will decrease as the quantity of plant mix in a given schedule increases. Up to a point, a contractor has certain mobilization costs that he or she must cover regardless of whether the schedule calls for 100 tons of SM-9.5A or for 10,000 tons. It is conceivable, using similar reasoning, to suppose that the unit cost may also be influenced by the total quantity of other plant mixes within the same schedule.

The impact of the quantity of an individual plant mix item proved to be negative and statistically significant at the 2% level or better under all regression specifications. Table 10 shows the result for the principal regression equation: the point estimate of the coefficient on the reciprocal of the number of tons of plant mix implied that some $2,693 of cost will be averaged over whatever number of tons is requested in the plant mix line item. The coefficient on tonnage in the alternative linear equation implied, similarly, that each additional thousand tons of mix will reduce the price by about $1.17/ton. The coefficient on the log of tonnage in the log-linear equation implied that a 10 percent increase in the number of tons will reduce the price by about 0.7 percent.

The impact of the total quantity of plant mix in the schedule varied from one regression equation to another. In the main linear specification, the coefficient on the reciprocal of total tonnage implied a negative impact: i.e., some $73,574 of fixed cost will be averaged over whatever number of tons is requested in the entire plant mix schedule. This coefficient was statistically significant at the 10 percent level. The coefficient in the two alternative linear equations, however, implied a positive impact. In the log-linear equation, moreover, the estimated positive impact was statistically significant at the 5 percent level. Although the original equation represents the specification with the strongest foundation in economic theory, the fact that two simple alternatives produced contradictory results is reason for caution in drawing any conclusions.

Impact of Other Independent Variables on Unit Price

Economic theory predicts that a buyer should receive a better price when competition exists among the sellers. However, the number of contractors able to bid competitively in a given county may be correlated with other variables, such as the size of each contractor's operation and the cost of living in the county, that have an opposite influence on price. Therefore, the influence of the number of bids on the agency's cost per ton of mix must be considered an empirical question.

The impact of the number of bidders proved to be negative under all regression specifications. Table 10 shows the result for the principal regression equation: the point estimate of the coefficient on the reciprocal of the number of bids implied that increasing the number of bids from one to two will reduce the price by some $11.20/ton and that adding a third bidder will reduce the price by another $3.73/ton. The coefficient was statistically significant at the 5 percent level. The coefficient on the number of bids in the alternative linear equation implied, similarly, that each additional bidder will lead to a price reduction of about $5.47/ton. This estimate was not statistically significant. The coefficient on the log of the number of bids in the log-linear equation implied that an increase of one in the number of bids will reduce the price by about 8.1 percent. This estimate was statistically significant at the 1 percent level.

The coefficients on all of the binder grade dummy variables were statistically significant at an overwhelmingly high confidence level in all regressions. This was to be expected given that this set of three variables took the place of the constant term in the regressions and that the average value of the dependent variable (the price per ton) was not normalized to 0. The point estimates of the coefficients on these dummies implied, curiously, that D mixes were associated with slightly higher prices than E mixes and slightly lower prices than A mixes—a counterintuitive result considering that D binder was more expensive than A—but the differences among the coefficients were never statistically significant.

The coefficients on the aggregate gradation dummies were never statistically significant from 0. The point estimates implied that 9.5 mixes were associated with slightly higher prices than 19.0 mixes, and with slightly lower prices than 12.5 and 9.0 mixes, however, the differences among the coefficients were not statistically significant.

Summary of Value Engineering Proposals

The largest of the VEPs in terms of tonnage applied to the schedule for Pittsylvania County. W&L Construction's VEP proposed to save $1.08/ton, a total of $18,977 each for VDOT and the vendor. The proposed increase in RAP content was slight, from 20 to 21 percent. The VEP derived most of its savings—$0.87 of the total $1.08/ton—by enabling the vendor to use an A binder instead of the costlier D binder.

The largest of the VEPs in terms of dollar savings applied to the schedule for Appomattox and Campbell counties. Marvin V. Templeton & Sons' VEP proposed to save $2.02/ton, a total of $29,736 each for VDOT and the vendor. The proposed increase in RAP content was from 20 to 25 percent. The VEP-derived savings of $0.85/ton by substituting RAP for costlier virgin materials and $1.17/ton by allowing the vendor to use an A binder instead of a D binder.

The other VEP from Templeton was similar to the one just described. The proposed increase in RAP content was from 20 to 25 percent. The VEP derived savings of $0.94/ton by substituting RAP for virgin materials and $1.14/ton by allowing the vendor to use an A binder instead of a D, summing to $2.08/ton. The total savings was $28,133 each for VDOT and the vendor.

These VEPs demonstrate that in at least some cases the use of a high-RAP mix design made it possible to reduce unit cost. It should be noted that the range of cost savings in the VEPs, from $1.08 to $2.08 per ton, lies well within the 95 percent confidence limits of the regression results.

These three cases entailed cost savings of $153,961. Would high-RAP mix have saved money in any of the other 102 cases? The previous figures imply that a savings of $18,977 was enough to make a VEP worth the contractor's while, but the fact that VDOT received only three high-RAP proposals may indicate that in the vast majority of cases the cost savings achievable from switching to a high-RAP mix design was too small to justify the effort of constructing a VEP. Without the evidence of *pro forma* cost savings computations from some of the 102 items for which no VEP was received, no firm conclusion is possible.

Summary of Analysis of 2007 Bid Price Data

Analysis of the 2007 bid price data revealed a small, statistically insignificant relationship between the bid price on a plant mix item and the use of a specification that allowed over 20 percent RAP. Analysis did reveal statistically significant relationships between bid price and (1) the number of tons in a plant mix item and (2) the number of bids received. Although the statistical results were inconclusive, the computations included with three VEPs did demonstrate that, on at least some jobs, the use of over 20 percent RAP can reduce unit cost. The figures in the VEPs were consistent, or at any rate not inconsistent, with the coefficient estimates in the statistical analysis.

Construction and Field Operations

A brief summary of field operations was derived from detailed reports prepared by the VDOT Materials Division personnel[10] and is provided in Appendix B. There did not appear to be any problems in construction that were attributed to the high-RAP contents. The construction methods used to handle and introduce the RAP into the hot mix appeared to be reasonably controlled, resulting in well-controlled mixes. Plants with less control would conceivably produce mixes with more variability. One project received a slight price adjustment on gradation, and another received a slight price adjustment on density. Those price adjustments could not be attributed to anything connected with the use of a high-RAP mix.

CONCLUSIONS

- There was no significant difference detected between average test result values for high-RAP and control mixes when tested with fatigue tests, rut tests, and TSR tests; therefore, the predicted performance is equal.
- A low temperature grading of –16 for recoveries on mixes containing more than 20 percent RAP will probably be required since 2 of 12 gradings of binder recovered from mix graded as a –16.
- Generally, the addition of RAP raised the high temperature grading one to two grades, which should be assumed in mix design.
- There were no construction problems reported for the high-RAP mixes.
- The plants that were investigated had good quality control processes in the handling of RAP, which had a strong influence on lack of price adjustments.
- The slight price adjustments assessed for these projects were not related to use of high-RAP mixes.
- Use of more than 20 percent RAP can reduce cost on at least some resurfacing jobs. The impact of the high-RAP specification on bid price was too small, however, to be distinguished with statistical significance in the 2007 price bid data.

RECOMMENDATIONS

1. *VDOT should continue to use the basic specifications contained in Appendix A for high-RAP mixes that were in effect for the trial sections placed in 2007.*

2. *To corroborate the preliminary findings in this report, VDOT's Materials Division should continue monitoring the high-RAP pavement sections placed in this study.*

COST AND BENEFIT ASSESSMENT

At present, the evidence supports a tentative forecast of some up-front cost savings and no later cost impact from allowing the use of over 20 percent RAP.

The evidence to date, logically compelling but empirically unimpressive, indicates that that the up-front cost impact is negative, i.e., favorable. No construction problems or price adjustments were attributed to the use of high-RAP mix. VEPs received in 2007 demonstrated unambiguously that using over 20 percent RAP could reduce the unit cost in at least a few cases. This is enough to justify the conclusion that the up-front cost impact of a specification that *allows* over 20 percent RAP is bound to be favorable in the aggregate. (This does not justify the conclusion that the up-front impact of a specification that *requires* over 20 percent RAP will be favorable.) The size of the total cost savings, however, could not be proven to exceed $153,961, and it is not clear what fraction of the total could be expected to accrue to VDOT in the regular bid and award process. VDOT's share of the cost savings could not be distinguished in the 2007 bid price data.

The evidence to date indicates no "down the road" cost impact. The results of fatigue tests, rut tests, and TSR tests have given no reason to expect that the pavements containing over 20 percent RAP will perform less satisfactorily than those containing less than or equal to 20 percent RAP. Field experience to corroborate the laboratory findings, however, will become available only with time.

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Many people contributed to the successful completion of this project. The Virginia Asphalt Association and VDOT's Asset Management Division provided impetus in suggesting and implementing the trial of high-RAP. W. R. Bailey III and Mourad Bouhajja of VDOT's Materials Division were instrumental in organizing the planning of the evaluation and documentation phase of the project. David Lee arranged for the planning group to tour plants in VDOT's Salem District during the initial planning stage of the project. Alexander Appea, Todd Rorrer, Robert Reid, and Scott Manning developed field reports of the construction process and acceptance test results. Troy Deeds and Ken Elliton were responsible for laboratory testing at VTRC in a timely manner.

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APPENDIX A

SPECIAL PROVISION ALLOWING HIGHER PERCENTAGE OF RAP

Surface and Intermediate Mixes

Section 211-Surface and Intermediate Mixes using RAP - Asphalt concrete mixtures used in surface and intermediate courses shall conform to the requirements of Section 211 except as noted herein.

Section 211.01—Description is amended to replace the "ESALs" table in the second paragraph with the following

	Equivalent Single Axle Load (ESAL)	Asphalt Performance Grade	Aggregate Nominal
Mix Type	Range (millions)		Maximum Size*
SM-9.0 A	0 to 3	64-16	3/8"
SM-9.0 D	3 to 10	70-16	3/8"
SM-9.0 E	Above 10	76-22	3/8"
SM-9.5 A	0 to 3	64-16	3/8"
SM-9.5 D	3 to 10	70-16	3/8"
SM-9.5 E	Above 10	76-22	3/8"
SM-12.5 A	0 to 3	64-16	½"
SM-12.5 D	3 to 10	70-16	½"
SM-12.5 E	Above 10	76-22	½"
IM-19.0 A	Less than 10	64-16	¾"
IM-19.0 D	10 and above	70-16	¾"

Section 211.03(f) is amended to replace the first sentence in the second paragraph with the following:

The Department will perform rut testing in accordance with the procedures detailed in VTM-110.

TABLE II-14A RECOMMENDED PERFORMANCE GRADE OF ASPHALT is replaced with the following:

TABLE II-14A
RECOMMENDED PERFORMANCE GRADE OF ASPHALT CEMENT

	Percentage of RAP in Mix	
Mix Type	%RAP ≤ 20.0%	20%<%RAP ≤ 30%
'A' Designated Surface & Intermediate Mixes	64-22	64-22
'D' Designated Surface& Intermediate Mixes	70-22	64-22
'E' Designated Surface& Intermediate Mixes	76-22	70-28

Section 211.06—Tests is amended to replace the “Abson Recovery” table in the second paragraph with the following:

Mix Type	Recovered Penetration		Ductility at 77^0 F
	RAP% ≤ 20%	**RAP% > 20%**	
SM-9.0A,9.5A, 12.5A	min 35	min 35	min. 40 cm
SM-9.0D,9.5D, 12.5D	min 35	min 35	min. 40 cm
IM-19.0A	min 35	min 35	min. 40 cm
IM-19.0D	min 35	min 35	min. 40 cm
NOTE: Recovered Penetration and Ductility shall not be performed on SM-9.5E, 12.5E, and all (M) and (S) mixes			

Section 211.06 – Testing is amended to replace the third paragraph with the following:

Abson recovery samples shall be PG graded according to the requirements of AASHTO M 320-05. Samples meeting the required grades specified in Section 211.01 shall be acceptable.

Note: The Special Provision does not apply to “E” mixes

8-27-06(SPCN)

APPENDIX B

SUMMARY OF FIELD OPERATIONS

Dinwiddie County

Although paving was scheduled to be done on two routes, State Route (S.R.) 40 and County Route (C.R.) 703, the majority (94 percent) was placed on S.R. 40, on which the field report concentrates. Paving of the 2-in lift on a surface that had not been milled was done August 23-30, 2007, requiring haul times from the plant ranging from 25 to 30 minutes. It was observed that the underlying surface contained some cracks.

RAP was initially processed through a Proto-Grind 1200 to break down the material to less than 2 in in size. It was then passed through a hammer mill that broke down the material to minus ¾ in. The plant has the capability to fractionate the RAP for use in specific mixes. The quality control plan calls for samples to be taken from the RAP stockpiles once per day and checked for gradation and asphalt content.

The single-barrel counter-flow drum hot-mix asphalt (HMA) plant was capable of incorporating 35 to 40 percent RAP in hot mix and producing 250 tons per hour. The average temperature in the truck of the high-RAP mix upon leaving the HMA plant was 302°F, and a similar mix containing 20 percent RAP was produced in 2006 at 312°F during the spring when ambient temperatures were possibly less.

Four 2,000-ton lots were tested for gradation and asphalt content with no price adjustments. Volumetric properties were within acceptable specification limits.

City of Chesapeake

Up to 2 in was milled and replaced with the mix containing 30 percent RAP on I-664 in the City of Chesapeake during the period of July 15-30, 2007. Milling was accomplished by a subcontractor 1 week before it was paved, during which time the traffic was allowed to run on the milled surface. Haul time was estimated to be only approximately 15 minutes for the HMA.

RAP was processed by an independent company at a remote facility and transported to the HMA plant. The unprocessed RAP enters a primary crusher where it is crushed and then screened over a 9/16-in screen; the oversized material is sent to a secondary crusher. The final RAP should pass a 9/16-in sieve.

The hot-mix plant is a double-barrel parallel flow drum type capable of producing up to 400 tons per hour. It is supposed to be capable of producing mixes containing up to 50 percent RAP and has produced some mixes supplied to private consumers containing 40 percent RAP. The average temperature of the mix upon leaving the plant was 305°F. A similar mix containing 20 percent RAP produced in 2006 during May, June, and October was 322°F. It was postulated by the authors of the field report that the higher RAP percentage may have caused a lower temperature.

Three lots were tested for compliance with gradation and asphalt specifications with no price adjustments. Ten samples were tested for volumetric properties with no failures.

Goochland County

This project on S.R. 6 was milled and replaced with an IM-19.0 mix containing 30 percent RAP and an SM-12.5 mix containing 25 percent RAP during the period May 8, 2007, to September 5, 2007. The existing surface was milled 3.5 in and replaced with 2.0 in of IM-19.0D and with 1.5 in of SM-12.5D. The haul time from the plant to the job mix site was approximately 30 minutes.

The unprocessed RAP is crushed with an Eagle Mobile Crusher at the same location as the hot-mix plant. The crushed material is scalped with a 9/16-in screen, and the oversized material returned to the crusher. The processed material is stockpiled nearby for use at the adjacent hot-mix plant and other close company plants. During production, the RAP is checked to ascertain that 100 percent passes the ½-in sieve and a maximum of 10 percent passes the No. 200 sieve. During hot-mix production, the moisture content is checked for each 2000 tons.

The hot-mix plant was a half-barrel counter-flow drum type with a capacity of 400 tons per hour. The RAP was scalped over a ¾-in screen before introduction into the drum at approximately the midway point. The maximum RAP capacity for the plant is 40 percent, and at least 35 percent RAP has been used in non-governmental work. The average temperature of mix leaving the plant was in the 310–320°F range for mixes containing both less than and more than 20 percent RAP.

No gradation or asphalt content price adjustments were assessed for three lots of surface mix and two lots of intermediate mix produced. Volumetric properties were also within specification limits for the three tests performed on each mix. A similar surface mix containing only 15 percent RAP in 2006 had received a slight adjustment for end-of-year variability of asphalt content.

Carroll County and Floyd County

The discussion is not separated for counties in this district since the mix was produced from the same hot-mix plant and the RAP was processed with the same equipment. It was specified in the original contract that the high-RAP 9.5 mm surface mix contain at least 30 percent RAP. Approximately 10,000 tons was placed on U.S. 58 in Carroll County during the period of September 21, 2007, to October 15, 2007. Approximately 7,500 tons was placed on U.S. 221 in Floyd County during the period of June 14-29, 2007. Both locations received a 1.5-in overlay with no prior milling of the existing surface.

The raw RAP was passed through an Eagle Crusher capable of processing approximately 1,000 tons per day. Oversized material was screened and sent back through the crusher. The final RAP product is generally less than ½-in top size.

A counter-flow double-barrel drum plant capable of producing approximately 200 tons per hour was used to produce the mix. It was normally used to produce mixes containing 15 percent RAP but was capable of producing mixes with up to 50 percent RAP. During production of HMA, the RAP was monitored for moisture content on a daily basis and asphalt content and gradation on a weekly basis. The temperature of mix at the HMA plant averaged 317°F with a haul time ranging from 12 to 58 minutes.

Generally, the mix met specifications after initial start up and adjustments, although some values were borderline and required close monitoring. There were some non-conforming mix and density test results during the period June 14-18, 2007, as adjustments were made to the construction process and mix design. Lot averages did not seem to be overly influenced by a few variable individual values. One small price adjustment for excessive No. 200 material was recorded on October 10, 2007. Pavement density was satisfactory with no failing average results.

Nelson County

The project on U.S. 29 was milled 2.0 in and paved with an SM-12.5D mix containing 25 percent RAP during the time period of August 27, 2007, to October 10, 2007. Haul times from the HMA plant to the road ranged from 10 to 30 minutes. This project originated from a VEP from the contractor offering a reduction in the original bid price if the RAP content could be increased from 20 to 25 percent.

A Proto-Grind 1200 Tub Grinder was used to crush the RAP. The processed RAP was passed over a 2-in scalping screen before being introduced into the hot-mix plant. During production of HMA, the RAP stockpiles were monitored for gradation and asphalt content weekly and for moisture daily.

The asphalt plant was a counter-flow drum plant with a capacity of approximately 300 tons per hour. Although the plant normally operates using 15 to 20 percent RAP, it was estimated that it could handle up to 40 percent. The average temperature of the mix leaving the plant was 310°F with no failing temperatures at the road site.

A total of 13 full lots and 1 partial lot were tested for gradation and asphalt content with no price adjustments. The single control strip qualified with an air void content of only 6.5 percent and 39 lots of pavement received no price adjustment for density, producing an average control strip density of 99.6 percent.

Appomattox and Campbell Counties

Approximately 90 percent of the total tonnage of SM-9.5D containing 25 percent RAP was placed on S.R. 24, with the remainder being placed on C.R. 691 during the period of May 22, 2007, to August 18, 2007. This project originated from a VEP from the contractor offering a reduction in the original bid price if the RAP content could be increased from 20 to 25 percent. The job mix was changed slightly after approximately 50 percent of the production to decrease the amount of minus No. 200 material. There was a slight price adjustment for the No. 200 sieve on two of the first seven lots but no further adjustments on the final six lots after the change was made in the job mix. Haul times ranged from 20 to 30 minutes.

The same equipment, processing, and monitoring were used on the RAP as was described in the section in Nelson County. The processed RAP was also passed over a 2-in scalping screen before entering the hot-mix plant even though this mix was supposed to contain ½-in top size aggregate.

The asphalt plant was a counter-flow drum plant capable of producing 400 tons per hour. Mixture normally contains 15 to 20 percent RAP, but the plant was capable of producing mix containing up to 30 percent RAP. The average temperature of mix leaving the plant was approximately 320°F.

As discussed previously, slight price adjustments occurred for the gradation of No. 200 material before the job-mix target was changed. The air voids of three pavement density control strips averaged 5.8 percent, less than the maximum allowable value of 7.8 percent. All of the 37 lots of pavement density passed with an average control strip density 99.0 percent.

Pittsylvania County

Approximately two thirds of the total tonnage for this schedule was placed on U.S. 29 during the period of September 11, 2007, to November 9, 2007. Paving on the lesser traveled routes occurred approximately during the same time period. This project originated from a VEP from the contractor offering a reduction in the original bid price if the RAP content could be increased from 15 to 21 percent. Obviously, the primary reason that the contractor chose to provide a high-RAP SM-9.5D mix (more than 20 percent RAP) was to save money in using a PG 64-22 binder instead of a PG 70-22 binder, which is normally required for a D mix. Most of the paving on U.S. 29 was close to the plant, requiring haul times of approximately 10 minutes.

The unprocessed RAP was crushed with an International Aggregates Impact Crusher and blended with uncrushed minus 5/8-in RAP. The gradation and asphalt content were checked weekly during crushing, and moisture content was determined daily during HMA production.

The hot-mix plant was a double-barrel counter-flow drum type plant with a maximum production rate of approximately 400 tons per hour. Normally, 10 to 20 percent RAP is used, but the hot-mix plant is capable of incorporating up to 30 percent RAP. The temperature of mix leaving the plant ranged from 285°F to 350°F, and the average temperature of mix leaving the plant was approximately 320°F.

No adjustment points were assessed for gradation and asphalt on any of the 15 lots for the project. Average volumetric results of gyratory specimens performed on mix collected during production were also within allowable ranges. A total of 49 pavement sections (lots) using 31,940 tons were tested for density. Only 1 lot representing 671 tons failed to meet the minimum of 98 percent of the control strip target density. The failed lot achieved a density of 97.4 percent of the target density.