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research report

Field Trials of High-Modulus High-Binder-Content Base Layer Hot-Mix Asphalt Mixtures

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16. Abstract:

The purpose of this study was to document the field experience of the Virginia Department of Transportation (VDOT) in the use of high-modulus high-binder-content (HMHB) base layer hot-mix asphalt (HMA) mixtures. Information was gathered with regard to the construction of HMHB base mixtures at three field trial sites in Virginia, and laboratory tests were conducted on samples that were gathered before and during construction. The three locations were the sites of deep rehabilitation or new construction, and HMA base mixtures were used at designed asphalt content, designed asphalt content plus 0.4% additional asphalt, and/or designed asphalt content plus 0.8% additional asphalt.

Two of the field trial locations had no construction-related issues; difficulties during compaction occurred at the third. Laboratory testing of materials collected from this location showed the mixture to have a low air void content, a high percentage of voids filled with asphalt, and a binder performance grade that was lower than expected. This was also the only location from which materials were collected for fatigue testing, the results of which did not show a clear relationship between binder content and fatigue life. It is thought that the mixture production and construction issues at this location were site specific and not generally indicative of a larger trend when HMHB mixtures are used.

The research showed that HMHB mixtures incorporating 0.4% additional asphalt binder could be successfully constructed but was unable to determine if the same was true of HMHB mixtures incorporating 0.8% additional asphalt binder. Further study may be needed to determine the maximum additional asphalt binder that can be successfully incorporated. Additional studies using repeated-load permanent deformation should be conducted to determine if a cutoff value (or a range) of the flow number can be established to determine optimum performance.

This study documented the field and laboratory knowledge gained by VDOT when producing and placing HMHB mixture test sections in an effort to achieve a long-lasting perpetual-type flexible pavement. These designs offer the potential to reduce fatigue cracking by incorporating additional asphalt binder and reducing the void content of the mixture. The use of an adjusted binder grade or RAP to maintain the necessary stiffness for high binder contents should provide the necessary stiffness to minimize the susceptibility for rutting during service. Quantification of the economic benefits of using HMHB mixtures is a future goal that can be realized after longer term study of field performance.

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FINAL REPORT

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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

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

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ABSTRACT

The purpose of this study was to document the field experience of the Virginia Department of Transportation (VDOT) in the use of high-modulus high-binder-content (HMHB) base layer hot-mix asphalt (HMA) mixtures. Information was gathered with regard to the construction of HMHB base mixtures at three field trial sites in Virginia, and laboratory tests were conducted on samples that were gathered before and during construction. The three locations were the sites of deep rehabilitation or new construction, and HMA base mixtures were used at designed asphalt content, designed asphalt content plus 0.4% additional asphalt, and/or designed asphalt content plus 0.8% additional asphalt.

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This study documented the field and laboratory knowledge gained by VDOT when producing and placing HMHB mixture test sections in an effort to achieve a long-lasting perpetual-type flexible pavement. These designs offer the potential to reduce fatigue cracking by incorporating additional asphalt binder and reducing the void content of the mixture. The use of an adjusted binder grade or RAP to maintain the necessary stiffness for high binder contents should provide the necessary stiffness to minimize the susceptibility for rutting during service. Quantification of the economic benefits of using HMHB mixtures is a future goal that can be realized after longer term study of field performance.

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INTRODUCTION

Fatigue cracking is considered to be one of the ultimate causes of failure for traditionally designed flexible pavements. It is considered to originate at the bottom of the asphalt layers as a result of repetitive wheel loads. In recent years, a new concept has emerged in the design of flexible pavement structures known as *perpetual pavement design* or *long-life pavement design.* Long-life pavements are designed with a structure that minimizes or eliminates fatigue cracks starting at the bottom of the asphalt layers. Therefore, the pavement distresses are concentrated in the surface layer through top-down cracking, oxidation, weathering, etc. and extend only a short depth into the pavement structure. This design philosophy is supposed to result in long-lasting pavements that do not require major reconstruction until 40+ years of service life; only replacement of the surface layer (at approximately 15- to 20-year intervals) is needed to remove cracking and restore functional characteristics (e.g., ride quality, friction, and appearance).

Design strategies to achieve a long-life pavement are summarized in various studies (Bushmeyer, 2002; Newcomb, 2002; Nunn and Ferne, 2001; St. Martin et al., 2001). One of these strategies is to use an asphalt-rich base layer to prevent fatigue cracking at the bottom of the asphalt structure. Various test sections and field installations have been built in several U.S. states and countries outside the United States. Generally, approximately 0.5% of additional asphalt binder is added to the conventional base mixture (Brown, 2002; Davey, 2009).

A laboratory study of high-modulus high-binder-content (HMHB) hot-mix asphalt (HMA) mixtures by the Virginia Transportation Research Council (VTRC) was completed in 2006. This study indicated potential benefits from using asphalt layers containing high-binder contents deep in the pavement structure (Maupin and Diefenderfer, 2006). Laboratory testing showed that fatigue life was increased slightly for an asphalt binder content 0.5% above optimum and significantly for an asphalt binder content approaching 1.0% above optimum. Flexural stiffness also peaked approximately 0.5% above the optimum asphalt binder content. Permeability decreased when the asphalt binder content was increased, which should enhance durability and reduce the potential for stripping.

The VTRC investigation also used the Mechanistic-Empirical Pavement Design Guide (MEPDG) software (version 0.90) to investigate the effects of changing the asphalt binder content, air voids, and binder grade of various asphalt layers on the service life for a typical interstate pavement. The results showed that increasing the asphalt binder content of the HMA base layer beyond the design optimum greatly decreased the predicted fatigue cracking (originating at the bottom of the asphalt layers, or bottom-up). In addition, reducing the void content of the base layer significantly reduced the same predicted fatigue cracking (again, originating at the bottom).

There was good indication from the VTRC investigation that pavement service life can be enhanced by increasing the asphalt binder content and decreasing the air void content of HMA base layers. Other independent studies also indicated the likelihood of extended service life when the asphalt binder content of the base layer is slightly increased (Newcomb, 2002; St. Martin, 2001). Upon hearing the results of the laboratory study (Maupin and Diefenderfer, 2006), the VTRC Asphalt Research Advisory Committee recommended that an attempt be made to test these concepts in an actual in-service pavement. A special provision was developed and is provided in Appendix A. This report describes the study to perform a field investigation using HMHB base layer HMA mixtures at various sites.

PURPOSE AND SCOPE

The purpose of this study was to document the field experience gained by the Virginia Department of Transportation (VDOT) using HMHB base layer HMA mixtures. HMHB base mix was placed on two projects in Virginia: one new construction project and one maintenance rehabilitation project. In addition, some basic data were gathered by personnel in VDOT's Materials Division on a third project in which VTRC personnel were not involved.

The HMA mixture studied in all field trials was either BM-25.0A or BM-25.0D, a base layer mixture having a nominal maximum aggregate size of 25.0 mm with either PG 64-22 or PG 70-22 binder, respectively. Various levels of additional binder were incorporated. VDOT allows Type D mixtures to be achieved by the use of a PG 70-22 asphalt binder or a softer grade binder (e.g., PG 64-22) and the use of more than 20% recycled asphalt pavement (RAP) so that the resulting binder performance grade meets or exceeds PG 70-16.

METHODS

Field Trials

The first field trial took place on a rehabilitation/maintenance project in Wythe County in VDOT's Bristol District on I-81, south of the intersection with State Route 90 (starting at approximately MP 60.6) in the southbound traffic lane on July 27 and 28, 2009. Approximately 4.5 in of pavement was removed by milling and was replaced with 3 in of BM-25.0 and 1.5 in of SM-12.5E mixtures. Three sections approximately 1 mi in length were paved with BM-25.0A, BM-25.0D, and BM-25.0D mixtures with a targeted 0.4% of additional asphalt binder (BM-

25.0D+0.4). The BM-25.0A mixture was included and tested with minimal effort since it was being used in routine rehabilitation work on adjacent pavement sections. All three mixtures contained 15% RAP, with the BM-25.0A mixture containing PG 64-22 binder and the BM-25.0D mixtures containing PG 70-22 binder.

A second trial was constructed on U.S. Route 460 in Nottoway County on September 16, 17, and 22, 2009. Materials were sampled by VDOT Materials Division staff; however, VTRC personnel were not present to participate in the testing. Although only limited test data are presented in this report, the location is mentioned as documentation for any potential future study.

Construction occurred in the eastbound travel lane, east of the town of Crewe. The project started at the intersection with County Route 1006 and proceeded east for approximately 1.2 miles. Work consisted of excavating the existing pavement in the travel lane from approximately 2 ft off the centerline to a width of 8 ft. Six inches of crushed aggregate base was placed and compacted. The bound layers consisted of 5 in of BM-25.0D mixture, 2 in of IM-19.0D mixture, and 2 in of SM-12.5D mixture. The project was subdivided into approximately one-third sections where the 5 in of BM-25.0D mixture in the western section was placed as two 2.5-in lifts of BM-25.0D mixture with a targeted 0.8% additional binder (BM-25.0D+0.8 mixture); the middle section included one 2.5-in lift of BM-25.0D+0.8 mixture capped with a 2.5-in lift of BM-25.0D mixture with a targeted 0.4% additional binder (BM-25.0D+0.4 mixture); and the eastern section included two 2.5-in lifts of BM-25.0D+0.4 mixture. All the BM-25.0D+0.8 mixture was placed on September 16 and the BM-25.0D+0.4 mixture was placed on September 17 and 22.

A third field trial was constructed in the Fredericksburg District near Carmel Church at the intersection of State Routes (SR) 207 and 652. The project comprised relocation and improvements to a busy intersection near two truck stops and several other small businesses just east of I-95. Three test sections were constructed on the southeastern branch of the project, as shown in Figure 1.

The test sections, comprising two lanes having sections of BM-25.0D, BM-25.0D+0.4 and BM-25.0D+0.8 mixtures, were constructed on October 26, 2009. The control section was placed from Station 15+25 to 22+00; the BM-25.0D+0.8 section was placed from Station 22+00 to 29+00; and the BM-25.0D+0.4 section was placed from Station 29+00 to 37+50. The design cross section consisted of 8 in of aggregate base, 6 in of BM-25.0D HMA base mixture (constructed in two lifts of 3 in each), 220 lb/yd^2 (2 in) of IM-19.0D HMA intermediate mixture, and 220 lb/yd^2 (2 in) of SM-12.5D HMA surface mixture. It was intended that both 3-in lifts of the asphalt base mixture be identical within each test section; however, the second lift throughout all test sections was changed to BM-25.0D mixture after paving difficulties in the high-binder sections in the first experimental lift. These difficulties are discussed later. VDOT allows Type D mixtures to be achieved by using PG 70-22 asphalt binder or a softer grade binder (e.g., PG 64-22) and using more than 20% RAP so that the resulting binder performance grade meets or exceeds the requirements for PG 70-16 binder. In this case, the Type D mixture used PG 64-22 binder and 25% RAP.

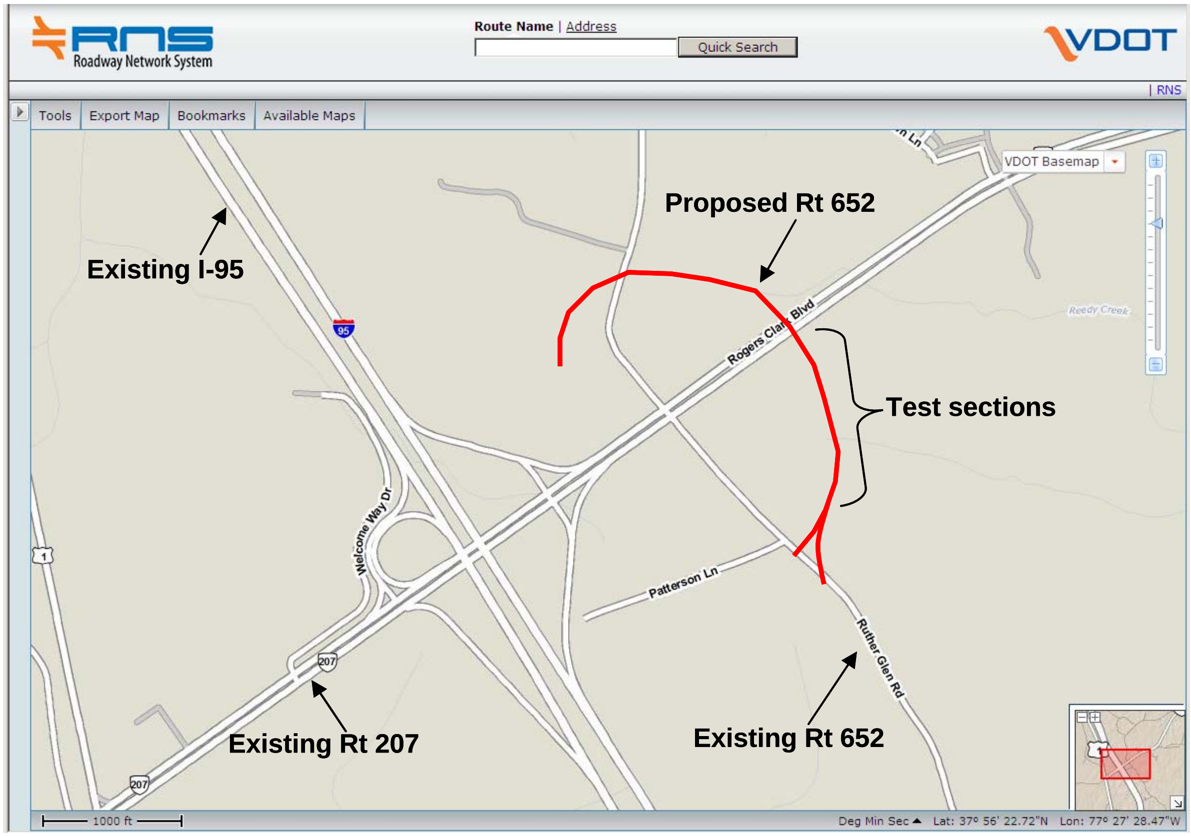

Figure 1. Approximate Location of Test Sections on Proposed Route 652

A variety of laboratory tests were conducted on samples taken during production and following construction; however, not all tests were performed on each project. Field testing performed on the Route 207/652 project included collection of cores and tests with the falling weight deflectometer (FWD) and ground-penetrating radar (GPR).

Test Methods

Volumetric Analysis and Gradation

Gyratory specimens were prepared with 65 gyrations, which is the design compactive effort required for asphalt mixtures produced for VDOT in accordance with AASHTO T-312 (American Association of State Highway and Transportation Officials [AASHTO], 2007). Air voids (voids in total mix [VTM]), voids in the mineral aggregate (VMA), and voids filled with asphalt (VFA) were determined on the gyratory specimens. In addition, the gradation was determined on loose materials collected during construction.

Coring

Core samples were collected on the SR 207/652 and I-81 projects to measure the in-place layer thickness and to determine the in-place air void content.

Stripping Tests

Stripping tests were performed in accordance with AASHTO T-283 (AASHTO, 2007) with two exceptions. The air void contents were targeted toward the void contents of cores removed from the pavement instead of the standard 7.0%. In addition, the control mixtures for each project were saturated by the standard procedure criterion (70%-80%) but the HMHB mixtures were saturated using the same amount of time required for the control mixtures. It was anticipated that this method of testing would be more indicative of how the mixtures would absorb water and perform in the field. Mixtures with less air voids should absorb less water, possibly strip less, and produce higher tensile strength ratio (TSR) values. The TSR test result consists of the ratio of the average indirect tensile strength of three conditioned specimens as compared to that of three unconditioned specimens.

Rut Tests

Rut tests were performed with the Asphalt Pavement Analyzer (APA) in accordance with Virginia Test Method 110 (VDOT, 2010). Tests were performed on 3 in by 5 in by 12 in (75 mm by 125 mm by 300 mm) beams at 120°F (49°C) using a load of 120 lbf (534 N) and hose pressure of 120 psi (827 kPa). Rutting was measured manually after 8,000 cycles. The reported test result is the average rut depth measured manually on three beams that were tested at the same time. Target air voids for this test are normally 8.0%, but an attempt was made to duplicate the average air voids that were measured from pavement cores for each section.

Fatigue Tests

Fatigue tests were performed for the SR 207/652 project in accordance with AASHTO T-321, a four-point flexural beam test (AASHTO, 2007). The tests were not performed for the I-81 project mixtures because it was not believed that significant fatigue improvement would be gained with only 0.4% additional asphalt binder. S*pecimen failure* was defined as the point when 50% of the initial flexural stiffness was reached. Specimens were tested at various strain levels in order to develop a strain versus cycles to fatigue curve. The fatigue data produce a linear log-log plot in the form of:

$$N = K\,(1/\varepsilon)^n$$

where

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

The endurance limit was computed for each mixture using the fatigue life and strain level for each of approximately 10 specimens. The *endurance limit* is defined as the strain at which an asphalt mixture can endure an infinite number of load cycles. In a practical sense for this experiment it was defined as the strain level that an asphalt mixture survives at least 50 million cycles, and it was projected from the regression of the test results for each mixture. 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 estimated from the 95% confidence one-sided lower prediction limit for a fatigue life of 50 million cycles, and that estimation was used in this study in accordance with the conclusions of Prowell et al. (2010) (see Figure 2).

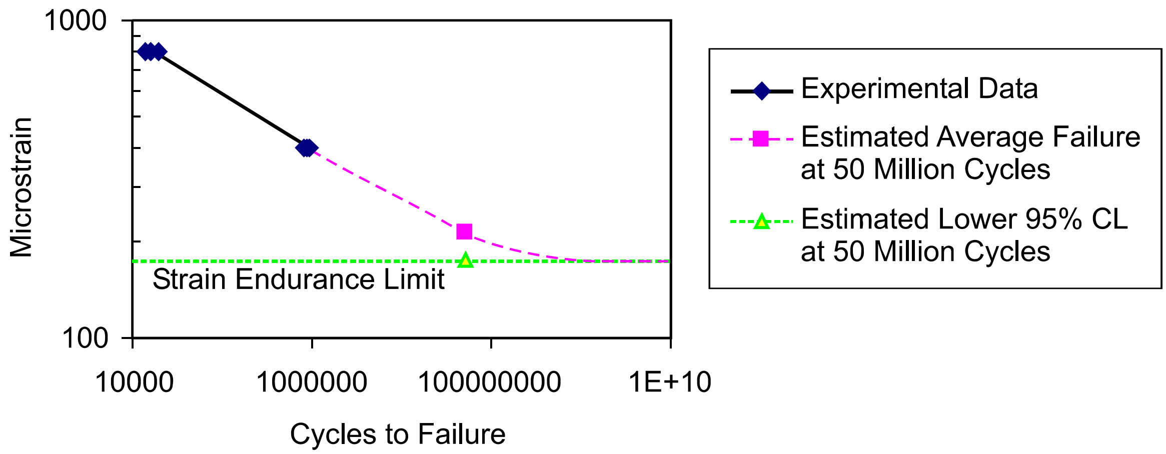

Figure 2. Example of Fatigue Endurance Limit Estimation, CL = confidence level.

Dynamic Modulus and Repeated-Load Permanent Deformation Tests

Dynamic modulus and repeated-load permanent deformation tests were performed in accordance with AASHTO TP-62 (AASHTO, 2007). The sigmoidal master curves for dynamic modulus were developed at a reference temperature of 70°F (21°C) from measurements made at temperatures ranging from 14°F (-10°C) to 130°F (54°C) and load frequencies ranging from 0.01 Hz to 25 Hz.

Repeated-load permanent deformation tests were performed in an unconfined state at a temperature of 130°F (54°C) and applied stress of 30 psi (207 kPa) from which the flow numbers (FNs) were determined. The *flow number* is the number of cycles at which tertiary flow starts (i.e., strain rate begins to increase) indicating the beginning of failure. A higher FN indicates a more rut-resistant mixture. FN has shown good correlation with rutting of asphalt mixtures for different traffic levels and in laboratory testing (Mohammad et al., 2006; Witczak, 2007).

Indirect Tension Tests

A method employing indirect tensile strength was used to predict rutting susceptibility for the projects in accordance with a procedure developed by Christensen and Bonaquist (2007). The testing temperature was 17°F (9°C) lower than the yearly 7-day average maximum temperature at the surface of the layer being analyzed. The pavement temperature was calculated using LTPPBind software. Indirect tension tests were performed on 64-mm-thick by 102-mm-diameter specimens as described for unconditioned specimens in AASHTO T-283 (AASHTO, 2007), which is normally used for determining moisture susceptibility.

Binder Recovery and Grading

Asphalt binder was recovered and performance graded from each mixture. Binder was recovered from mixture samples by extraction in accordance with AASHTO T-164, Method A (AASHTO, 2007), and Abson recovery in accordance with AASHTO T-170 (AASHTO, 2007). The recovered binder was then graded in accordance with AASHTO M-320 (AASHTO, 2007). Multiple temperatures were used to determine an exact grade rather than just the passing grade, which is normally obtained for acceptance testing. The grading was done to determine whether the binders conformed to the specified stiffness characteristics, which were essential for good performance in this high-modulus application.

Subgrade Survey

The subgrade on the SR 207/652 project was sampled by personnel from VDOT's Fredericksburg District Materials Section. The results of testing, including moisture content, Atterberg limits, percentage passing the No. 200 sieve, and AASHTO classification, are presented in Appendix B. This information is presented to provide background information for future analysis.

Ground-Penetrating Radar

GPR was used to assess the layer thickness of the BM-25.0 layers placed on the SR 207/652 project. This technique has been shown to be an effective means for nondestructively determining the pavement layer thickness (Maser, 2002; Maser and Scullion, 1992).

The GPR system used in this study consisted of a 2.0 GHz air-launched horn antenna and a SIR-20 controller unit, both manufactured by Geophysical Survey Systems, Inc. The antenna was mounted on a survey vehicle as shown in Figure 3. The pulse rate of the antenna was

Figure 3. VDOT's Air-Launched GPR System

maintained at a rate of 1 scan per foot, regardless of the vehicle speed, using an integrated distance measuring instrument. All data were processed by the software RADAN (version 6.6) developed by Geophysical Survey Systems, Inc. The software allows the user to view the collected data and identify the layer boundaries. The thickness to each layer boundary is automatically calculated. Information from GPR testing can be used in the FWD analysis and can also be used to identify differences in planned versus as-built conditions.

Falling Weight Deflectometer

Deflection testing was performed using a Dynatest Model 8000 FWD in both directions. The FWD load plate was located in approximately the center of each lane during testing. The FWD was equipped with nine sensors at radial distances of 0, 8, 12, 18, 24, 36, 48, 60, and 72 in from the center of a load plate. Testing was conducted at approximately 50-ft intervals and at three load levels (6,000; 9,000; and 12,000 lbf). The output from the FWD is provided as a text-delimited raw data file.

The previous day average air temperature (average of high and low) was obtained from a nearby weather station from Weather Underground (www.wunderground.com). These data were used to calculate a temperature-corrected deflection under the load plate (D_0). In addition, the subgrade resilient modulus and effective structural number were calculated.

RESULTS

I-81

Laboratory Volumetric, Gradation, and Core Test Results

The volumetric properties of gyratory specimens and gradation/asphalt content results are listed in Tables 1 and 2, respectively. Also included in Table 1 are the average air voids and thickness of cores taken from the different sections. The contractor's volumetric results are represented by a single sample, and the VTRC results are represented by the average of two samples. The contractor's gradation/asphalt content results are represented by the average of three samples, and the VTRC results are the average of two samples. The pavement core results are the average of 10 cores from each section.

Table 1. Gyratory Volumetric and Core Results for I-81

Properties	BM-25.0A		BM-25.0D		BM-25.0D+0.4	
	VTRC	Contractor	VTRC	Contractor	VTRC	Contractor
VTM, %	4.3	4.0	3.8	2.8	3.1	2.1
VMA, %	14.9	13.9	14.1	13.6	14.1	13.0
VFA, %	71.3	70.8	73.1	79.5	77.8	83.9
Average VTM from pavement cores, %	7.6	---	7.6	---	6.0	---
Average thickness from pavement cores, in	2.9	---	3.0	---	3.0	---

VTRC = Virginia Transportation Research Council, VTM = voids in total mix, VMA = voids in the mineral aggregate, VFA = voids filled with asphalt.

Table 2. Gradation and Asphalt Content Results for I-81

Sieve	BM-25.0A Job Mix	BM-25.0A		BM-25.0D		BM-25.0D+0.4	
		VTRC	Contractor	VTRC	Contractor	VTRC	Contractor
1 ½ in	100	100	100	100	100	100	100
1 in	94	98	95	96	96	97	95
¾ in	87	92	86	90	90	89	87
½ in		74	71	69	74	70	68
3/8 in		64	60	58	62	58	59
No. 4		40	36	37	39	38	38
No. 8	27	25	23	24	25	25	24
No. 16		17		17		17	
No. 30		13	12	13	12	13	12
No. 50		10	9	10	10	10	10
No. 100		8.7		8.3		8.4	
No. 200	5.0	7.0	5.7	6.8	6.0	6.9	5.8
% asphalt binder	4.5	4.9	4.6[a]	4.7	4.9[b]	5.0	5.0

VTRC = Virginia Transportation Research Council.
[a] Minimum binder content for a BM-25.0A mixture is 4.4%.
[b] Minimum binder content for a BM-25.0D mixture is 4.6%.

The contractor's volumetric results indicate that air voids decreased as the mixture was changed from a BM-25.0A, to a BM-25.0D, to a BM-25.0D+0.4 mixture. Similarly, VTRC results show a decrease in air voids; however, the initial and final levels of the VTRC results are at a higher air void content than the results from the contractor. The average of the pavement voids for the BM-25.0D+0.4 section was significantly less (1.6%) than that for the other sections at a 95% confidence level. The previous VTRC study predicted that generally an increase of 0.4% asphalt would decrease the pavement voids in the range of 1.0% to 1.5% (Maupin and Diefenderfer, 2006). The average asphalt content of two samples by VTRC indicated 0.3% more asphalt in the BM-25.0D+0.4 section than in the BM-25.0D section. As planned, there were no major differences in gradations between sections.

Stripping Test Results

The stripping test results are listed in Table 3. The air void contents were targeted toward the void contents of cores removed from the pavement instead of the standard 7.0%. In addition, the control mixture, BM-25.0A, was saturated to 70% to 80% in accordance with the test method but the other mixtures were saturated for the same time interval as required for the BM-25.0A mixture. Even though the saturation time was controlled and not the degree of saturation, the degree of saturation was virtually the same for all mixtures. The BM-25.0D+0.4 mixture had a slightly higher TSR, but it was not possible to test whether it was statistically different since only one test was performed.

Table 3. Stripping Test Results for I-81

Mixture	Voids in Total Mix, %	% Saturation	Tensile Strength Ratio
BM-25.0A	7.5	76	0.81
BM-25.0D	6.7	77	0.78
BM-25.0D + 0.4	5.9	73	0.88

Rut Test Results

The results of the rut tests performed with the APA are listed in Table 4. An attempt was made to duplicate the average air voids measured from pavement cores for each mixture. The difference between the rut depth results of each mixture was not statistically significant at a 95% confidence level. The VDOT maximum rut depth test criteria for surface mixtures is 7.0 mm, 5.5 mm and 3.5 mm for light, moderate, and heavy traffic situations, respectively. Although the mixtures tested were base mixtures, the results are much less than any of the surface mixture criteria, and base mixtures should be less vulnerable to rutting because they are deeper in the pavement structure.

Table 4. Rut Test Results for I-81

Mixture	Voids in Total Mix, %	Rut depth, mm
BM-25.0A	7.6	1.04
BM-25.0D	7.5	0.94
BM-25.0D+0.4	6.3	0.78

Dynamic Modulus and Repeated-Load Permanent Deformation Test Results

Figure 4 shows the dynamic modulus master curve plots for the I-81 mixtures. Although it may not be obvious because of the scale, the curves show that the BM-25.0A mixture (having a PG 64-22 binder) had considerably lower moduli at low frequency (i.e., slow loading rate or high temperature) than the moduli for the BM-25.0D mixtures (having a PG 70-22 binder).

Table 5 lists the results of the repeated-load permanent deformation tests, performed at 130°F and 30 psi applied stress, in terms of the FN. The FN for the mixture with a PG 64-22 binder is much less than the FN for the mixtures with a PG 70-22 binder. Relatively lower FNs indicate more susceptibility to rutting. There was very little difference in the FNs between the BM-25.0D and BM-25.0D+0.4 mixtures. Compared with the regression modeling by Mohammad et al. (2006), the results shown in Table 5 suggest that the BM-25.0A mixture may be more susceptible to rutting than the BM-25.0D and the BM-25.0D+0.4 mixtures. Further, the latter two mixtures appear to comply with VDOT's laboratory-based rut test guidelines for high traffic (3.5 mm) if results similar to those of Mohammad et al. (2006) are valid for the mixtures studied during this project.

Binder Recoveries and Grading Results

The recovered binder from all test sections graded as having an effective PG 70-22 binder, as shown in Table 6. Even the BM-25.0A mixture achieved an effective PG 70-22 binder grading (the mixture was produced with PG 64-22 binder plus 15% RAP). The two sections of Type D mixture nearly graded as having an effective PG 76-22 binder. It would be expected that the Type D mixtures containing PG 70-22 virgin binder would be stiffer than the Type A mixture containing PG 64-22 virgin binder even though the recovered binders from all of the mixtures passed as PG 70-22.

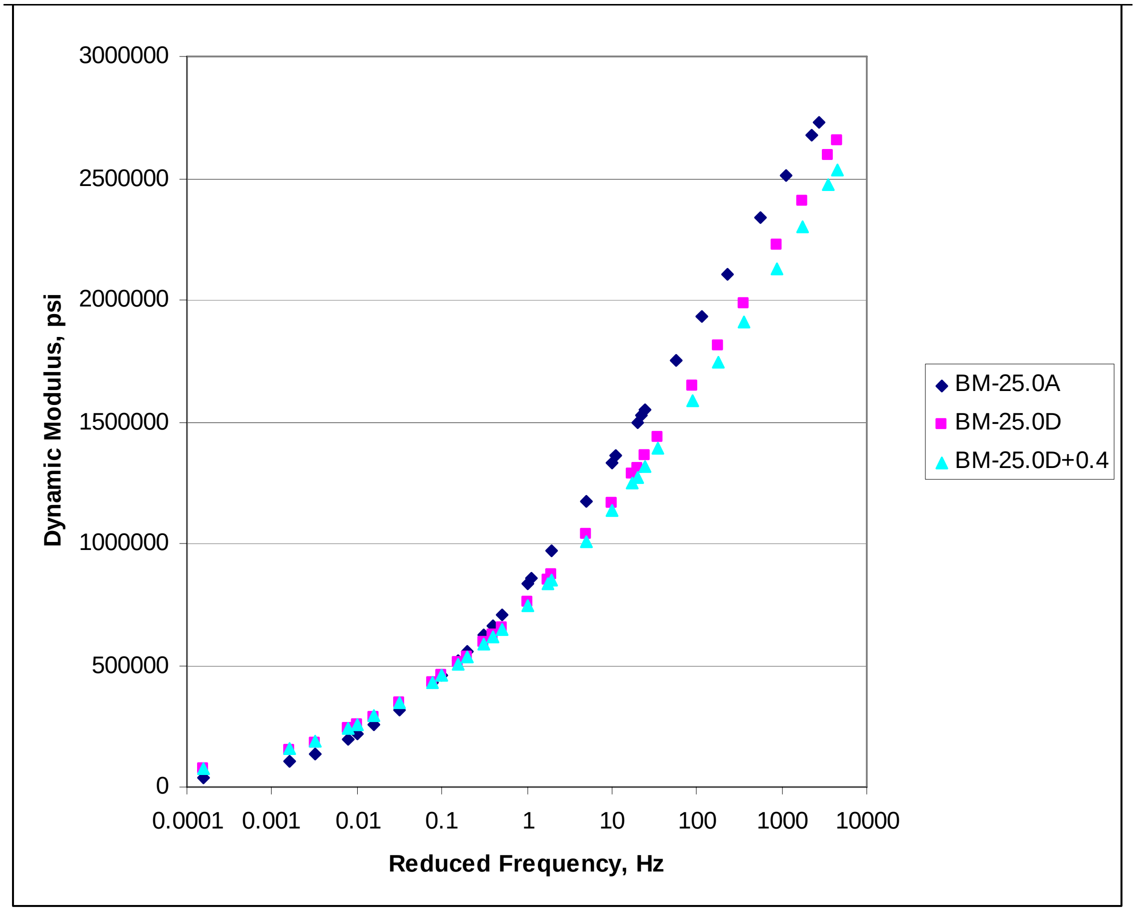

Figure 4. Dynamic Modulus Master Curves for I-81 Mixtures

Table 5. Flow Number Test Results for I-81 Project

Mixture	Flow number, cycles
BM-25.0A	2326
BM-25.0D	6454
BM-25.0D+0.4	6781

Table 6. Grading of Binder Recoveries From Field Samples on I-81

Mixture ID	Performance Grading	
	Exact	Passing
BM-25.0A	PG 71.2-22.3	PG 70-22
BM-25.0D	PG 75.6-23.8	PG 70-22
BM-25.0D + 0.4	PG 75.9-24.7	PG 70-22

Indirect Tension Test Results

Indirect tension tests were performed on the BM-25.0D mixture from mixture fabricated in the laboratory prior to construction in as previously described. The testing temperature was 91°F (33°C). The tensile strength was 140 psi (965 kPa) and 135 psi (930 kPa) for the BM-25.0D and BM-25.0D+0.4 mixtures, respectively. These strength values were tentatively classified as being excellent for rut resistance under heavy traffic by Christensen and Bonaquist (2007).

U.S. Route 460

Laboratory Volumetric, Gradation, and Core Test Results

The volumetric properties of gyratory specimens and gradation/asphalt content results are provided in Tables 7 and 8, respectively. The volumetric results for the BM-25.0D+0.8 mixture are represented by the average of two samples. The volumetric results for the BM-25.0D+0.4 mixture are represented by the average of three samples for each day of production. The results shown in Table 7 indicate that the VTM was less than and the VFA was greater than typically accepted norms for well-performing mixtures.

Table 7. Gyratory Volumetric and Core Results for U.S. Route 460

Properties	BM-25.0D+0.8	BM-25.0D+0.4 (September 17, 2009)	BM-25.0D+0.4 (September 22, 2009)
VTM, %	0.4	1.2	1.4
VMA, %	13.0	12.5	12.6
VFA, %	97.3	90.0	89.0

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

Table 8. Gradation and Asphalt Content Results for U.S. Route 460

Sieve	BM-25.0D+0.4 Job Mix	BM-25.0D+0.8	BM-25.0D+0.4 (September 17, 2009)	BM-25.0D+0.4 (September 22, 2009)
1½ in	100	100	100	100
1 in	94	97	91	99
¾ in	78	85	79	83
½ in		72	64	70
3/8 in		66	58	64
No. 4		46	42	44
No. 8	29	34	32	32
No. 16		25	25	25
No. 30		20	20	19
No. 50		14	15	14
No. 100		9	10	9
No. 200	6.0	6.3	6.6	6.2
% asphalt binder	5.0	5.41	4.84	4.79

SR 207/652: Carmel Church

Laboratory Volumetric, Gradation, and Core Test Results

The volumetric properties of gyratory specimens and gradation/asphalt content results are provided in Tables 9 and 10, respectively. The VTM and thickness measured from pavement cores collected during construction are shown in Table 9. The volumetric and gradation results are based on only one sample for both VTRC and the contractor because of the short test sections and small tonnages placed. Therefore, slight differences could be expected. In addition, the volumetric and gradation specimens created by VTRC and the contractor were not created from split samples, as they were collected during different times of the production day. The pavement core data shown in Table 9 are the average of five cores from the BM-25.0D section and six cores from the BM-25.0D+0.4 and BM-25.0D+0.8 sections.

Table 9. Gyratory Volumetric and Core Results for SR 207/652

Property		BM-25.0D		BM-25.0D+0.4		BM-25.0D+0.8	
		VTRC	Contractor	VTRC	Contractor	VTRC	Contractor
VTM, %		2.4	4.1	2.2	1.3	1.8	0.9
VMA, %		12.6	13.0	12.5	11.8	12.9	12.4
VFA, %		80.8	68.6	82.7	89.2	85.8	92.7
Average VTM from pavement cores, %		5.5	---	5.2	---	4.7	---
Average thickness from pavement cores, in	Top	3.6	---	3.5	---	3.9	---
	Bottom	2.4	---	2.5	---	2.6	---
	Total	6.1	---	6.0	---	6.5	---

VTRC = Virginia Transportation Research Council, VTM = voids in total mix, VMA = voids in the mineral aggregate, VFA = voids filled with asphalt

Table 10. Gradation and Asphalt Content Results for SR 207/652

Sieve	BM-25.0D Job Mix	BM-25.0D		BM-25.0D+0.4		BM-25.0D+0.8	
		VTRC	Contractor	VTRC	Contractor	VTRC	Contractor
1½ in	100	100	100	100	100	100	100
1 in	95	97	97	96	96	95	98
¾ in	76	82	83	78	83	76	81
½ in		66	62	62	65	59	63
3/8 in		60	55	56	58	50	55
No. 4		47	43	44	46	39	42
No. 8	28	36	32	33	34	29	31
No. 16		25	23	23	24	20	22
No. 30		18	16	17	17	14	15
No. 50		12	11	12	11	10	10
No. 100		9	8	8	8	7	7
No. 200	4.3	6.4	5.5	5.9	5.5	5.0	5.0
% asphalt binder	5.0	4.8	4.2[a]	4.8	4.9	5.1	5.3

VTRC = Virginia Transportation Research Council.
[a] Minimum binder content for a BM-25.0D mixture is 4.6%.

There was a considerable difference between the VTRC and contractor volumetric results for the BM-25.0D section that was at least partially caused by gradation differences. Both laboratories showed a decrease of air voids as the asphalt binder content was increased; however, the contractor's laboratory results show a larger decrease. Although the gradation results are somewhat finer than the job-mix formula, the mixtures appeared quite coarse and segregated on the roadway. Table 10 also shows that the BM-25.0D mixture did not comply with the minimum binder content according to the contractor results. In summary, the mixture produced in the field was not the same as what would be expected according to the job-mix formula. In addition, for the BM-25.0D+0.4 and BM-25.0D+0.8 mixtures, the VTM was less than and the VFA was greater than typically accepted norms for well-performing mixtures.

During construction, an attempt was made to establish a roller pattern for the BM-25.0D+0.4 and BM-25.0D+0.8 mixtures. However, difficulties were encountered as the unconfined mixtures tended to spread sideways as more roller passes were applied in an effort to achieve maximum density. During construction of a rich-bottom layer in Ontario, Canada, the contractor observed that an extra 0.5% of asphalt binder acted as a lubricant such that not quite as much compactive effort was needed (Davey, 2009). In retrospect, it probably would have been better to develop a roller pattern on the BM-25.0D mixture (control) and use the same number of passes or possibly fewer passes for the other two sections.

Stripping Test Results

The results of the stripping test performed on mixture sampled during production are shown in Table 11. As discussed previously, stripping tests were performed in accordance with AASHTO T-283 with two exceptions. First, the air void contents were targeted toward the void contents of cores removed from the pavement instead of the standard 7.0%. Second, the BM-25.0D mixture (control) was saturated 70% to 80% in accordance with the test method but the BM-25.0D+0.4 and BM-25.0D+0.8 mixtures were saturated for the same time interval as was required for the control. It was thought that improved stripping resistance might be indicated by possibly showing that less water would be able to enter and produce less stripping in specimens containing more asphalt binder. The results indicated that the degree of saturation was the same for the three mixtures. The BM-25.0D+0.8 mixture had a slightly higher TSR but it was not possible to test whether it was statistically different since only one test was performed. The anti-stripping agent used in all mixtures was a chemical-based additive.

Table 11. Stripping Test Results for SR 207/652

Mixture	Voids in Total Mix %	% Saturation	Tensile Strength Ratio
BM-25.0D	5.9	74	0.85
BM-25.0D+0.4	6.0	76	0.84
BM-25.0D+0.8	5.0	76	0.90

Rut Test Results

The results of rut tests performed on the APA using mixture sampled during production are provided in Table 12. There average rut depth between the BM-25.0D and BM-25.0D+0.4 mixtures or between the BM-25.0D+0.4 and the BM-25.0D+0.8 mixtures were not statistically different at a 95% confidence level. However, there was a statistically significant difference between the average rut depth of the BM-25.0D and BM-25.0D+0.8 mixtures. The rut depths for all of the mixtures were less than any of the VDOT maximum criteria for light, moderate, or heavy traffic situations, i.e., 7.0 mm, 5.5 mm, and 3.5 mm, respectively (VDOT, 2010).

Table 12. Rut Test Results for Route 207/652 project

Mixture	Voids in Total Mix, %	Rut depth, mm
BM-25.0D	5.7	1.05
BM-25.0D+0.4	5.5	1.31
BM-25.0D+0.8	4.6	1.59

Indirect Tension Test Results

Indirect tension tests were performed on specimens prepared prior to construction in accordance with the mix design. The method described previously was used with a testing temperature of 91°F (33°C). Air void contents were targeted toward the expected field voids.

Indirect tension tests were also performed on the gyratory specimens created using mixture sampled during production that was also used for volumetric determination. The results are provided in Table 13. The tensile strength of the production specimens was approximately twice that of the preconstruction specimens. The air void contents of the volumetric specimens were considerably less than the air voids of the preconstruction specimens, so the strengths would be expected to be higher. However, the values may still serve as a comparison of the relative strengths of the different mixtures. Even the low values were tentatively classified as being "very good" for rut resistance under heavy traffic by Christensen and Bonaquist (2007).

Table 13. Indirect Tension Test Results for SR 207/652

Mixture	Preconstruction		Production	
	Voids in Total Mix, %	Strength, kPa	Voids in Total Mix, %	Strength, kPa
BM-25.0D	7.3	599	2.4	1054
BM-25.0D+0.4	5.7	564	2.2	1040
BM-25.0D+0.8	5.1	572	1.8	1047

Dynamic Modulus and Repeated-Load Permanent Deformation Test Results

Figure 5 shows the dynamic modulus master curve plots for mixture sampled during production. Although it may not be obvious because of the graph scale, the curves show that the

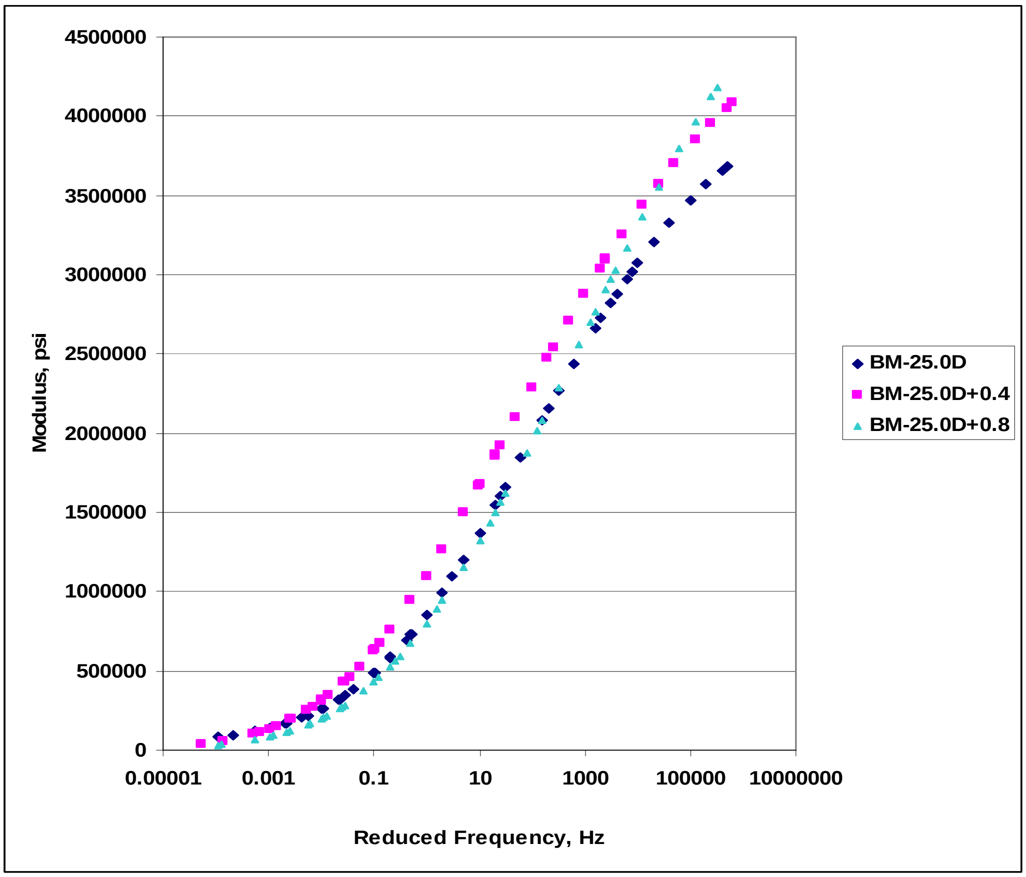

Figure 5. Dynamic Modulus Tests at Reference Temperature of 70°F on SR 207/652 Mixtures

BM-25.0D+0.8 mixture had considerably lower moduli at low frequencies (i.e., slow loading rate or high temperature) than the BM-25.0D mixture (control) and the BM-25.0D+0.4 mixture. At intermediate frequencies, the moduli of the BM-25.0D+0.8 mixture were approximately equal to the moduli of the BM-25.0D mixture (control) and were higher at very high frequencies. The BM-25.0D+0.4 mixture had slightly lower moduli than the BM-25.0 mixture (control) at very low frequencies but had higher moduli for most of the rest of the frequency range.

Table 14 provides the corresponding repeated-load permanent deformation results in terms of the FN. The FN was found to increase as the binder content increased. Although no FN criteria have been assigned as being indicative of acceptable mixtures, based on the regression modeling shown in Mohammad et al. (2006), the results shown in Table 14 suggest that these mixtures may be susceptible to permanent deformation. Although there is presently no absolute FN acceptance criterion to gauge mixtures, the results here can be used to show relative differences between mixtures.

Table 14. Flow Number Test Results for SR 207/652 Project

Mixture	Flow Number, cycles
BM-25.0D	1465
BM-25.0D + 0.4	1164
BM-25.0D + 0.8	779

Fatigue Test Results

Approximately 10 fatigue tests were performed at various strain levels on each mixture type from mixture sampled during production. This was done to determine a failure regression plot and predict a strain endurance limit as defined previously. The fatigue failure results for the three mixtures are shown in Figure 6 and provided in Table 15. The calculated endurance limits are also listed in Table 15. There was no significant difference observed in the fatigue behavior of the three mixtures. The BM-25.0D+0.8 mixture did not show improved fatigue behavior as expected even though the air voids were slightly less (i.e., higher density) than the air voids of the other two mixtures. Normally, an increase in density improves fatigue life.

Binder Recoveries and Grading Results

This project required Type D mixture. VDOT allows Type D mixtures to be achieved by using a PG 70-22 or PG 64-22 binder with at least 20% RAP. The specification assumes that the PG 64-22 virgin binder and stiffened binder contained in 20% RAP will combine to form a PG 70-16 binder. Examination of the recovered binder high temperature grades listed in Table 16 reveal that the combined binders produced only an effective PG 64-22 grade. The addition of RAP did not produce a PG 70-16 binder as expected. This may be due to the virgin binder grade being too soft (close to a PG 64-xx binder) and when RAP was added, the combined mixture did not stiffen to meet the PG 70-xx requirement. In addition, with increasing virgin binder contents, the exact mixture grade should have decreased with a constant RAP percentage. As evident in Table 16, the binder grades were practically the same for all three mixtures. With the lower that expected mixture grades, the mixture stiffness would be expected to be lower, potentially affecting the construction, field performance, and laboratory performance.

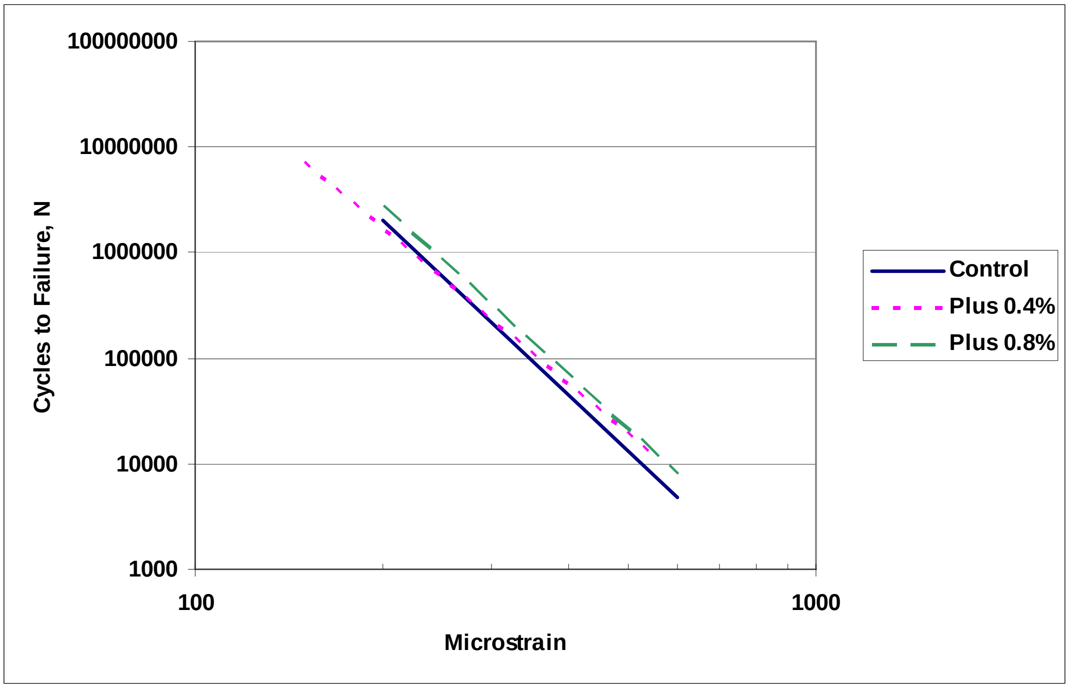

Figure 6. Fatigue Curves for SR 207/652 Project Mixtures

Table 15. Fatigue Results for SR 207/652 Project

Mixture	Voids in Total Mix, %	Curve	Endurance Limit, με
BM-25.0D	5.3	$N = 7.5001 \times 10^{-15} (1/\varepsilon)^{5.5241}$	94
BM-25.0D+0.4	4.9	$N = 9.8175 \times 10^{-13} (1/\varepsilon)^{4.9319}$	80
BM-25.0D+0.8	4.0	$N = 6.7905 \times 10^{-14} (1/\varepsilon)^{5.2992}$	98

Table 16. Grading of Binder Recoveries of Field Samples for SR 207/652 Project

Mixture ID	Performance Grading	
	Exact	Passing
BM-25.0D	PG 68.0-24.4	PG 64-22
BM-25.0D+0.4	PG 67.5-24.8	PG 64-22
BM-25.0D+0.8	PG 68.4-24.1	PG 64-22

Subgrade Survey Results

Samples of the subgrade material were collected in October 2009 by staff of VDOT's Fredericksburg District Materials Section. Samples were collected from Stations 21+00 to 32+00. Materials from Stations 16+50 through 20+50 and 34+00 through 37+50 were not collected as these areas were stabilized with granular materials and a geotextile fabric. The results of the subgrade survey are presented in Appendix B and are included for use in future analysis.

Ground-Penetrating Radar Results

Figure 7 shows the results of the GPR testing. The figure shows the thickness (depth from the surface) of the two BM-25.0 layers. The average total thickness (including both layers)

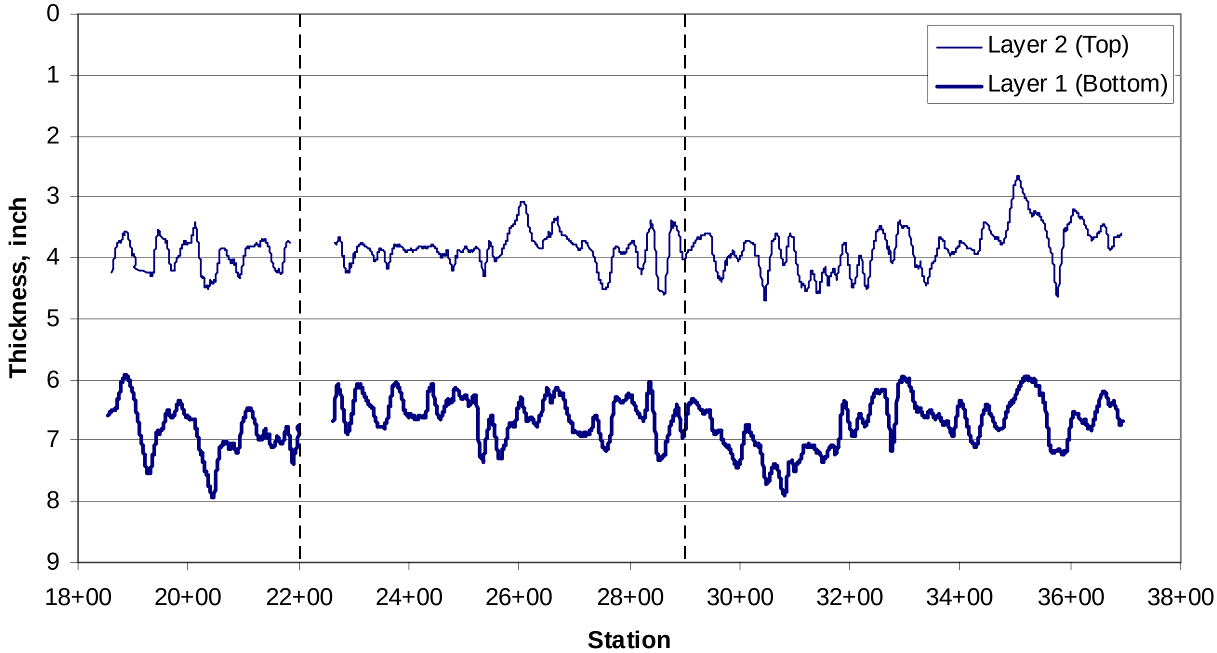

Figure 7. BM-25.0 Layer Thickness, SR 207 Northbound (vertical dashed line indicates section boundary)

from the GPR testing in the three test sections (BM-25.0D, BM-25.0D+0.4, and BM-25.0D+0.8) was 6.4, 6.6, and 6.7 in, respectively. The gap in the data at approximately Station 22+50 was in the area of a full-depth repair that was under way on the day of testing. This information was used during the FWD analysis and is presented for use in future analysis.

Falling Weight Deflectometer Results

The results of the FWD tests are shown in Figures 8 through 11. Figures 8 and 9 show the deflection (D_0) at the 9,000 lbf load level for the northbound and southbound directions, respectively. Figures 10 and 11 show the structural number and the subgrade resilient modulus for the northbound and southbound directions, respectively.

At the time of testing, the in-place pavement structure consisted of subgrade, granular base, and two lifts of BM-25.0 HMA base mixture. If typical layer coefficients for the granular base and BM-25.0 mixture (0.12 and 0.44, respectively) are multiplied by the planned thickness (8 and 6 in, respectively), a representative structural number can be calculated; this value was calculated as 3.6. Figures 10 and 11, in general, compare favorably with this value, with the exception of a portion of the northbound lane starting at approximately Station 33+00. The results of the FWD testing suggest that the pavement was performing as designed in terms of structural capacity. This information is also expected to be used for future analysis to document an “as-built” structural condition.

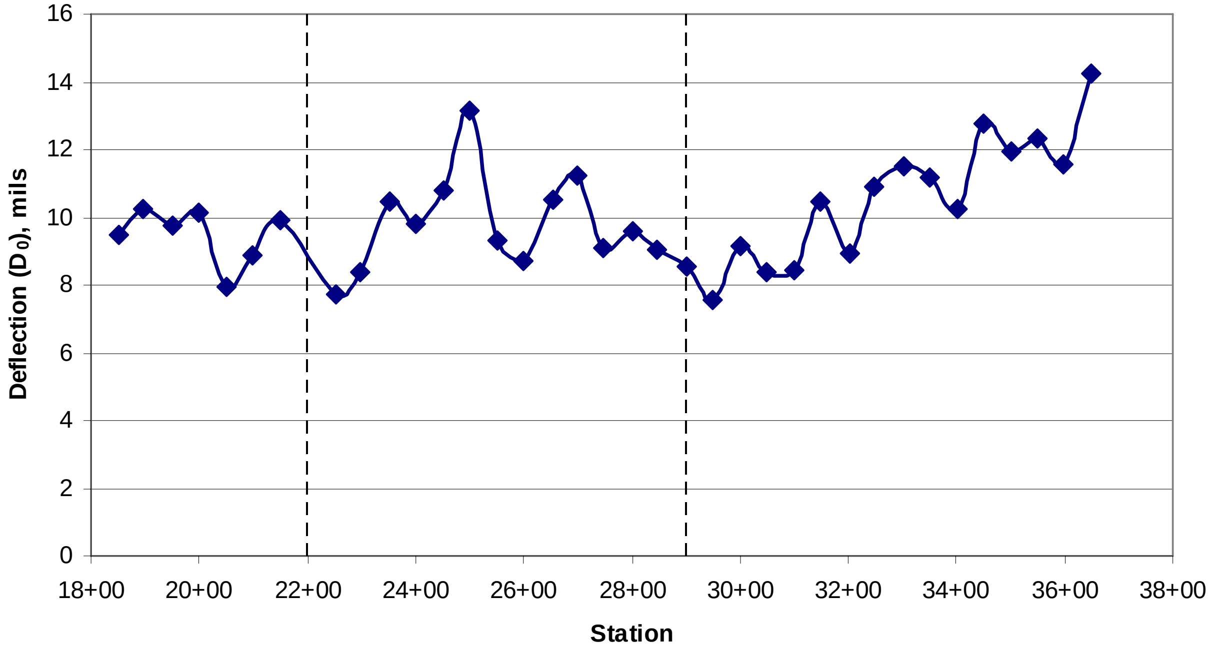

Figure 8. Deflection (d_0) at 9,000 lbf Load Level, SR 207 Northbound (vertical dashed line indicates section boundary)

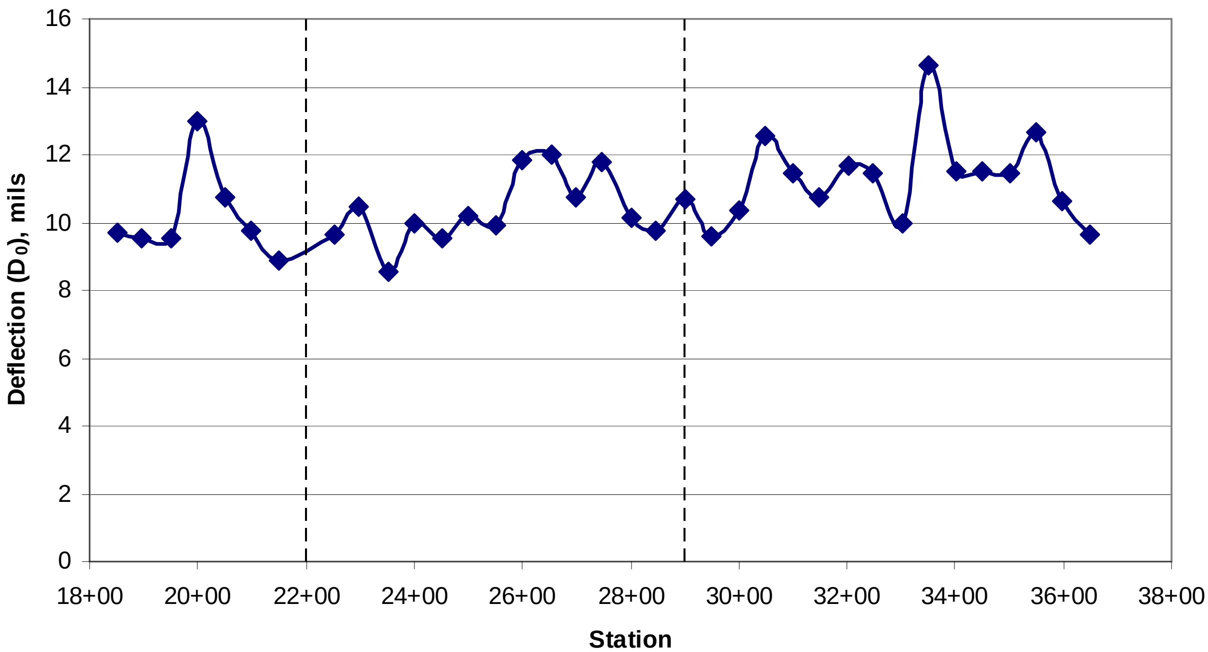

Figure 9. Deflection (d_0) at 9,000 lbf Load Level, SR 207 Southbound (vertical dashed line indicates section boundary)

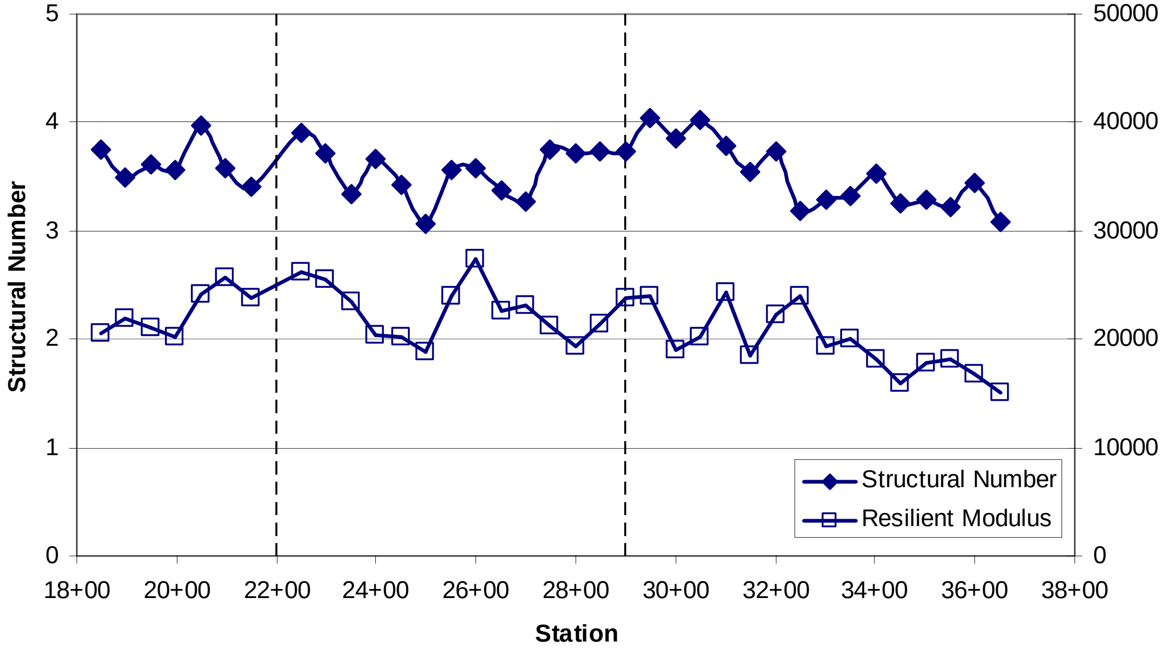

Figure 10. Structural Number and Subgrade Resilient Modulus at 9,000 lbf Load Level, SR 207 Northbound (vertical dashed line indicates section boundary)

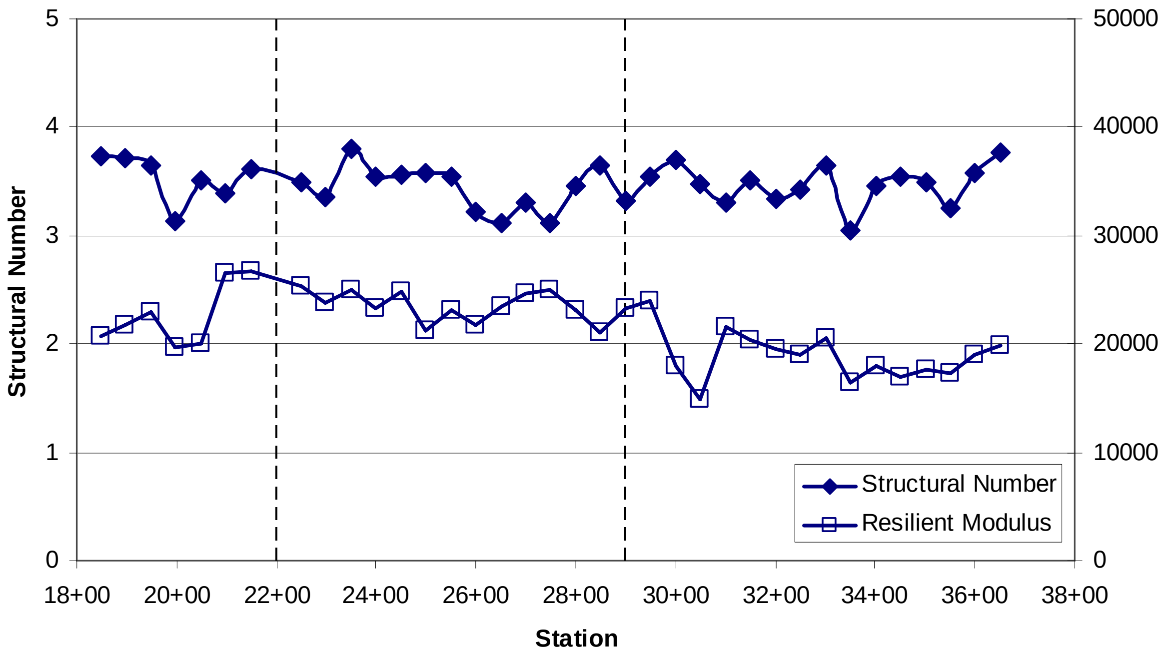

Figure 11. Structural Number and Subgrade Resilient Modulus at 9,000 lbf Load Level, SR 207 Southbound (vertical dashed line indicates section boundary)

DISCUSSION

The primary purpose of this study was to gain field experience with the HMHB mixtures related to mix design, construction, and early field performance. It is anticipated that additional information related to longer term field performance will be gathered for the sections in the future.

The main benefit of using HMHB mixtures is thought to be an extension of the pavement service life by a reduction of the in-place air void content and an increase in the binder content. The reduction of air voids should lead to a mixture that is more resistant to the damaging effects of moisture and in conjunction with the increased binder content possibly offer increased fatigue resistance. However, increased fatigue resistance was not shown during the laboratory portion of this study, but the mixture tested was collected from the Route 207/652 project and conclusions cannot be drawn from the results for the reasons stated previously. At the start of this study, VDOT specifications were such that a BM-25.0 mixture was designed at 3.5% air voids (VDOT, 2007). Currently, the specification is that a BM-25.0 mixture is designed at 2.5% air voids (VDOT, 2009). The mixtures placed at the test sites in this study were all designed in accordance with the 3.5% design air voids specification.

Much of the laboratory testing of field-placed mixtures was conducted on materials collected from the SR 207/652 project. When the information in Table 9 is reviewed, it can be seen that the VTM is less than and the VFA is greater than accepted values that are typical for well-performing mixtures. Table 10 shows the results of the binder content tests. If the VTRC results are considered, the binder contents for the BM-25.0D, BM-25.0D+0.4, and BM-25.0D+0.8 mixtures were 4.8%, 4.8%, and 5.1%, respectively. In all cases, these values were less than expected. Table 16 also shows that the recovered binder did not meet the higher stiffness of a PG 70-22 grading. Thus, the performance of this mixture (in terms of in-situ and laboratory performance) is likely not indicative of the performance of other HMHB mixtures in general.

Most high-binder base mixtures discussed in the literature targeted a maximum of 0.5% additional asphalt binder. Additional research should determine the potential benefit of increasing this value through field trials, as was attempted here. Binder stiffness is very important for high-binder mixtures; therefore, care should be exercised to make sure that binders with adequate stiffness are used. Table 16 shows that a Type D mixture (having an effective PG 70-22 binder) was not achieved on the SR 207/652 project. Since some high-binder mixtures may have a lack of stability during compaction, the use of conventional roller patterns to develop the optimum number of roller passes may not work for certain mixtures. Lack of stability, as observed at the SR 207/652 project, could also be due to variations in the gradation as compared to the expected performance of the job-mix formula.

SUMMARY OF RESULTS

- Binder stiffness had a positive influence on mixture stiffness on the SR 207/652 and I-81 projects.

- Volumetric analysis showed that the mixture produced during the SR 207/652 project did not meet the traditionally accepted ranges for VMA and VFA. This mixture had lateral stability issues during rolling, possibly caused by a combination of poor mixture volumetric properties and aggregate gradation.

- The BM-25.0+0.8 mixture from the SR 207/652 project had lateral stability issues while rolling; however, it was reported to the authors that such issues were not observed at the U.S. 460 project where a BM-25.0+0.8 mixture was also used.

- The I-81 project showed that approximately 1.5% less pavement air voids resulted when 0.3% additional asphalt was used. This verified data developed in the earlier laboratory study.

- The results of laboratory APA rut tests were satisfactory for HMHB base HMA mixtures from both projects, but repeated-load permanent deformation test results were possibly marginal for mixture from the SR 207/652 project obtained during construction. This may be a result of the gradation variation from the job-mix formula.

- Fatigue results for mixture obtained during production at the SR 207/652 project showed some difference in performance, but the differences were marginal. According to the test results, the differences in binder contents for the three mixtures placed were less than anticipated.

- The repeated-load permanent deformation test results from mixtures collected at the I-81 project showed a significantly higher rutting resistance where binder recovery data indicated a stiffer binder was achieved.

- Repeated-load permanent deformation test results showed a significantly lower rutting resistance for all mixtures from the SR 207/652 project as compared to those from the I-81 project. Specifically, the rutting resistance for the BM-25.0+0.8 mixture on the SR 207/652 project was the lowest of all. This may be a result of the SR 207/652 mixture not achieving a stiff enough binder grade.

CONCLUSIONS

- *An HMA base mixture having a slightly higher than optimum binder content and containing an effective PG 70-22 binder can be successfully placed using conventional paving techniques.*

- *The binder stiffness for an HMHB mixture should be at least equivalent to that of a PG 70-22 binder to guard against potential rutting.*

- *When an HMHB base mixture is placed, the roller pattern may need to be modified from that used for the same mixture at optimum binder content.*

- *Repeated-load permanent deformation test results may be beneficial in determining appropriate applications for HMHB mixtures.*

- *Additional laboratory testing may be needed to define an optimum additional binder content in a study having a wider range of BM-25.0 mixtures. This could be based on repeated-load permanent deformation results.*

RECOMMENDATIONS

1. *VDOT's Materials Division should cap the additional binder content to 0.4% until additional field projects and laboratory testing can be performed.* Care must be taken to ensure the HMHB base mixture complies with material specifications as provided in VDOT's special provision (see Appendix A).

2. *VDOT's Materials Division should require the use of a PG 70-xx binder when HMHB is specified on a project to ensure the high modulus value is achieved.* RAP should be allowed to be used with the PG 70-22 binder. PG 64-22 binder should not be allowed unless the contractor can certify that the final mixture with RAP produces a mixture having a binder PG of 70-xx or higher.

SUGGESTED FUTURE RESEARCH

- *VTRC should pursue additional laboratory testing to assess the impacts of gradations on HMHB base mixtures.* The difficulty with compacting the HMHB mixture on the SR 207/652 project did not occur on the I-81 or U.S. 460 projects. If merited, VTRC should recommend new gradation bands for HMHB base mixtures to address compaction issues. Such a laboratory study should include not only volumetric analysis but also performance testing such as rut testing and dynamic modulus, repeated-load permanent deformation, and fatigue testing.

- *VTRC should pursue additional laboratory testing on a wider range of HMHB mixtures to determine if additional binder in mixtures designed at 3.5% air voids is beneficial when compared to mixtures designed at 2.5% air voids without additional binder.* The change in design air void contents occurred after the start of this study and was the result of a specification change based on earlier laboratory testing. Such a laboratory study should include not only volumetric analysis but also performance testing such as rut testing and dynamic modulus, repeated-load permanent deformation, and fatigue testing.

- *VTRC should pursue additional testing of base layer HMA mixtures using repeated-load permanent deformation testing to determine an acceptable mixture stiffness for HMHB mixture application.*

- *VTRC should continue to monitor periodically the test sites described in this report to determine the long-term performance of the HMHB base layer HMA mixtures used.*

BENEFITS AND IMPLEMENTATION PROSPECTS

This study documented the field and laboratory knowledge gained by VDOT when producing and placing HMHB mixture test sections in an effort to achieve a long-lasting perpetual-type flexible pavement. These designs offer the potential to reduce fatigue cracking by incorporating additional asphalt binder and reducing the void content of the mixture. The use of an adjusted binder grade or RAP to maintain the necessary stiffness for high binder contents should provide the necessary stiffness to minimize the susceptibility for rutting during service. Quantification of the economic benefits of using HMHB mixtures is a future goal that can be realized after longer term study of field performance.

ACKNOWLEDGMENTS

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APPENDIX A

SPECIAL PROVISION, HMHB FOR SR 207/652 PROJECT

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
BM-25.0D WITH INCREASED ASPHALT CONTENT
(0095-016-111, PE-101; PPMS No. 56184)

August 15, 2008

I. DESCRIPTION

The work described in this special provision is specifically intended for supplying, testing and installing asphalt concrete base for the above cited project. BM-25.0D+0.4 and BM-25.0D+0.8 shall be placed at locations identified in the contract documents

II. MATERIALS

The Contractor shall furnish, test and install BM-25.0D with additional asphalt cement content in accordance with the requirements of this special provision. The first mix, designated as BM-25.0D+0.4, will have an additional 0.4% asphalt cement content. The second mix, designated as BM-25.0D+0.8, will have an additional 0.8% asphalt cement content. These two mixes shall conform to all of the requirements of a standard BM-25.0D in Section 211 of the Road and Bridge Specifications except as noted herein. The locations for each mix will be shown on the plans.

BM-25.0D+0.4 and BM-25.0D+0.8 asphalt concrete bases shall conform to the requirements of Section 211 of the Road and Bridge Specifications except as noted herein.

Construction and Acceptance of one or more courses of asphalt concrete consisting of BM-25.0D+0.4 or BM-25.0D+0.8 asphalt concrete base shall be in accordance with the requirements of a BM-25.0D in Section 315 of the Road and Bridge Specifications.

An equivalent single axle load (ESAL) will be established by the Engineer and the mix types may be specified as one of the types listed as follows:

TABLE 1

Mix Type	Equivalent Single Axle Load (ESAL) Range (millions)	Final Asphalt Performance Grade (PG)	Aggregate Nominal Maximum Size*
BM-25.0D+0.4	All ranges	70-16	1”
BM-25.0D+0.8	All ranges	70-16	1”

Asphalt concrete shall conform to the requirements for the type designated.

*Nominal Maximum Size is defined as one sieve size larger than the first sieve to retain more than 10 percent aggregate.

A. Job-Mix Formulas

Three asphalt concrete base mixes will be supplied to this project: a BM-25.0D per Section 211, a BM-25.0D+0.4 and a BM-25.0D+0.8 both per this special provision. All three asphalt concrete base mixes shall have identical percentages of material components to achieve the same target gradation for each mix.

BM-25.0D+0.4 and BM-25.0D+0.8 shall be initially designed in accordance with the requirements of a BM-25.0D under the Road and Bridge Specifications Section 211. The Job Mix Formula (JMF) asphalt cement (AC) content shall then be adjusted from the AASHTO R35 optimized AC content per Table 2 herein for the mix type specified.

TABLE 2
JOB MIX FORMULA AC CONTENT

Mix Type	JMF AC
BM-25.0D+0.4	R35 Optimum AC +0.4%
BM-25.0D+0.8	R35 Optimum AC +0.8%

During production the BM-25.0D+0.4 and BM-25.0D+0.8 mixes shall be controlled according to the requirements of Table 3 herein.

TABLE 3
PRODUCTION CRITERIA

Mix Type	VTM Production (%)	VFA (%)	Min. VMA (%)	Fines/Asphalt Ratio	Number of Gyrations N Design	Number of Gyrations N Initial
BM-25.0D+0.4	1.0 – 4.0	67 – 92	12.0	0.6 – 1.3	65	7
BM-25.0D+0.8	0.5 – 3.5	67 – 92	12.0	0.6 – 1. 3	65	7

1. The Laboratory mixing and compaction temperature for testing and design shall be as follows:

   The mix temperature shall be 310 ^{o}F to 320 ^{o}F and the compaction temperature shall be 295 ^{o}F to 300 ^{o}F.

2. Field correction factor. The field correction factor is determined by subtracting the bulk specific gravity of the aggregate from the effective specific gravity of the aggregate determined at the JMF AC content achieved using Table 2.

TABLE 4
RECOMMENDED PERFORMANCE GRADE OF ASPHALT

	Percentage RAP in Mix	
Mix Type	**%RAP < 25.0**	**%RAP ≥ 25.0**
BM-25.0D (+0.4 and +0.8)	PG 70-22	PG 64-22

III. TESTING

When asphalt cement is extracted and recovered in accordance with AASHTO T170, the recovered asphalt cement shall have the following penetration and ductility at 77 degrees F:

Mix Type	Recovered Penetration [1/10th mm]	Ductility at 77^0 F
BM-25.0D (+0.4 and +0.8)	min 25	min 40 cm

Abson recovery samples that fail recovered penetration or ductility shall be PG graded according to AASHTO M 320. If the samples meet the required grade specified in Table 1, they shall be deemed acceptable.

In addition to the acceptance testing that is to be performed per the contract, VDOT will perform additional testing as noted in the table below. Testing will occur in the following sections:

1. Control Section (Connection Route 652 South): Station 15+25 to 22+00
2. +0.8% Section (Proposed Route 652 South): Station 22+00 to 29+00
3. +0.4% Section (Proposed Route 652 South): Station 29+00 to 38+53

Activity No.	Activity	Layer	When Performed	Length of Testing Required by VDOT, days	Notification Required by Contractor, days
1	Shelby Tube & SPT	Subgrade	After final grading	1	2
2	Lightweight Deflectometer (LWD)	Subgrade	After final grading	1	2
3	FWD	21B	After final grading	1	5
4	Instrument bottom of BM25	BM25	After final grading of 21B	1	3
5	FWD	BM25	After paving of upper BM25 layer	1	5
6	Coring	BM	Concurrent w/ activity 5	1	2
7	FWD	SM	After SM paving	1	5
8	Ground Penetrating Radar	SM	After activity 7	1	2
9	Coring	SM	Concurrent w/ activity 8	1	2

This testing will be performed by VDOT for the time duration stated. The contractor shall notify VDOT when the various layers will be available given the prior notification required (as shown in the table).

IV. Acceptance and Adjustments

Acceptance and adjustments shall be in accordance with the requirements for a BM-25.0D in Section 211.08 and 211.09 of the Road and Bridge Specifications.

V. Measurement and Payment:

BM-25.0D WITH INCREASED ASPHALT CONTENT will be measured and paid for in accordance with Section 315 in the Road and Bridge Specifications to include all modifications and requirements as stipulated herein.

Payment will be made under:

Pay Item	Pay Unit
BM-25.0D+0.4	Ton
BM-25.0D+0.8	Ton

APPENDIX B

RESULTS OF SUBGRADE SURVEY, SR 207/652 PROJECT

Table B1. Results of Subgrade Survey, SR 207/652 Project.

Station	Field Description	Depth, ft		Field Moisture	Liquid Limit	Plastic Limit	% passing No. 200 Sieve	AASHTO Classification
		From	To					
21+00	Light brown fine sandy clayey Silt	0.00	1.50	9.1	29.3	14	52.6	A-6(4)
		1.50	3.00	11.2	29.3	14	52.6	A-6(4)
		3.00	4.50	11.0	-	-	-	-
		4.50	6.00	-	-	-	-	-
24+00	Light brown fine silty Sand	0.00	1.50	11.3	-	-	-	-
		1.50	3.00	13.5	33.2	14	46.3	A-6(3)
		3.00	4.50	15.3	33.2	14	46.3	A-6(3)
	Gray fine sandy clayey Silt	4.50	6.00	10.1	-	-	-	-
27+00	Light brown fine sandy clayey Silt	0.00	1.50	10.7	31.5	14	41.7	A-6(2)
		1.50	3.00	14.1	31.5	14	41.7	A-6(2)
	Brown fine sandy clayey Silt	3.00	4.50	12.7	-	-	-	-
		4.50	6.00	13.2	-	-	-	-
30+00	Light brown fine sandy Clay	0.00	1.50	13.3				
	Dark gray fine silty Sand, organic smell	1.50	3.00	10.0				
		3.00	4.50	10.5	16.6	3.9	46.3	A-4(0)
	Gray fine clayey Silt	4.50	6.00	11.4	16.6	3.9	46.3	A-4(0)
32+00	Light brown fine silty Sand	0.00	1.50	8.4	N/A	NP	17.7	A-2-4(0)
		1.50	3.00	15.3	N/A	NP	17.7	A-2-4(0)[a]
		3.00	6.00					

[a] Wet sample.