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Evaluation of Fiber-Modified Asphalt Mixtures Using BMD Tests

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The Virginia Department of Transportation (VDOT) is interested in ways to improve asphalt mixture durability. These improvements can be accomplished through several approaches, including the use of performance-enhancing additives, such as fibers, and the incorporation of performance criteria in mixture design and acceptance. This project evaluated the initial laboratory performance of asphalt mixtures that incorporated aramid fiber additives, along with associated control mixtures not containing fibers, on VDOT pilot projects. The mixtures included traditionally designed mixtures (i.e., Superpave) and those designed to meet VDOT's balanced mix design (BMD) criteria. The study documented production and construction details. Materials were collected during production to evaluate the mixture properties. The laboratory performance information was used to benchmark the as-constructed mixture performance and assess the potential performance benefits of fiber-modified mixtures.

For most of the mixtures evaluated, the addition of fibers did not improve performance test results compared with test results from the control mixtures because of reductions in production binder content from the design binder content. Mass loss, CT index, and indirect tensile strength appeared most influenced by effective binder content and film thickness. Volumetric and BMD test results indicated that fiber-modified mixtures should be designed and optimized based on performance criteria. Long-term field performance of these mixtures must be evaluated to determine the relative performance of the control and fiber-modified mixtures under field conditions.

It is recommended that fiber-modified mixtures be designed using BMD. In addition, the potential benefits of fiber-modified mixtures in resisting cracking should continue to be evaluated when mixtures are properly designed and produced.

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FINAL REPORT

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ABSTRACT

The Virginia Department of Transportation (VDOT) is interested in ways to improve asphalt mixture durability. These improvements can be accomplished through several approaches, including the use of performance-enhancing additives, such as fibers, and the incorporation of performance criteria in mixture design and acceptance. This project evaluated the initial laboratory performance of asphalt mixtures that incorporated aramid fiber additives, along with associated control mixtures not containing fibers, on VDOT pilot projects. The mixtures included traditionally designed mixtures (i.e., Superpave) and those designed to meet VDOT's balanced mix design (BMD) criteria. The study documented production and construction details. Materials were collected during production to evaluate the mixture properties. The laboratory performance information was used to benchmark the as-constructed mixture performance and assess the potential performance benefits of fiber-modified mixtures.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) is interested in ways to improve the durability of asphalt mixtures to make the roadway network longer lasting, more economical, and more sustainable. These improvements can be accomplished through several approaches, including the use of performance-enhancing additives, such as fibers, and the incorporation of performance criteria in mixture design and acceptance.

Fibers are used to enhance the performance of asphalt mixtures by minimizing rutting and cracking. Fibers provide additional tensile strength in the mixture and thus increase fatigue and fracture properties of the asphalt mixture (Al-Hosainat et al., 2023; McDaniel, 2015). Different types of fibers can be used as additives to asphalt mixtures. However, the most widely used fiber types are polypropylene and aramid fibers.

The Federal Highway Administration studied the performance of fiber-reinforced asphalt mixture in the laboratory using full-scale accelerated pavement testing and found that that the fatigue cracking of the fiber-reinforced section was considerably less than that of the polymer-modified and unmodified sections (Gibson et al., 2012). A New Jersey DOT study compared the performance of plant-produced mixtures with and without fibers and found through overlay test results that the fiber mix had much greater resistance to crack propagation than the control mixture (Bennert, 2012). Kaloush et al. (2010) conducted a laboratory performance evaluation of fiber-reinforced asphalt mixtures and found that mixtures exhibited higher tensile strength, total fracture energy, and slower crack propagation according to the indirect tensile (IDT) strength test.

The balanced mix design (BMD) method addresses mixture durability through the incorporation of performance criteria into mixture design and acceptance. This method allows innovations in mixture design by evaluating mixture performance rather than only volumetrics. VDOT is in the process of implementing the use of BMD to focus on asphalt mixture performance.

VDOT has limited field experience with fiber-modified asphalt mixtures, which were initially assessed for reflective cracking mitigation when placed over Portland cement concrete pavements. The potential benefits of using fiber-modified mixtures for other applications has led to interest in their use, particularly because the use of BMD is expected to capture the improved performance of these mixtures, especially during design. Thus, further studies of the fibers' ability to improve mixture performance properties are needed.

PURPOSE AND SCOPE

The objective of this project was to evaluate the initial laboratory performance of asphalt mixtures that incorporate aramid fiber additives, along with associated control mixtures not containing fibers on VDOT pilot projects. The mixtures included traditionally designed mixtures (i.e., Superpave) and mixtures designed to meet VDOT's BMD criteria.

The scope of the study included the documentation of production and construction details. Materials were collected during production to evaluate the mixture properties. Laboratory performance testing was used to benchmark the as-constructed mixture performance and to assess the potential performance benefits of fiber-modified mixtures.

METHODS

Five tasks were performed to achieve the study objectives:

1. Obtain the job mix formula (JMF) and design submittal information.
2. Sample mixtures and binder during production and construction.
3. Document the design, production, and construction processes.
4. Test sampled mixtures.
5. Evaluate mixture and test results to assess potential performance benefits.

Field Trials

Richmond District

The Richmond district pilot project was constructed in 2022 on US 60 westbound in New Kent County between mile points 0.21 and 4.11, which has an average annual daily traffic (AADT) value of approximately 12,000 vehicles. The SM-12.5E control mixture (mixture 1) used a PG 64E-22 polymer-modified binder. The SM-12.5D fiber-modified asphalt mixture (mixture 1F) used an unmodified PG 64S-22 binder, and the fiber incorporation was compared with polymer modification. Both mixtures had the same design except for the binder type and addition of fiber. Fiber-modified mixture 1F was placed between mile points 0.21 to 2.27 and control mixture 1 was placed between mile points 2.27 to 4.11.

Hampton Roads District

The pilot project in the Hampton Roads district was constructed in 2022 on U.S. 460 in Sussex County. At the project location, US 460 is a four-lane undivided highway with a center turn lane and an AADT value of approximately 12,000 vehicles. The project spanned mile points 0.0 to 6.94 and 7.74 to 13.05 in both directions. The SM-12.5D control mixture (mixture 2) was placed on the inside left lane, which had an existing full-depth asphalt structure. The SM-12.5D fiber-modified asphalt mix (mixture 2F) was placed in the outside right lane, which was existing composite pavement (asphalt over jointed concrete pavement), to evaluate the mixture's ability to reduce reflective cracking. Both mixtures had the same design except for the addition of fibers and both were produced with PG 64S-22 binder. This pilot project compared the performance of the mixtures through laboratory testing and evaluation. Expected field performances cannot be compared because the pavement structures under each mixture are not equivalent.

Salem District

Two pilot projects were constructed in 2022 in the Salem district using an aramid fiber-modified mixture, along with a non-fiber-modified companion mixture for comparison.

The first pilot project was paved on US 460 in Giles County. The trial consisted of an aramid fiber-modified SM-9.5D mixture (mixture 3F) along with a companion SM-9.5D (mixture 3) mixture for comparison. The two mixtures had the same design except for the addition of fibers. The fiber-modified SM-9.5D was placed at 1.5-inch depth in the eastbound and westbound lanes from the West Virginia State line to approximately 0.14 miles east, terminating at a bridge approach; this location has an AADT value of approximately 9,000 vehicles. The underlying mainline was existing jointed concrete pavement. The SM-9.5D mixture serving as a control was placed on eastbound U.S. 460 from milepost 24.41 to milepost 25.31, which has an AADT value of approximately 13,000 vehicles. The underlying pavement was asphalt and was milled at a depth of 1.75 inches and repaved with 1.75 inches of SM-9.5D. This pilot project compared the performance of the mixtures through laboratory testing and evaluation. Expected field performance cannot be compared, however, because the pavement structures and traffic at each mixture location are not comparable.

The second pilot project was paved on State Route 87 in Henry County. This project was a BMD contract, so both the unmodified and aramid fiber-modified surface mixtures, mixtures 4 and 4F, respectively, were required to meet VDOT's 2022 *Special Provision for Surface Mixtures Designed Using Performance Criteria*. The project consisted of approximately two miles of two-lane pavement with shoulders having an approximate AADT value of 8,900 vehicles. The northbound lane was paved with the BMD SM-9.5D performance plus volumetric optimized (P+VO) mixture (mixture 4) that served as a control. The fiber-modified BMD SM-9.5 P+VO mixture (mixture 4F) was paved in the southbound lane. The two mixtures had the same design except for the addition of fibers. Prior to placement of the surface mixtures, the mainline and shoulders and connections were milled at depths of 5 inches and 2 inches, respectively, and a 3-inch layer of BM 25.0D was placed.

Materials

The mixtures evaluated in this study included volumetrically designed dense-graded surface mixtures designed in accordance with Section 211 of VDOT's *Road and Bridge Specifications* (VDOT, 2020) and BMD mixtures designed in accordance with VDOT's *Special Provision for Dense-graded Surface Mixtures Designed Using Performance Criteria*, found in the Appendix. Table 1 shows the performance-testing criteria for the BMD mixtures.

Table 1. Performance Testing Criteria

Distress	Test	Test Method	Specimens	Criteria
Durability	Cantabro test	AASHTO TP 108	3 replicates	Mass loss ≤ 7.5%
Rutting	APA test	AASHTO T 340	4 replicates	Rutting ≤ 8.0 mm
Cracking	IDT-CT test	ASTM D8225	5 replicates	CT index ≥ 70

APA = asphalt pavement analyzer; IDT-CT = indirect tensile cracking test.

Four pairs of mixtures were evaluated in this study. Each pair consisted of a non-fiber-modified mixture and a fiber-modified mixture. All fiber-modified mixtures were designed using the drop-in method, in which the fiber was added to the mixture after either volumetric design or BMD was performed with no additional modifications, based on standard practice and the manufacturer's recommendations.

Laboratory Testing and Evaluation

Mixture volumetric properties and gradation were determined for all mixtures from samples taken during production. Binder was sampled from producer tanks during production for performance grading. Binder from each plant-produced mixture was also extracted and recovered for performance grading. Testing in the Virginia Transportation Research Council (VTRC) laboratory was conducted on laboratory compacted specimens fabricated from reheated plant-produced loose mixture samples.

Design BMD test results were obtained for the two BMD mixtures paved in Salem District. Producer and VDOT Salem District production volumetrics and BMD test results were acquired for the mixtures paved in the Salem district. All production BMD testing was performed on non-reheated plant-produced laboratory compacted specimens.

Mixture Volumetric Properties and Gradations

The job mix formula provided mixture design information, including volumetric properties, gradation, and BMD test results. The producer performed all design and evaluation of design. VDOT's Materials Information Tracking System provided production data for volumetric properties and gradations.

The theoretical maximum specific gravity of each mixture was determined in accordance with AASHTO T 209, Standard Method of Test for Theoretical Maximum Specific Gravity (Gmm) and Density of Asphalt Mixtures. The asphalt binder content of each mixture was determined by the ignition method in accordance with AASHTO T 308, Standard Method of Test for Determining the Asphalt Binder Content of Asphalt Mixtures by the Ignition Method, and Virginia Test Method 102, Determination of Asphalt Content From Asphalt Paving Mixtures by the Ignition Method (VDOT, 2013). The size distribution (gradation) of the recovered aggregate was determined in accordance with AASHTO T 11, Standard Method of Test for Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing, and AASHTO T 27, Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates. Loose mixtures were conditioned at the compaction temperature and compacted to N_{design} gyrations using a Superpave gyratory compactor in accordance with AASHTO T 312, Preparing and Determining the Density of Asphalt Mixtures Specimens by Means of the Superpave Gyratory

Compactor. Additional properties such as bulk specific gravity (Gmb), voids in total mixture, voids in mineral aggregate, voids filled with asphalt, fines to aggregate ratio, aggregate effective specific gravity, aggregate bulk specific gravity, absorbed asphalt binder content, effective asphalt binder content, and effective film thickness were determined.

Cantabro Mass Loss Test

The Cantabro Mass Loss test was performed on mixtures to evaluate durability in accordance with AASHTO TP 108, Standard Method of Test for Abrasion Loss of Asphalt Mixture Specimens. Test specimens were compacted to N_{design} and tested in triplicate at 25±1°C.

Asphalt Pavement Analyzer Rut Depth

Testing was performed in accordance with AASHTO T 340, Determining Rutting Susceptibility of Hot Mix Asphalt (HMA) Using the Asphalt Pavement Analyzer (APA), using a test temperature of 64±0.5°C. An APA Junior test machine was used to perform two replicate tests consisting of two specimens each for each mixture. The test specimens were compacted to 7±0.5% air voids.

Indirect Tensile Cracking Test

Using dry specimens, testing at 25±0.5°C in accordance with ASTM D8225, Standard Test Method for Determination of Cracking Tolerance Index of Asphalt Mixture Using the Indirect Tensile Cracking Test (IDT-CT) at Intermediate Temperature. At least five replicate specimens compacted to 7±0.5% air voids were tested, although in cases of testing errors, results from only three or four replicates were considered.

Binder Performance Grading

Asphalt binder performance grading was performed in accordance with AASHTO M 320, Standard Specification for Performance-graded Asphalt Binder, and AASHTO M 332, Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test. Testing was performed on binders collected from contractor tanks during production and on extracted and recovered asphalt binders from the mixtures collected at the plant. Extraction of asphalt binder from collected mixtures was performed in accordance with AASHTO T 164, Quantitative Extraction of Asphalt Binder From Hot Mix Asphalt (HMA), Method A, using *n*-propyl bromide as the solvent. The asphalt binder was then recovered from the solvent using the Rotavap recovery procedure specified in AASHTO T 319, Quantitative Extraction and Recovery of Asphalt Binder From Asphalt Mixtures.

Difference in Critical Low Temperature Performance Grade (ΔTc)

The difference in critical low temperature PG limiting temperatures, commonly referred to as ΔTc, is a binder parameter that addresses cracking behavior affected by binder durability related to aging. It primarily indicates properties that can contribute to non-load-related cracking and other distresses related to aging and embrittlement. However, other forms of cracking may be indirectly related to the binder ΔTc (Asphalt Institute, 2019).

At least 10 agencies have adopted ΔTc requirements in specifications (Asphalt Institute, 2019). Of these agencies, five have requirements after 20-hour pressure-aging vessel (PAV) aging, ranging from a minimum of –2.0°C to –6.0°C (Asphalt Institute, 2019).

Equation 1 shows how ΔTc was calculated by subtracting the m-critical low temperature (Tc,m) from the S-critical low temperature (Tc,S) (FHWA, 2021). Both temperatures were determined using the bending beam rheometer in accordance with AASHTO T 313, Standard Method of Test for Determining the Flexural Creep Stiffness of Asphalt Binders Using the Bending Beam Rheometer (BBR). The m-critical low temperature (Tc,m) is the resulting low temperature at which the creep relaxation m-value at 60 seconds of loading is exactly equal to the specification value of 0.300. The S-critical low temperature (Tc,S) is the resulting low temperature at which the creep stiffness S-value at 60 seconds of loading is exactly equal to the specification value of 300 MPa.

$$\Delta T_c = T_{c,S} - T_{c,m} \quad \text{Equation 1}$$

RESULTS AND DISCUSSION

Loose mixture samples were collected during production to evaluate volumetric and gradation properties and for mechanical testing purposes.

Mixture Designs

Table 2 shows mixture designs for the control and fiber mixtures. The table shows that no adjustments were made to the mixture designs aside from the addition of fiber. As mentioned before, mixture 1 incorporated a polymer-modified binder and other mixtures used PG 64S-22 binder. Mixtures 1 and 1F used only 15% reclaimed asphalt pavement (RAP) in the mixture. However, mixtures 2, 2F, 3, and 3F incorporated 30% RAP in the mixture, and mixtures 4 and 4F had 26% RAP in the mix.

Table 2. Summary of Mix Designs

Properties	Mix 1	Mix 1F	Mix 2	Mix 2F	Mix 3	Mix 3F	Mix 4	Mix 4F
NMAS	12.5	12.5	12.5	12.5	9.5	9.5	9.5	9.5
RAP Content, %	15	15	30	30	30	30	26	26
Asphalt Type	64E-22	64S-22	64S-22	64S-22	64S-22	64S-22	64S-22	64S-22
Asphalt Content, %	5.6	5.6	5.5	5.5	5.8	5.8	6.0	6.0
Fiber	n/a	2.1 oz/ton	n/a	2.1 oz/ton	n/a	1 lb/ton	n/a	1 lb/ton
Fiber Type	n/a	Aramid	n/a	Aramid	n/a	Aramid	n/a	Aramid
Rice SG, Gmm	2.430	2.430	2.445	2.434	2.473	2.472	2.584	2.584
VTM, %	3.5	3.5	4.0	3.5	4.0	3.9	3.4	3.1
Sieve Size								
3/4 inch (19.0 mm)	100	100	100	100	100	100	100	100
1/2 inch (12.5 mm)	99	99	96	96	100	100	100	100
3/8 inch (9.5 mm)	90	90	87	87	92	92	95	95

Properties	Mix 1	Mix 1F	Mix 2	Mix 2F	Mix 3	Mix 3F	Mix 4	Mix 4F
No. 4 (4.75 mm)	58	58	59	59	58	58	67	67
No. 8 (2.36 mm)	43	43	42	42	39	39	41	41
No. 30 (0.6 mm)	23	23	20	20	23	23	-	-
No. 200 (0.075 mm)	5.7	5.7	4.7	4.7	6.4	6.4	4.9	4.9

n/a = not applicable; – = data not available. NMAS = nominal maximum aggregate size; RAP = reclaimed asphalt pavement; SG = specific gravity; VTM = voids in total mix.

Laboratory Testing and Evaluation

Volumetric Properties and Gradations

Table 3 shows the volumetric properties and gradations from loose mixture samples collected during production for mixtures 1, 1F, 2, and 2F. Table 4 shows the same information for mixtures 3, 3F, 4, and 4F and includes VDOT and producer data. For mixture 3, nearly a month lapsed from the time of paving and sampling the location considered as the control to when the sample for VTRC was collected. Because of this time difference, Table 4 shows the producer result from the closest date to the VTRC sample date, and the change in the control mixture volumetrics over time is evident. Several differences between the control and fiber mixtures are evident. Although design asphalt contents were the same, fiber mixtures were produced with less binder than control mixtures for all pairs of mixtures except mixtures 3 and 3F. This difference was not expected, and no explanation was found for any of the mixtures; this difference in binder content has considerable effects on further test results. Mixture pairs 1, 2, and 4 show a corresponding drop in voids filled with asphalt, effective binder content, and effective film thickness for the fiber mix as the asphalt content drops. The gradations of corresponding control and fiber production mixtures for all projects were comparable.

Table 3. VTRC Volumetric Properties and Gradations for Mixtures 1, 1F, 2, and 2F

Properties	Mix 1	Mix 1F	Mix 2	Mix 2F
NMAS, mm	12.5	12.5	12.5	12.5
Binder	PG 64E-22	PG 64S-22	PG 64S-22	PG 64S-22
RAP Content, %	15	15	30	30
Asphalt Content, %	5.8	5.3	5.9	5.7
Maximum Theoretical SG, Gmm	2.457	2.463	2.430	2.439
VTM, %	3.9	4.4	2.0	2.7
VMA, %	17.1	16.5	15.6	15.8
VFA, %	77.0	73.6	86.9	83.2
FA Ratio	1.01	1.24	0.93	0.96
Bulk SG, Gmb	2.360	2.355	2.381	2.374
Effective SG, Gse	2.684	2.672	2.656	2.659
Aggregate Bulk SG, Gsb	2.683	2.671	2.655	2.658
Absorbed Binder (Pba), %	0.01	0.01	0.01	0.01
Effective Binder Content (Pbe), %	5.7	5.3	5.9	5.7
Effective Film Thickness (Fbe), mm	10.3	8.8	10.9	10.4
Sieve Size				
3/4 inch (19.0 mm)	100.0	100.0	99.6	99.3
1/2 inch (12.5 mm)	98.1	98.4	94.9	95.6

Properties	Mix 1	Mix 1F	Mix 2	Mix 2F
3/8 inch (9.5 mm)	89.1	89.8	86.9	87.9
No. 4 (4.75 mm)	56.5	58.1	56.6	57.7
No. 8 (2.36 mm)	42.8	41.6	39.3	39.9
No. 16 (1.18 mm)	32.2	29.6	28.6	29.1
No. 30 (0.6 mm)	22.0	20.6	19.6	20.0
No. 50 (0.3 mm)	12.3	14.0	13.0	13.3
No. 100 (0.15 mm)	8.0	9.5	8.5	8.6
No. 200 (0.075 mm)	5.8	6.6	5.5	5.5

FA = fines to asphalt; NMAS = nominal maximum aggregate size; PG = performance grade; RAP = reclaimed asphalt pavement; SG = specific gravity; VFA = voids filled with asphalt; VMA = voids in mineral aggregate; VTM = voids in total mixture.

Table 4. Volumetric Properties and Gradations for Mixtures 3, 3F, 4, and 4F. Producer and VDOT Results are for Matching Samples.

Properties	Mix 3				Mix 3F			Mix 4			Mix 4F		
	Producer	VDOT	Producer	VTRC	Producer	VDOT	VTRC	Producer	VDOT	VTRC	Producer	VDOT	VTRC
NMAS, mm	9.5				9.5			9.5			9.5		
Binder	PG 64S-22				PG 64S-22			PG 64S-22			PG 64S-22		
RAP Content, %	30				30			26			26		
Sample Date	8/22/22		9/18/22	9/19/22	7/11/22			12/1/22			12/10/22		12/11/22
Extraction Asphalt Content, %	–	–	–	5.4	–	–	5.3	–	–	6.4	–	–	5.6
Ignition Asphalt Content, %	4.6	5.0	6.1	6.1	5.8	5.7	5.9	6.8	6.6	6.5	5.74	5.47	6.0
Maximum Theoretical SG, Gmm	2.495	2.494	2.442	2.440	2.451	2.457	2.456	2.564	2.543	2.569	2.593	2.593	2.596
VTM, %	5.2	5.3	2.4	1.1	1.3	1.4	1.5	1.8	1.6	4.0	3.7	4.3	5.5
VMA, %	15.6	16.6	16.3	15.4	14.8	14.9	15.4	16.9	16.0	18.1	16.1	15.9	18.2
VFA, %	67.0	68.0	85.0	92.7	91.0	91.0	90.3	89.0	90.0	77.9	77.0	73.0	69.7
Dust/AC Ratio	1.80	1.2	0.90	0.86	1.00	1.00	1.02	1.00	1.00	0.95	1.10	1.20	1.01
Bulk SG, Gmb	2.365	2.362	2.384	2.413	2.419	2.422	2.420	2.518	2.502	2.466	2.496	2.493	2.453
Effective SG, Gse	–	–	–	2.680	–	–	2.692	–	–	2.868	–	–	2.873
Aggregate Bulk SG, Gsb	–	–	–	2.678	–	–	2.691	–	–	2.814	–	–	2.819
Absorbed Binder (Pba), %	–	–	–	0.03	–	–	0.01	–	–	0.69	–	–	0.69
Effective Binder Content (Pbe), %	4.5	4.9	6.1	6.1	5.6	5.7	5.9	6.2	5.9	5.9	5.1	4.8	5.3
Effective film thickness (Fbe), mm	–	–	–	11.7	–	–	10.3	–	–	9.5	–	–	8.4
Sieve Size													
3/4 inch (19.0 mm)	100	100	100	99	100	100	100	100	100	100	100	100	100
1/2 inch (12.5 mm)	100	100	99	99	100	99	99	100	100	100	100	100	100
3/8 inch (9.5 mm)	92	93	90	87	89	89	91	99	98	98	97	95	96
No. 4 (4.75 mm)	53	60	55	51	54	54	55	70	69	69	69	65	68
No. 8 (2.36 mm)	41	46	43	38	42	40	41	46	45	45	47	45	46
No. 16 (1.18 mm)	35	40	35	32	34	32	34	34	33	33	35	34	34
No. 30 (0.6 mm)	26	30	26	24	25	24	25	26	25	25	27	26	27
No. 50 (0.3 mm)	17	15	13	12	14	13	13	19	18	18	19	19	18
No. 100 (0.15 mm)	11	15	7	7	8	13	8	11	18	10	10	19	10
No. 200 (0.075 mm)	8.0	5.9	5.4	5.2	5.9	5.9	6.0	6.0	5.7	5.6	5.5	5.7	5.4

– = data not available. FA = fines to asphalt; NMAS = nominal maximum aggregate size; PG = performance grade; RAP = reclaimed asphalt pavement; SG = specific gravity; VFA = voids filled with asphalt; VMA = voids in mineral aggregate; VTM = voids in total mixture.

Cantabro Mass Loss

Figure 1 shows mass losses. Only mixtures 4 and 4F were designed to meet mass loss criteria. As Table 5 shows, mixtures 1F and 4F had the highest average mass loss values, which were significantly different from their paired control mixtures, 1 and 4, respectively. The differences in performance for these pairs of mixtures are likely related to the differences in binder content (0.5% for each pair of mixtures) and film thickness. No difference in average mass loss was seen between mixtures 2 and 2F or mixtures 3 and 3F. These pairs of mixtures had only 0.2% difference in binder content during production. Design mass loss results for mixtures 4 and 4F indicate that although the design and reheat mass loss values for mixture 4 were similar, the design and reheat results for mixture 4F were drastically different. Producer and VDOT mass loss data are shown for mixtures 4 and 4F specimens fabricated from non-reheated plant-produced loose mixture and show the difference in mass loss between specimens fabricated from non-reheated and reheated loose mixtures.

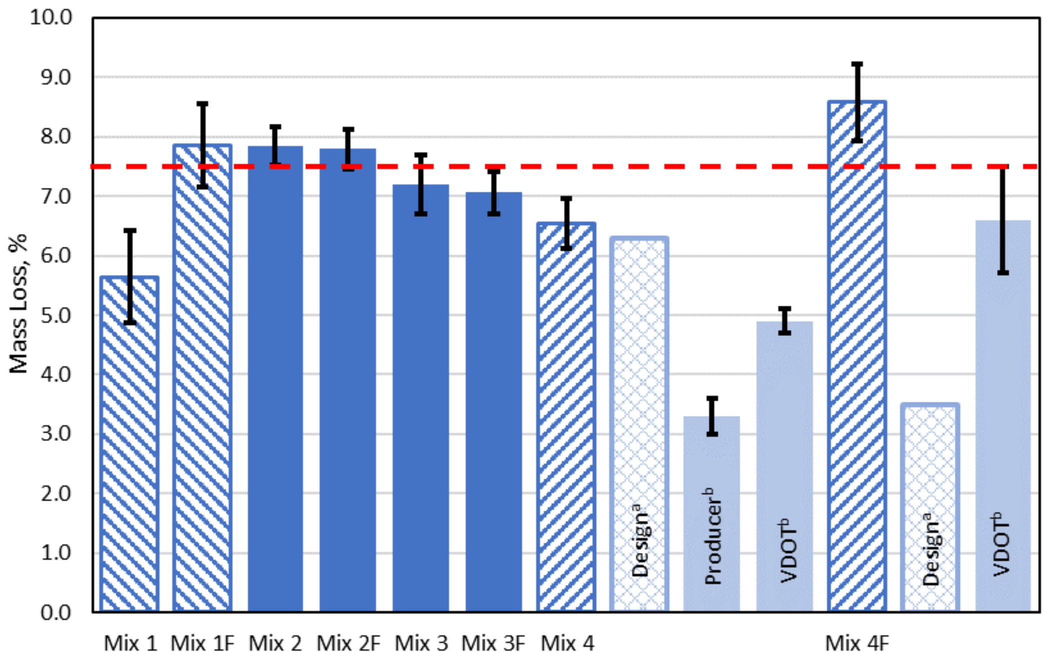

Figure 1. Mass Loss Results. I-bars indicate one standard deviation. Red dashed line represents VDOT's balanced mix design maximum mass loss criterion. Striped pairs of mixtures indicate statistically significant difference between the control and fiber-modified mixtures in the pair. [a] Design testing was performed on specimens fabricated from lab-produced loose mixture; variability of test result was not available. [b] Production and VDOT testing was performed on specimens fabricated from non-reheated plant-produced loose mixture.

The differences in air void contents were also considered for the reheat test results. Significant differences were seen only for mixtures 2 and 2F and mixtures 4 and 4F (Table 5). However, these differences appear to have less influence on the mass loss than the difference in binder content. Figure 2 shows the relationship between air voids and mass loss for each of the mixtures. The highest variability in air voids is seen for mixtures 1 and 1F, which likely contributes to the significant differences in mass loss seen for these mixtures.

Table 5. Mass Loss Test Results

Replicate		Air Voids 1	Air Voids 2	Air Voids 3	Air Voids Avg.	Air Voids St. Dev.	Air Voids *p*-value	Mass Loss, % 1	Mass Loss, % 2	Mass Loss, % 3	Mass Loss, % Avg.	Mass Loss, % St. Dev.	Mass Loss, % *p*-value
Mix 1	Reheat	3.7	3.9	4.2	3.9	0.23	0.0846	4.8	6.4	5.7	5.6	0.8	0.0213
Mix 1F	Reheat	4.3	4.3	4.5	4.4	0.09		7.1	8.3	8.2	7.9	0.7	
Mix 2	Reheat	1.9	2.0	2.2	2.0	0.15	0.0298	7.9	8.1	7.5	7.8	0.3	0.8766
Mix 2F	Reheat	2.7	2.7	2.6	2.6	0.03		8.1	7.8	7.5	7.8	0.3	
Mix 3	Reheat	1.0	1.2	1.2	1.1	0.07	0.9432	7.7	6.7	7.2	7.2	0.5	0.7073
Mix 3F	Reheat	1.1	1.1	1.2	1.1	0.04		7.5	6.9	6.8	7.1	0.4	
Mix 4	Reheat	2.3	2.4	2.5	2.4	0.07	0.0059[a]	6.1	6.6	6.9	6.5	0.4	0.0193[a]
	Design[b]	–	–	–	–	–		–	–	–	6.3	–	
	Producer[c]	–	–	–	–	–		–	–	–	3.3	0.3	
	VDOT[c]	–	–	–	–	–		–	–	–	4.9	0.2	
Mix 4F	Reheat	1.5	1.5	1.8	1.6	0.14		7.9	8.7	9.2	8.6	0.6	
	Design[b]	–	–	–	–	–		–	–	–	3.5	–	
	VDOT[c]	–	–	–	–	–		–	–	–	6.6	0.9	

[a] *p*-value shown for comparison of reheat values for Mix 4 and 4F. [b] Design testing was performed on specimens fabricated from lab-produced loose mixture; variability of test result was not available. [c] Production and VDOT testing was performed on specimens fabricated from non-reheated plant-produced loose mixture. – = data not available; Avg. = average; St. Dev. = standard deviation.

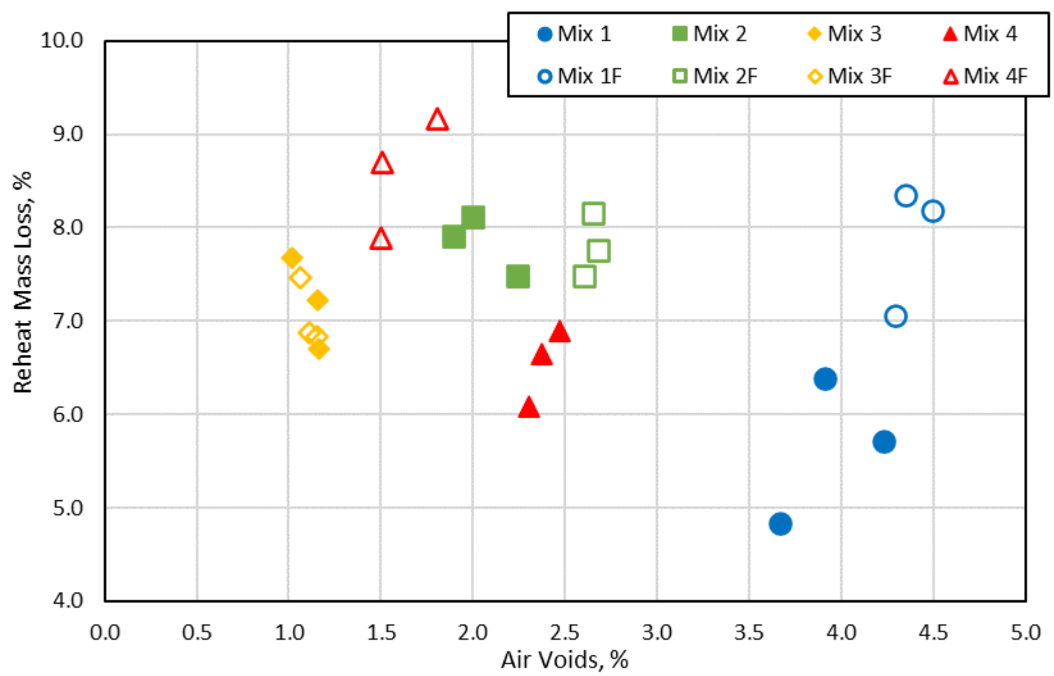

Figure 2. Reheat Mass Loss versus Air Voids

Indirect Tensile Cracking Test

IDT-CT testing was conducted to evaluate cracking potential of the mixtures. Three fiber mixtures had lower CT index values than their control mixture, although the difference was statistically significant for only one pair of mixtures, 1 and 1F (Figure 3). However, mixture 1 used a polymer-modified binder (PG 64E-22) compared with mixture 1F, which used PG 64S-22 binder. Additionally, mixtures 1 and 1F had only 15% RAP in the mix. Figure 3 shows design CT index results for mixtures 4 and 4F, and producer and VDOT CT index results on specimens fabricated from non-reheated loose mixture. Producer and VDOT results from mixture 4 were similar to the reheat results, although the design value was much lower. In contrast, reheat results for mixture 4F were considerably higher results than the design, producer, or VDOT values.

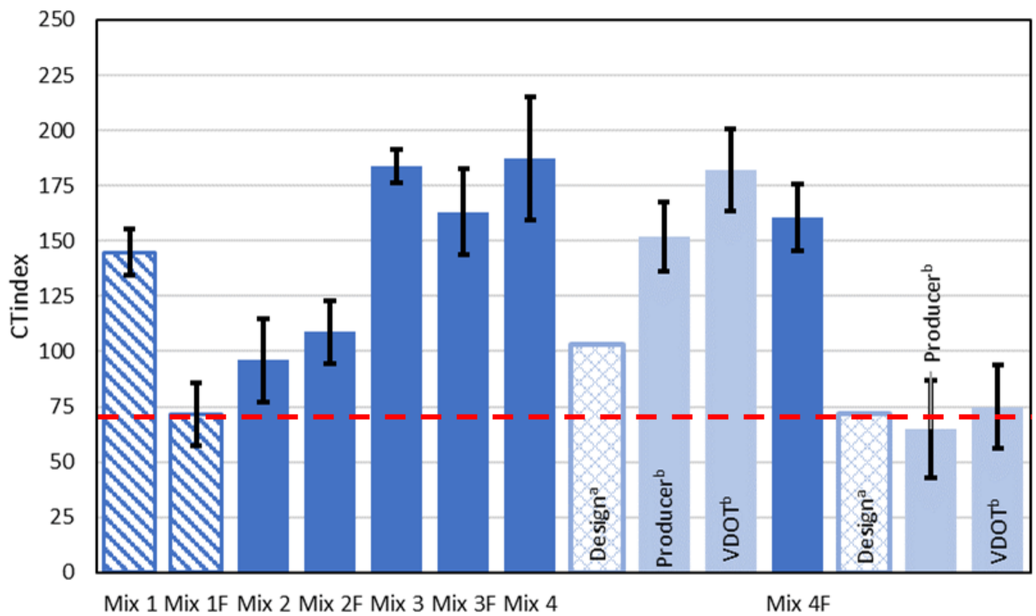

Figure 3. CT index Results. I-bars indicate one standard deviation. Red dashed line represents VDOT's balanced mix design minimum CT index criterion. Striped pairs of mixtures indicate statistically significant difference between the control and fiber-modified mixtures in the pair. [a] Design testing was performed on specimens fabricated from lab-produced loose mixture; variability of test result was not available. [b] Production and VDOT testing was performed on specimens fabricated from non-reheated plant-produced loose mixture. CT = cracking tolerance.

Further evaluation of the IDT strength for each pair of mixtures found that differences were statistically significant for three of the four mixture pairs (Figure 4). Significantly higher strengths were seen for the fiber mixtures from mixture pairs 1 and 1F and 3 and 3F. The fiber mixtures for pairs 2 and 2F and 4 and 4F showed lower strengths than the control mixture, although the difference was significant for mixture pair 4 and 4F only. These results contradict the claims that fibers can improve cracking resistance (Al-Hosainat et al., 2023; McDaniel, 2015). For mixtures 4 and 4F, the significant decrease in strength may be related to the decrease in asphalt content seen during production of mixture 4F. The addition of fibers for improved cracking resistance cannot make up for insufficient binder content.

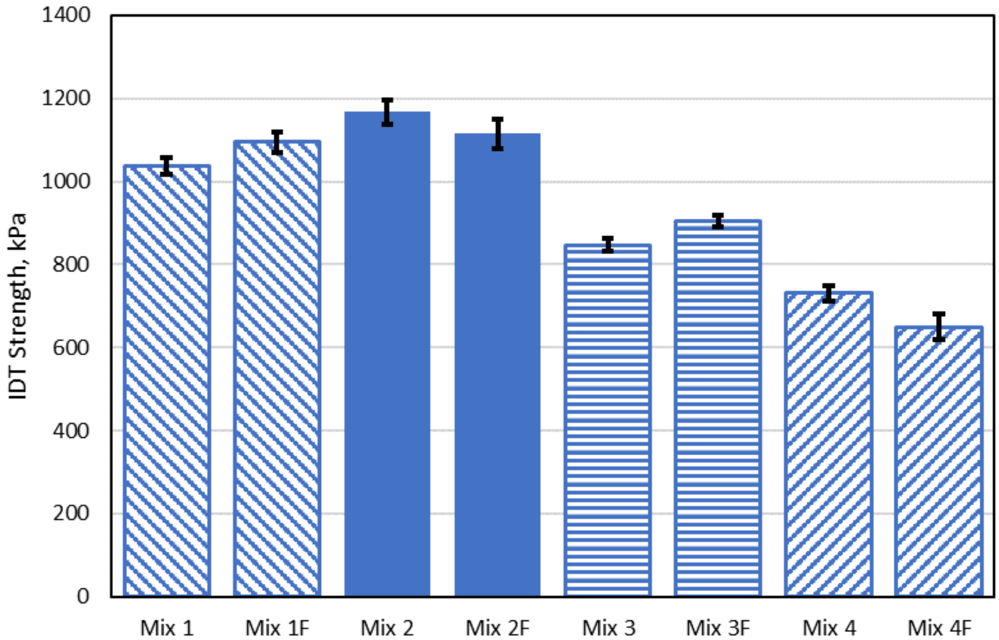

Figure 4. Indirect Tensile Strength Results. I-bars indicate one standard deviation. Striped pairs of mixtures indicate a statistically significant difference between the control and fiber-modified mixtures in the pair.

Asphalt Pavement Analyzer Rut Depth

Rut testing using the APA Junior was performed only for a subset of mixtures because rutting is rarely seen in Virginia mixtures (Table 6). All mixtures tested showed acceptable rutting resistance. Mixture 2F had a higher rut depth than mixture 2; the difference was not statistically significant. The average rut depths for mixtures 4 and 4F were the same.

Table 6. Asphalt Pavement Analyzer Rut Test Results

Replicate		1	2	Average	Standard Deviation	*p*-value
Mix 1	Reheat	–	–	–	–	–
Mix 1F	Reheat	2.6	2.9	2.7	0.2	–
Mix 2	Reheat	3.6	4.1	3.8	0.3	0.5237
Mix 2F	Reheat	3.6	4.7	4.2	0.8	
Mix 3	Reheat	–	–	–	–	–
Mix 3F	Reheat	–	–	–	–	–
Mix 4	Reheat	4.9	6.7	5.8	1.2	0.8891[a]
	Design[b]	–	–	2.2	–	
Mix 4F	Reheat	5.0	6.5	5.8	1.1	
	Design[b]	–	–	3.2	–	

[a] *p*-value shown for comparison of reheat values for Mix 4 and 4F. [b] Design testing was performed on specimens fabricated from lab-produced loose mixture; variability of test result was not available. "–" = data not available.

Binder Performance Grading

Binder grading was performed on all but one of the virgin binders used in each mixture. In addition, binder was extracted and recovered from loose mixture samples of all mixtures. Table 7 shows the results for mixtures 1, 1F, 2, and 2F. Table 8 presents the remaining results.

Table 7. Binder Properties for Mixtures 1, 1F, 2, and 2F

Property		Mix 1		Mix 1F		Mix 2		Mix 2F	
		Virgin	Recovered	Virgin	Recovered	Virgin	Recovered	Virgin[a]	Recovered
Dynamic Shear, 10 rad/sec, Specification: |G*|/sinδ > 1.00 kPa									
Orig. |G*|/sin δ, kPa	64°C	3.862	–	1.402	–	1.608	–	1.608	–
	70°C	2.139	–	0.656	–	0.748	–	0.748	–
	76°C	1.213	–	–	–	–	–	–	–
	82°C	0.704	–	–	–	–	–	–	–
Original Failure Temperature, °C		**78.17**	–	**66.67**	–	**67.72**	–	67.72	–
Rolling Thin Film Oven Residue AASHTO 240, Mass Loss < 1.00%									
RTFO Mass Loss		– 0.047	–	0.259	–	0.09%	–	0.09%	–
Dynamic Shear, 10 rad/sec, Specification: |G*|/sinδ > 2.20 kPa									
RTFO |G*|/sin δ, kPa	64°C	–	3.393	3.009	6.586	3.414	8.617	3.414	6.483
	70°C	4.033	1.889	1.360	2.924	1.539	3.949	1.539	3.005
	76°C	2.292	–	–	1.356	–	1.892	–	1.444
	82°C	1.322	–	–	–	–	–	–	–
RTFO Failure Temperature, °C		**76.5**	**68.44**	**66.37**	**72.27**	**67.31**	**74.75**	**67.31**	**72.59**
Dynamic Shear, 10 rad/sec, Specification: |G*|.sinδ < 5,000 kPa									
PAV |G*|.sin δ, kPa	19°C	5084	–	–	–	–	–	–	
	22°C	3499	4462	5541	6956	5505	–	5505	
	25°C	2356	3046	3816	4966	3720	5569	3720	6460
	28°C	–	2046	–	3476	–	3902	–	4508
PAV Failure Temperature, °C		**19.16**	**21.03**	**22.83**	**24.35**	**22.74**	**25.91**	**22.74**	**27.14**
Creep Stiffness, 60 sec, Specification: Stiffness (S) < 300 MPa and m-value > 0.300									
Stiffness (S), MPa	– 6°C	–	–	73.58	82.39	–	98.47	–	107.65
	– 12°C	127.72	125.84	141.56	179.19	181.01	200.42	181.01	206.20
	– 18°C	255.44	285.62	–	–	285.46	–	285.46	–
m-value	– 6°C	–	–	0.370	0.324	–	0.352	–	0.336
	– 12°C	0.316	0.336	0.281	0.285	0.319	0.285	0.319	0.280
	– 18°C	0.295	0.281	–	–	0.234		0.234	–
Stiffness Failure Temperature (Ts), °C		– 20.1	– 18.5	– 26.0	– 19.5	– 18.8	– 17.9	– 18.8	– 17.7
m-value Failure Temperature (Tm), °C		– 16.6	– 15.9	– 10.7	– 9.7	– 13.3	– 10.7	– 13.3	– 9.9
$\Delta Tc = T_{c,S} – T_{c,m}$, °C		– 3.5	– 2.6	– 15.3	– 9.8	– 5.5	– 7.2	– 5.5	– 7.9
PAV Low Failure Temperature, °C		**– 26.6**	**– 25.9**	**– 20.7**	**– 19.7**	**– 23.3**	**– 20.7**	**– 23.3**	**– 19.9**
PG (AASHTO M 320)		**76-22**	**64-22**	**64-16**	**70-16**	**64-22**	**70-16**	**64-22**	**70-16**
Multiple Stress Creep Recovery Test at 64°C									
J_{nr} kPa-1	0.1 kPa	1.22	0.75	2.97	1.21	2.66	0.81	2.66	1.24
	3.2 kPa	2.00	1.22	3.17	1.32	2.89	0.90	2.89	1.36
J_{nrdiff}	max 0.75	0.64	0.63	0.07	0.09	0.09	0.11	0.09	0.10
Avg. % Recovery, %	0.1 kPa	57.24	50.66	3.30	8.68	4.64	16.62	4.64	9.55
	3.2 kPa	36.26	33.06	1.16	3.98	1.33	9.66	1.33	4.61
PG (AASHTO M 322)		**64H-22**	**64H-22**	**64S-16**	**64H-16**	**64S-22**	**64H-16**	–	**64H-16**

[a] Same virgin binder was used for mixtures 2 and 2F. – = data not available. PAV = pressure-aging vessel.

Table 8. Binder Properties for Mixtures 3, 3F, 4, and 4F

Property		Mix 3		Mix 3F		Mix 4		Mix 4F	
		Virgin	Recovered	Virgin	Recovered	Virgin	Recovered	Virgin	Recovered
Dynamic Shear, 10 rad/sec, Specification: |G*|/sinδ > 1.00 kPa									
Orig. |G*|/sin δ, kPa	64°C	1.054	–	1.213	–	1.265	–	1.251	–
	70°C	0.506	–	0.576	–	0.602	–	0.598	–
Original Failure Temperature, °C		**65.43**	–	**65.55**	–	**65.9**	–	**65.82**	–
Rolling Thin Film Oven Residue AASHTO 240, Mass Loss < 1.00%									
RTFO Mass Loss		– 0.29%	–	0.23%	–	– 0.13%	–	– 0.26%	–
Dynamic Shear, 10 rad/sec, Specification: |G*|/sinδ > 2.20 kPa									
	58°C	–	–	–	–	–	3.351	–	–
RTFO |G*|/sin δ, kPa	64°C	2.897	4.215	3.239	4.374	2.969	1.505	3.236	3.843
	70°C	1.321	1.983	1.474	2.089	1.364	–	1.474	1.814
RTFO Failure Temperature, °C		**66.1**	**69.17**	**66.95**	**69.58**	**66.31**	**61.15**	**66.94**	**68.46**
Dynamic Shear, 10 rad/sec, Specification: |G*|.sinδ < 5,000 kPa									
PAV |G*|.sin δ, kPa	19°C	6956	–	–	–	–	5964	–	6154
	22°C	4984	–	5259	–	5292	4257	5793	4454
	25°C	3495	3867	3745	5379	3725	2980	4117	3160
	28°C	–	2703	–	3829	–	2041	–	–
PAV Failure Temperature, °C		**21.91**	**22.72**	**22.45**	**25.73**	**22.49**	**20.57**	**23.29**	**20.9**
Creep Stiffness, 60 sec, Specification: Stiffness (S) < 300 MPa and m-value > 0.300									
	– 6°C	93.48	–	80.73	83.31	68.52	–	66.81	52.58
Stiffness (S), MPa	– 12°C	174.66	138.39	150.76	157.21	134.77	109.61	148.83	112.81
	– 18°C	–	305.89	–	–	–	215.37	–	222.58
	– 6°C	0.322	–	0.319	0.341	0.351	–	0.327	0.357
m-value	– 12°C	0.265	0.313	0.282	0.288	0.278	0.340	0.274	0.335
	– 18°C	–	0.264	–	–	–	0.279	–	0.272
Stiffness Failure Temperature (Ts), °C		– 21.3	– 17.8	– 24.8	– 23.6	– 27.0	– 22.8	– 23.1	– 23.7
m-value Failure Temperature (Tm), °C		– 8.3	– 13.6	– 9.1	– 10.6	– 10.2	– 15.9	– 9.1	– 14.8
PAV Low Failure Temperature, °C		**– 18.3**	**– 23.6**	**– 19.1**	**– 20.6**	**– 20.2**	**– 25.9**	**– 19.1**	**– 24.8**
$\Delta Tc = T_{c,S} – T_{c,m}$, °C		– 12.9	– 4.2	– 15.7	– 13.0	– 16.8	– 6.9	– 14.0	– 8.9
PG (AASHTO M 320)		64-16	64-22	64-16	64-16	64-16	58-22	64-16	64-22
Multiple Stress Creep Recovery Test at 64°C									
J_{nr} kPa-1	0.1 kPa	3.05	1.80	2.72	1.66	3.08	–	2.76	2.17
	3.2 kPa	**3.35**	**2.03**	**2.98**	**1.98**	**3.35**	**–**	**2.98**	**2.45**
J_{nrdiff}	max 0.75	0.10	0.13	0.09	0.19	0.09	–	0.08	0.13
Avg. % Recovery, %	0.1 kPa	4.51	7.82	4.65	9.60	3.64	–	3.60	6.88
	3.2 kPa	1.23	2.81	1.52	3.13	1.16	–	1.29	2.32
PG (AASHTO M 322)		64S-16	64S-22	64S-16	64H-16	64S-16	–	64S-16	64S-22

– = data not available. PAV = pressure-aging vessel.

Mixture 1 was designed using PG 64E-22 binder. However, the virgin binder testing for mixture 1 indicates that a PG64H-22 binder was used whereas the recovered binder testing indicated that the binder remained a 64H-22 after recovery. Mixture 1F was designed with a PG 64S-22 binder, although virgin binder grading indicated that it met PG64S-16 requirements; recovered binder was stiffened and graded as PG 64H-16.

All other mixtures were designed using PG64S-22 binder. Virgin binder grading for mixture 2 showed that PG 64S-22 binder was used, although the virgin binders for mixtures 3, 3F, 4, and 4F graded as PG 64S-16 binders.

Recovered binders for mixtures 2 and 2F indicated that stiffening occurred because the binders were PG 64H-16. Recovered binder from mixtures 3 and 4F graded as PG 64S-22, and the recovered binder from mixture 4F graded as PG 64H-16. The recovered binder from mixture 3F graded as a PG 58-28. This grade may be because of lower stiffness from RAP binder (less aged RAP).

Difference in Critical Low Temperature Performance Grade (ΔTc)

Tables 7 and 8 present the 20-hour PAV ΔTc values for the virgin and recovered binders. All binders had negative ΔTc values, indicating m-controlled behavior. The ΔTc values for all binders in this study ranged from −2.6°C to −16.8°C. Only two virgin binders and two recovered binders, both from non-fiber-modified control mixtures, did not exceed the –6.0°C minimum adopted by several states. After recovery, the ΔT_c values improved for all mixtures except mixture 2. In comparing the control to fiber mixtures, ΔT_c was found to worsen for every fiber mixture pair, both for the virgin and recovered binders.

Balanced Mix Design Analysis

To examine the change in balance for each mixture pair, the rut depth versus the CT index was plotted (Figure 5). Because APA rut testing was not performed for mixtures 1, 3, and 3F, those values are not available. Mixture 1F shows bias toward rutting resistance because it has a very low rut depth and barely passes the CT index criterion. Mixtures 2 and 2F show the desired improvement in cracking resistance as VDOT BMD rutting criterion. Mixtures 4 and 4F show the opposite of the intended effect of adding fibers because mixture 4F had a decreased CT index. This decrease is likely because of the reduced binder content during production.

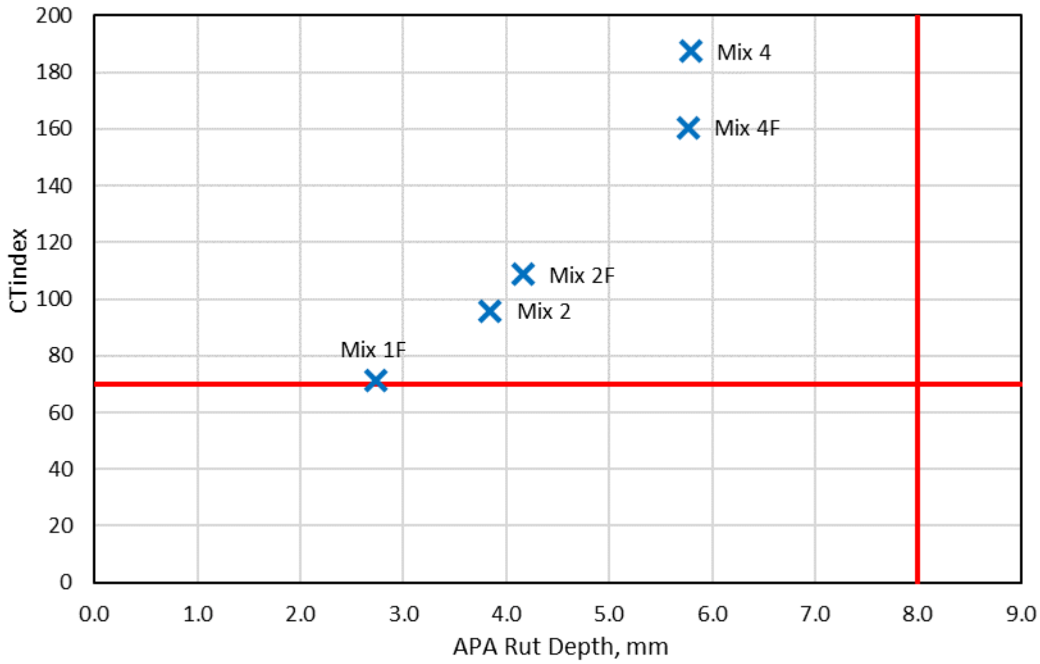

Figure 5. CT index versus Rut Depth

CONCLUSIONS

- *For most of the mixtures evaluated, the addition of fibers did not improve performance test results compared with the test results of the control mixtures because of reductions in production binder content from the design binder content.*
- *Mass loss, CT index, and IDT strength appeared most influenced by effective binder content and film thickness.*
- *Further evaluation of ΔT_c, including field verification of mixtures with and without cracking, must be performed with additional binders and projects.*
- *Volumetric and BMD test results indicated that fiber-modified mixtures should be designed and optimized based on performance criteria.*
- *Long-term field performance of these mixtures must be evaluated to determine the relative performance of the control and fiber-modified mixtures under field conditions.*

RECOMMENDATIONS

1. *VDOT's Materials Division should require that fiber-modified asphalt mixtures be designed using BMD.*

2. *VDOT's Materials Division and VTRC should continue to evaluate the potential benefits of fiber-modified asphalt mixtures to resist cracking when mixtures are properly designed and produced.*

IMPLEMENTATION AND BENEFITS

The researchers and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

With regard to Recommendation 1, VDOT's Materials Division will work with VTRC and industry to modify current BMD specifications or develop a draft special provision requiring fiber-modified mixtures to be designed using the BMD process. This work will be completed by December 2026.

With regard to Recommendation 2, VDOT's Materials Division and VTRC will collaborate to continue evaluating the potential benefits of fiber-modified mixtures. A research needs statement to evaluate fiber-modified mixtures for reflective cracking resistance was presented to the Pavements Research Advisory Committee for rating in the fall of 2023. A field project using fiber-modified mixtures over jointed concrete was completed in the summer of 2024.

Benefits

Implementing Recommendation 1 will ensure that asphalt mixtures incorporating fibers are properly designed to optimize the performance-enhancing characteristics of the fibers so that the in-service performance benefits can be further evaluated and maximized for future efforts.

Implementing Recommendation 2 will allow accurate characterization of the potential benefits of fiber-modified asphalt mixtures. Once the benefits are verified and quantified, fiber-modified mixtures can be applied to appropriate locations so that their benefits can be utilized for improved pavement performance.

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APPENDIX: 2022 SPECIAL PROVISION FOR BALANCED MIX DESIGN (BMD) SURFACE MIXTURES DESIGNED USING PERFORMANCE CRITERIA

SQ315-000200-01

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR

Balanced Mix Design (BMD) Surface Mixtures Designed using Performance Criteria

October 26, 2021

I. Description

This Specification covers the requirements and materials used to produce surface mixtures designed using performance criteria. Balanced Mix Design (BMD) surface mixtures shall be designed, produced, and placed as required by this Special Provision and Sections 211 and 315 of the Specifications.

II. Materials

All materials shall conform to Section 211.02 of the Specifications with the exception that Recycled Asphalt Shingles (RAS) will not be allowed in these mixes.

III. Job-Mix Formula (JMF)

Mix Types SM-9.5A, SM-9.5D, SM-12.5A, and SM-12.5D shall be designed to meet the Performance + Volumetric Optimized (BMD P+VO) criteria included in this section. Each mix type used shall conform to Section 211 of the Specifications. The Contractor shall submit the mix design at least 30 days before the mix is produced. Approval from the Engineer is required if the Contractor uses a PG binder grade not recommended by Table II-14A of Section 211 of the Specifications.

Type Performance + Volumetric Optimized (BMD P+VO) asphalt mixtures shall be designed to conform to Section 211.03 of the Specifications as well as Table 1 herein, except that the following table shall replace Table II-13 in Section 211.03 of the Specifications:

Asphalt Concrete Mixtures: Design Range

Mix Type	Percentage by Weight Passing Square Mesh Sieves							
	¾ in	**½ in**	**3/8 in**	**No. 4**	**No. 8**	**No. 30**	**No. 50**	**No. 200**
SM-9.5 A,D		100[1]	90-100	90 max.	32-67			2-10
SM-12.5 A,D	100	90-100	90 max.		28-58			2-10

The design binder content should be selected at 3.0% - 4.5% air voids. Design type shall be “BMD P+VO” when submitting the mix design.

This mix shall conform to Table 1 at the design binder content.

The results of supplementary performance testing at different binder contents (informational purposes) in addition to the design binder content shall be reported as follows:

- APA rut testing (AASHTO T 340): at design binder content and at 0.5% above the design binder content
- Cantabro testing (AASHTO TP 108): at design binder content and at 0.5% below the design binder content
- CT_{index} testing (ASTM D8225): at design binder content, at 0.5% above, and at 0.5% below the design binder content

The minimum design asphalt contents shall be based on the following unless otherwise approved by the Engineer:

Bulk Specific Gravity of the Total Aggregate	Minimum Design AC Content Mix Type (%)	
	SM-9.5	SM-12.5
Less Than 2.65	5.5	5.3
2.65 - 2.74	5.4	5.2
2.74 - 2.85	5.3	5.1
Greater Than 2.85	5.2	5.0

For the BMD P+VO mixtures, a set of 5 CT_{index} pills with the final design JMF (only at the design binder content) shall be fabricated from long-term aged loose mix and tested in accordance with ASTM D8225. Test results shall be submitted with the JMF for the mix design review. Long-term aging shall be performed by aging loose laboratory produced mix for 8 hours at 135ºC, after short term oven aging is performed as required by Table 1. During long-term aging, the mix shall be uniformly placed in a pan such that the height of the loose mix shall not exceed the mixture nominal max aggregate size. Opening of the oven door shall be minimized during long-term aging. Specimens shall be heated to compaction temperature following aging and then compacted. The heating to compaction temperature shall not exceed 75 minutes.

The JMF shall meet the nominal max aggregate size of the designated mix type. The JMF shall establish a single percentage of aggregate passing each required sieve, a single percentage of liquid asphalt material to be added to the mix, the Superpave volumetric properties defined by AASHTO R 35 and a temperature at which the mixture is to be produced.

Table 1. Performance Testing Requirements

Test	Requirements	Criteria
AASHTO T 340 Method Of Test For Determining Rutting Susceptibility Of HMA Using The Asphalt Pavement Analyzer (APA)	• Testing shall be performed at 64ºC. • 4 gyratory pills: 150 mm dia., 75 ± 2 mm ht. • Compact to 7±0.5% air voids. • Lab-produced mix: Condition loose mix for 2 hours at the design compaction temperature before compacting.	Rutting ≤ 8.0mm

Test	Requirements	Criteria
	• Plant-produced mix: Minimize any cooling, bring mix to the compaction temperature, and compact immediately.	
AASHTO TP 108 Standard Method of Test for Determining the Abrasion Loss of Asphalt Mixture Specimens (Cantabro)	• 3 gyratory pills: 150 mm dia., 115 ± 5 mm ht. • Compact to N_{design}, report air voids. • Lab-produced mix: Condition loose mix for 2 hours at the design compaction temperature before compacting. • Plant-produced mix: Minimize any cooling, bring mix to the compaction temperature, and compact immediately.	Mass loss ≤ 7.5%
ASTM D8225 Determination of Cracking Tolerance Index of Asphalt Mixture Using the Indirect Tensile Cracking Test at Intermediate Temperature	• 5 gyratory pills: 150mm dia., 62 ± 1 mm ht. • Compact to 7±0.5% air voids. • Lab-produced mix: Condition loose mix for 4 hours at the design compaction temperature before compacting. • Plant-produced mix: Minimize any cooling, bring mix to the compaction temperature, and compact immediately. • Before testing, condition pills at 25 ± 1°C for 2 hours ± 10 min. Pills must remain dry; if conditioning in a water bath, pills must be sealed in plastic bags.	$CT_{index} \geq 70$

IV. Production Testing

The Contractor and the Department will conduct testing as required by Sections 211.05 and 211.06 of the Specifications. In addition to all of the testing requirements for Superpave mixes, performance testing shall also be conducted by the Contractor**,** in accordance with Table 1 and at the frequency shown in Table 2. Nothing in Table 2 is intended to change the lot sizes defined by Sections 211 and 315 of the Specifications. The Contractor shall report Quality Control (QC) performance test results within 1 week of sampling to the Department. Submitting QC performance test results within 48 hrs by the Contractor is strongly recommended. If less than 300 tons of asphalt mixture is produced under a single JMF in a day, Superpave testing and performance testing will not be required on that day. That day’s tonnage shall be added to subsequent production. When the accumulated tonnage exceeds 300 tons, minimum testing frequency for Superpave and performance testing shall apply and results shall be reported. The Contractor shall fabricate and provide the specimens meeting requirements in Table 1 including dimensions and air voids, to the Department.

Property/Test	Frequency (tons)	Number of Specimens (per lot)
CT_{index}[1]	2,000	10
Cantabro[1]	2,000	6
CT_{index}[1] – VDOT[2]	4,000	5
Cantabro[1] – VDOT[2]	4,000	3
Rutting[1] – VDOT[2]	1 per project	4 per project

Table 2. Performance Testing Frequency (per lot)

[1] Minimize any cooling of the plant produced mix and bring the specimens to the compaction temperature and compact immediately to the specimen requirements in Table 1.
[2] VDOT pills shall be fabricated in accordance with Table 1 and provided to the Department by the Contractor.

V. Acceptance

Lot acceptance for BMD P+VO shall be as required by Section 211.08 of the Specifications. Although acceptance will be based on Section 211, should any performance test results (based on the average of required number of specimens tested) fail to meet the criteria as specified in Table 1, the Department may require that production be stopped until corrective actions are taken by the Contractor.

Field density shall be determined in accordance with Section 315 of the Specifications.

VI. Adjustment System

The Department will determine adjustment points in accordance with Section 211.09 of the Specifications except for the following:

- If the total adjustment is 25 points or less and the Contractor does not elect to remove and replace the material, the unit price for the material will be reduced 3% of the unit price bid for each adjustment point the material is outside of the process tolerance.
- The Engineer will reduce the unit bid price by 1.0 percent for each adjustment point applied for standard deviation.
- The Engineer will increase the unit bid price by 5% if the following criteria are met: 1) the standard deviation of the AC content is within the ranges of 0.0 – 0.15; 2) there are no adjustment points assigned for any sieve sizes as noted in Table II-16; and 3) the average AC content is no less than 0.10% below and no more than 0.20% above the approved mix design AC content.

VII. Initial Production

Mix type BMD P+VO shall be subject to Section 211.15 of the Specifications at the Engineer’s discretion.

VIII. Measurement and Payment

Asphalt Concrete BMD P+VO will be measured in tons and will be paid for at the Contract ton price. Net weight information shall be furnished with each load of material delivered in accordance with Section 211 of the Specifications. Batch weights will not be permitted as a

method of measurement unless the Contractor's plant is equipped in accordance with Section 211 of the Specifications, in which case the cumulative weight of the batches will be used for payment. This price shall include all labor, equipment, and materials necessary to furnish, install, and finish the work described herein.
Payment will be made under:

Pay Item	**Pay Unit**
Asphalt Concrete BMD P+VO (mix type)	Ton