Final Report VTRC 11-R5

Virginia Transportation Research Council

research report

Investigation of Optimized Mixture Design for Superpave Surface Mixtures

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Standard Title Page—Report on State Project

Report No.: VTRC 11-R5	Report Date: October 2010	No. Pages: 17	Type Report: Final	Project No.: 91322
			Period Covered: 8-15-08 through 8-30-10	Contract No.:

Title:
Investigation of Optimized Mixture Design for Superpave Surface Mixtures

Key Words: Asphalt, hot mix, asphalt content, gradation, Superpave, surface mix

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Abstract:

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Analysis of current 9.5 mm mixture production data and production data of similar mixtures produced prior to the adoption of Superpave revealed no significant difference in asphalt content. Gradation differences may have affected these results. Additional analysis of the production 12.5 mm mixtures possibly over certain time intervals is recommended. Analysis of several mixtures in the laboratory revealed that some mixtures may be able to tolerate more asphalt, thereby improving durability; however, additional asphalt would be detrimental to the performance of other mixtures.

Based on the findings of this study, the Virginia Department of Transportation's specifications regarding mixture design should not be changed at this time, but additional research work is justified.

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INVESTIGATION OF OPTIMIZED MIXTURE DESIGN FOR SUPERPAVE SURFACE MIXTURES

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

Charlottesville, Virginia

October 2010
VTRC 11-R5

DISCLAIMER

ABSTRACT

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INTRODUCTION

Approximately 97 percent of the Virginia's paved roads are surfaced with asphalt.[1] Virginia used the Marshall mixture design system for many years with success, but pavement deficiencies, particularly rutting, suggested a need for change. In the 1990s, a new asphalt mixture design system known as Superpave was implemented in Virginia. Superpave was developed through a multi-million dollar national effort over a 5-year period, but when states began to use the new system, it was realized that refinements were needed to produce satisfactory mixtures. Although rutting has been virtually eliminated with Superpave, there are concerns about the durability of Superpave mixtures.

The Superpave mixture design system reflected major changes in areas such as mixture gradation, binder specifications, aggregate quality characteristics, laboratory compaction equipment, and laboratory compactive effort. Although there was considerable effort to develop the system based on past mixture performance information, there was inadequate time available to refine the system properly. The laboratory tests that have been used to evaluate the predicted performance of Superpave mixtures are rather time-consuming and require specialized equipment. The follow-up development of a planned simple laboratory performance test(s) that can be used to help validate mixture designs has been slow. With the absence of a simple test to validate good performance, there is an inclination to be conservative in the addition of binder, the addition of which usually enhances durability but can also lead to severe rutting.

It was reported in a recent survey concerning Superpave mixtures that "[m]any states expressed concern that the mixes were low in binder content."[2] The survey reported that some design binder contents dropped 0.1 to 0.2 percent when Superpave was implemented, with some indicating that the decrease was more drastic, as much as 0.7 percent. The unease about the effect of decreased binder content on durability was especially expressed in the northeast and southeast regions of the United States. A Texas laboratory study concluded that Superpave binder contents could possibly be increased as much as 0.5 to 1.0 percent.[3]

Similarly, Virginia Department of Transportation (VDOT) engineers and the local paving industry have questioned the durability of VDOT surface mixtures since the adoption of Superpave. A 2003 study by the Virginia Transportation Research Council (VTRC) found that the asphalt content of a majority of nine mixtures examined in the laboratory could be increased as much as 0.5 percent with beneficial effects.[4] VDOT decreased the laboratory design compactive effort to 65 gyrations, which tended to increase asphalt content; however, there is still some doubt about mixture durability.

Another recent VTRC study found that dense-graded surface mixtures containing PG 70-22 binder were not performing as well as mixtures containing PG 64-22 binder.[5] Although the study indicated that this finding might be caused by traffic loading or underlying pavement structure, it raises doubts concerning the influence of mixture design on service life. Mixtures containing different types of binders were compacted in the laboratory at the same temperature prior to Superpave. Superpave requires that mixtures containing different types of binders be compacted at the temperature that provides the same viscosity; therefore, mixtures containing stiff binder (PG 70-22) require a higher compaction temperature than mixtures containing PG 64-22 binder. This could mean that pre-Superpave mixtures containing stiff PG 70-22 binder attained thicker binder films under the old design system than were attained presently. Film thickness could possibly influence durability. Would film thickness be influenced enough under the two design systems to effect differences in mixture durability?

After considerable discussion, the VTRC Asphalt Research Advisory Committee recommended that VTRC initiate a study to investigate ways of improving VDOT's current design of surface mixtures.[6] A subsequent meeting by a panel selected to oversee the research discussed possible approaches to the research. Even though asphalt binder was selling at a premium price, it was believed that the increased service life anticipated by the addition of more binder would more than offset the extra cost of the additional binder.

PURPOSE AND SCOPE

The purpose of this study was to investigate whether changes are needed in VDOT's method of surface mixture design to improve durability. Special emphasis was placed on the importance of asphalt content. Quality assurance test results and mixture designs of similar mixtures produced by Superpave and pre-Superpave methods since 1989 were analyzed and compared. The current 9.5 mm surface mixture was studied primarily since that mixture is currently used most widely in Virginia. A brief history of mixture design specifications over the same time period was also developed. One of the components of the investigation involved limited laboratory testing of mixture design variations of several SM-9.5 mixtures that have been used.

The primary concern usually mentioned during a discussion of Superpave deficiencies is the possible lack of durability attributable to insufficient asphalt binder. Therefore, the main focus of this study was asphalt content, but another aspect of mixture design, i.e., gradation, was also considered.

METHODS

Three tasks were conducted to achieve the study objectives.

1. *A brief history of mixture design changes in VDOT specifications over the last 20 years was developed.*

2. *Production data of mixtures used by VDOT over the last 20 years, including recent 9.5 mm surface mixtures, were examined.* Since low binder content was suspected in the current mixtures, a comparison of the binder content of current mixtures and previous mixtures was anticipated to be useful. It was hoped that past production data would provide a clue concerning any changes that were possibly needed.

3. *Laboratory testing.* Four typical 9.5 mm dense-graded surface mixtures were chosen for laboratory testing. Mixture gradations were similar to job-mix designs that had been used in field applications. The mixtures were selected from different geographical locations in order to use different aggregate types. The mixture designs and materials were supplied by Superior Paving Corp. (Superior), Branscome Inc. (Branscome), Virginia Paving Company (Virginia Paving), and Lee Hy Paving Corporation (Lee Hy). Each of the four mixtures was compacted with 65 gyrations at the design asphalt content, at the design asphalt content minus 0.5 percent, and at the design asphalt content plus 0.5 percent. Volumetric properties were determined, and the asphalt content producing 4.0 percent air voids (voids in total mix [VTM]) was then designated the new "optimum AC" (i.e., asphalt content). The new optimum AC was then used in making comparative specimens using the 65 gyration compactive effort and 50-blow Marshall compactive effort that was used before Superpave. Volumetric properties of the two sets of specimens were compared.

   Volumetric properties were determined for several of the mixtures containing both PG 64-22 binder and PG 70-22 binder that were compacted at the temperature currently used with Superpave and at the temperature used prior to Superpave. The primary purpose was to determine whether current mixtures, particularly those containing PG 70-22 binder, would have less asphalt binder than those mixtures produced under the previous design method.

RESULTS

Virginia's Asphalt Mixture Design History

The brief history of VDOT's mixture design requirements from 1987 through 2008 given here was based on notes taken by the researcher at an internal VDOT/industry meeting and information gathered from VDOT specification books. A summary of the primary specifications is provided in Table 1.

There were changes in the types of surface mixtures with approximately the same maximum nominal 3/8 in aggregate that has been specified since 1987. In 1991, in an effort to reduce the wide range of asphalt mixtures a contractor might be asked to provide, the total number of mixtures was reduced from 15 to 9 and the number of surface mixtures was reduced

Table 1. VDOT’s Surface Mixture Design Specifications From 1987 Through 2008

Gradation								
Specification Year	**Mixture ID**	**3/4 in**	**½ in**	**3/8 in**	**No. 4**	**No. 8**	**No. 30**	**No. 200**
1987	S-5		100		53-67		19-27	4-8
1991	SM-2	100	97-100	82-94	48-62		18-24	4-7
1994	SM-2	100	97-100	82-94	48-62		18-24	4-7
1997	SM-2	100	97-100	82-94	48-62		18-24	4-7
2002	SM-9.5		100	90-100	<90	32-67		2-10
2007	SM-9.5		100	90-100	<80	38-67		2-10
Design Volumetrics								
Specification Year	**Method**	**% VTM**	**% VFA**	**% VMA**				
1987	Marshall	3-6	70-85	14.8-20.0				
1991	Marshall	3-6	65-80	> 15.0				
1994	Marshall	3-6	65-80	> 15.0				
1997	Marshall	3-6	65-80	> 15.0				
2002	Superpave	2.5-5.5	73-79	> 15.0				
2007	Superpave	2.0-5.0	73-79	> 15.0				

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

from 6 to 3. The S-5 mixture was eliminated and replaced with an SM-2 mix, which was slightly coarser than the S-5 mixture. Combinations of design compaction effort (50 and 75 blows) and type of binder (AC-20, AC-30) were then specified for various traffic loading levels. Generally, Type A mixtures were used in low-traffic situations and Type D mixtures were used in high-traffic situations. Type A mixtures required the design 50-blow compactive effort that yielded higher asphalt contents than that produced with the 75-blow compactive effort used for the Type B and C mixtures. Type D Marshall mixtures were later designed using a 50-blow compactive effort and an AC-30 binder.

In 2000, with the adoption of the Superpave design system, two surface mixtures were specified: SM-9.5 and SM-12.5. This study focused on the 9.5 mm mixture since it has become the surface mixture used most often today. VDOT initially experimented with Superpave N-design compactive levels of 86, 95, and 109 gyrations for low, medium, and high traffic levels, respectively. However, VDOT decided to use compactive efforts of 65 and 75 gyrations in mixture designs for different traffic levels. Later (2002), a change was instituted to require all mixtures to be designed with a 65 gyration compactive effort. The lower gyration level was assigned in an attempt to force higher binder contents and, it was hoped, to aid durability. Harder binders (PG 70-22 and PG 76-22), rather than higher design gyration levels, were used to provide stability for heavy traffic loading.

Some, but not all, natural sands tended to have a rounded shape, which possibly caused mixture instability. Since there was no requirement for the fine aggregate to influence mixture stability, natural sand was limited to 20 percent from 1991 until 2000, when Superpave was adopted. Current specifications require that a fine aggregate angularity (FAA) test be conducted to ensure a fine aggregate shape and surface texture that enhances mixture stability.[7]

Analysis of Production Test Data for Surface Mixtures

Asphalt Content

The binder contents of three mixtures, S-5, SM-2, and SM-9.5, were compared in various combinations by using VDOT's quality assurance test results database. S-5 and SM-2 mixtures were designed with the Marshall method, and SM-9.5 mixtures were designed with the Superpave system. Approximately 110 mixture designs, 22,000 tests, and 32,000 tests were analyzed for the S-5, SM-2, and SM-9.5 mixtures, respectively, from the period 1989 through 2008. Only a small amount of data was available for S-5 mixture since the database was activated only in the late 1990s and only a few mixture designs could be located.

The test results were analyzed according to mixture type and VDOT district. Figures 1 and 2 indicate the comparison of asphalt content between SM-2 and SM-9.5 mixtures for Type A and D mixtures, respectively. Depending on the time period, Type A mixtures used an AC-20 or PG 64-22 binder and Type D mixtures used an AC-30 or PG 70-22 binder. Although the standard deviation error bars are not shown, it is obvious that there is no significant difference between the asphalt contents of the two mixtures in any district because of the proximity of the test results. In fact, in six of eight districts, the average asphalt content of the SM-9.5A mixtures was equal to or slightly above the average asphalt content of the SM-2A mixtures. Similarly, in six of eight districts, the average asphalt content of the SM-9.5D mixture, which was used in heavy traffic locations, was equal to or slightly above the average asphalt content of the SM-2D mixtures.

The small sample of S-5 mixtures that represented only four districts, i.e., Northern Virginia, Lynchburg, Fredericksburg, and Richmond, produced an average asphalt content of 5.5 percent. That average was nearly equal to or slightly less than the asphalt content of the SM-9.5A mixtures from each of those districts.

Table 2 lists the average asphalt content (and standard deviation) for all districts. The average asphalt contents were equal for SM-9.5 and SM-2 mixtures; however, the standard deviations indicate that asphalt content may vary as much as ±0.6 percent within a district.

Gradation

Table 2 lists the average gradations of the three basic surface mixtures. An examination of Figure 3 indicates that the gradation of the average production SM-9.5A mixture was on the coarse side of the current design gradation band. The SM-2A mixtures were slightly coarser than the current SM-9.5A mixtures for the sieve sizes above the No. 30 sieve. The statewide average asphalt content for both mixture types was identical; however, considering the gradation difference, possibly more asphalt should have been present in the finer mixture. The average SM-2 production gradation would actually qualify the mixture as a nominal 12.5 mm mixture. Currently, SM-9.5 mixtures typically contain about 0.2 percent more asphalt than do SM-12.5 mixtures.

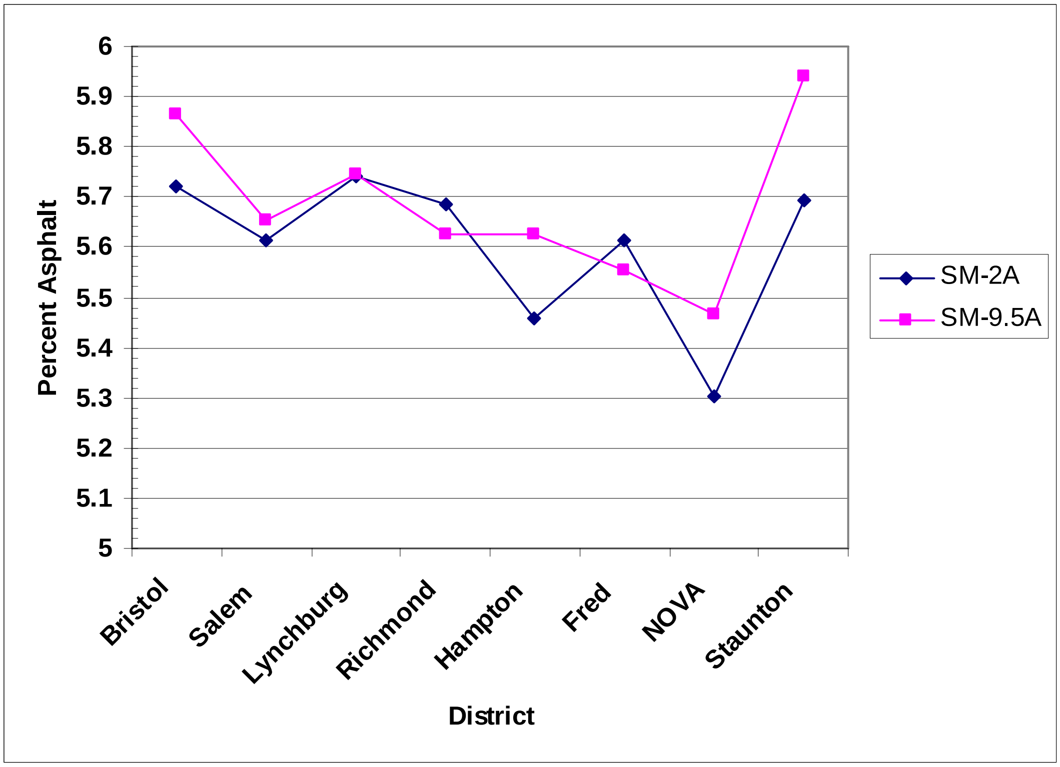

Figure 1. Average Production Asphalt Content of SM-2A Mixtures Produced During 1995-2002 and SM-9.5 Mixtures Produced During 2000-2008. Fred = Fredericksburg; NOVA = Northern Virginia.

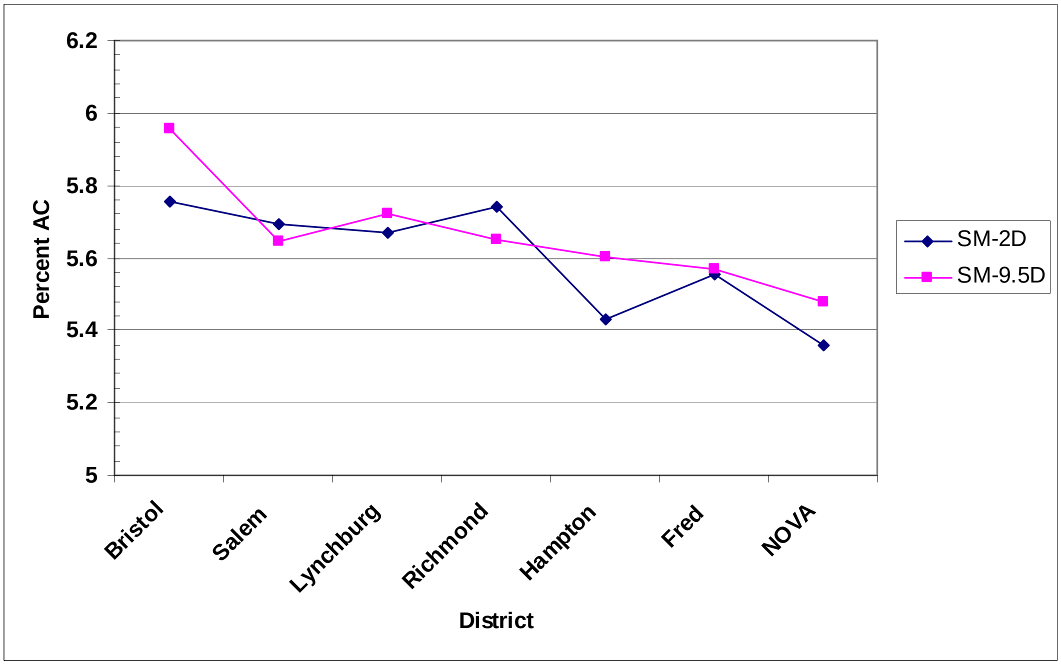

Figure 2. Average Production Asphalt Content of SM-2D Mixtures Produced During 1995-2002 and SM-9.5D Mixtures Produced During 2000-2008. AC = asphalt content; Fred = Fredericksburg; NOVA = Northern Virginia.

Table 2. State Average of Production and Design Tests

Sieve	Percent Passing Sieve		
	S-5 (mixture designs)	**SM-2A (production)**	**SM-9.5A (production)**
¾ in		100.0	100.0
½ in	100.0	98.6	99.8
3/8 in (9.5 mm)		89.6	94.1
No. 4	60.5	58.0	61.3
No. 8		38.3	42.4
No. 30	22.1	20.4	20.6
No. 50		13.1	13.5
No. 200	5.3	5.5	5.5
Average % asphalt	5.5	5.6	5.6
Average % asphalt standard deviation (within districts)	0.29	0.32	0.28
No. of mixture designs	110	-	-
No. of tests	-	22,000	32,000

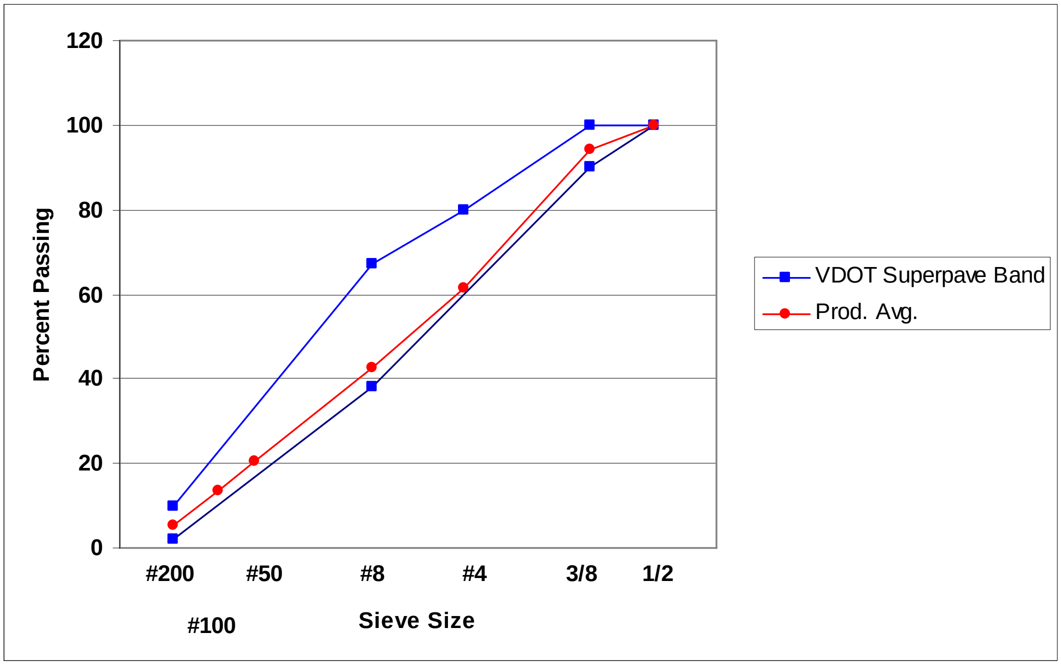

Figure 3. Average Production Gradation of SM-9.5A Mixtures During 2000-2008 With Reference to Current VDOT Band. Prod. Avg. = production average.

The difference in gradation could have influenced the asphalt binder film thickness, which may have an effect on mixture durability. An estimation of film thickness based on the average gradation and average asphalt content showed that the average film thickness of the SM-9.5 mixtures was only 0.3 micron less than the average film thickness of the SM-2 mixtures.

The S-5 mixtures are often cited in conversations as being durable and long-lasting. The data in Table 2 for the S-5 mixture are based on mixture designs and not on production tests. Although there were not as many control sieves for the S-5 mixtures, there was no apparent difference between the gradations of the S-5 mixtures and other mixtures. The SM-9.5 mixture gradation was plotted with reference to the former S-5 mixture design gradation band in Figure 4. Below the No. 8 sieve, the gradation was slightly below the S-5 mixture median but followed the S-5 median for the coarser sieves. It was not possible to compare the mixtures at the 3/8 in (9.5 mm) nominal sieve for the SM-9.5 mixture because the specifications did not require the results for that sieve to be reported for the S-5 mix.

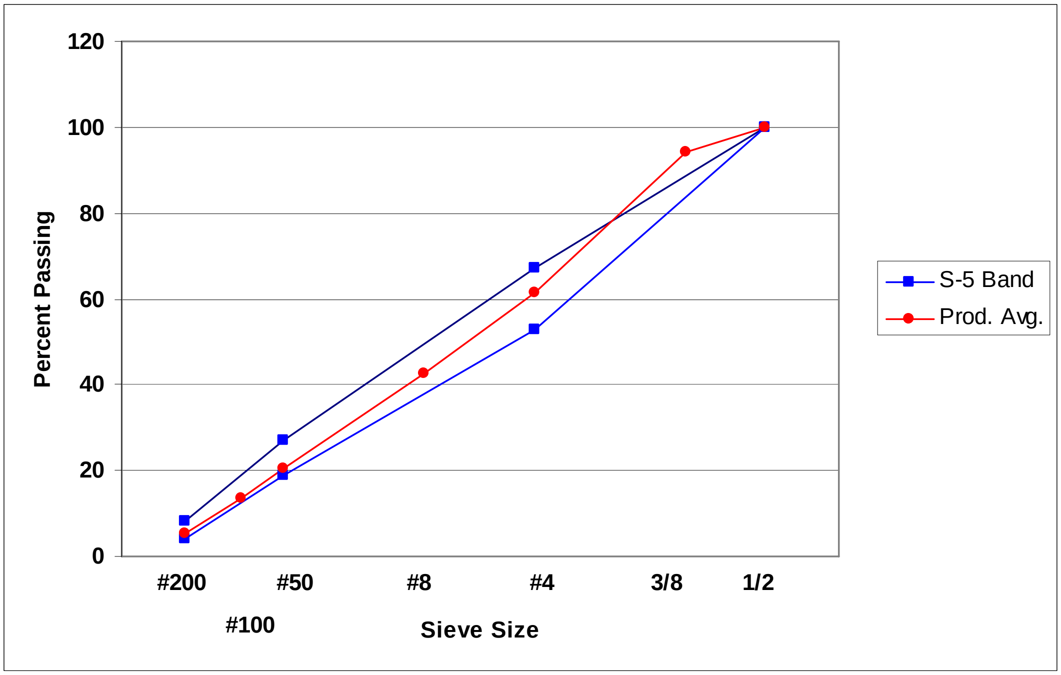

Figure 4. Average Production Gradation of SM-9.5A Mixtures During 2000-2008 With Reference to Previous S-5 Mixture Band. Prod. Avg. = production average.

Laboratory Testing

Gyratory Volumetric Properties

As indicated previously, gyratory specimens were compacted at the contractor's design asphalt content and also at ±0.5 percent asphalt content. Table 3 shows the void contents achieved at these asphalt contents. The mixtures from Superior and Virginia Paving could have tolerated an additional 0.5 percent asphalt cement and still have maintained approximately 4 percent air voids. However, the additional 0.5 percent asphalt cement produced dangerously low air void levels in the mixtures from Branscome and Lee Hy. Part of the explanation for this observation regarding the mixture from Lee Hy could be the excess minus 75 µm material that occurred in the laboratory testing (see Table 4). Raw aggregates were combined according to percentages designated in the contractor's mixture design and not separated and recombined by individual sieve size. On the other hand, the Branscome laboratory mixture was coarser than the contractor's mixture design but still produced low voids.

Table 3. Laboratory Volumetric Test Data for Typical SM-9.5A Mixtures

Mixture	-0.5% AC		Design % AC		+0.5% AC	
	% AC	% VTM	% AC	% VTM	% AC	% VTM
Superior Paving Corp.	4.9	7.5	5.4	5.1	5.9	4.1
Virginia Paving Company	4.9	7.4	5.4	5.8	5.9	4.0
Branscome Inc.	5.2	5.2	5.7	3.1	6.2	1.9
Lee Hy Paving Corp.	5.3	3.6	5.8	2.8	6.3	1.5

AC = asphalt content; VTM = voids in total mix.

Table 4. Mixture Gradations

Sieve	Superior Paving Corp.		Virginia Paving Company		Branscome Inc.		Lee Hy Paving Corporation	
	Design	Lab	Design	Lab	Design	Lab	Design	Lab
¾ in						100		
½ in	100	100	100	100	100	99	100	100
3/8 in	93	94	95	98	94	95	95	96
No. 4	60	60	61	74	56	58	64	63
No. 8	40	38	38	46	47	41	44	40
No. 16		27		32		32		29
No. 30		20		22		22		21
No. 50		13		15		13		14
No. 100		7.7		10.1		8.0		9.5
No. 200	5.4	4.7	6.1	6.6	6.0	4.9	5.5	7.4

Gyratory Versus Marshall Properties

New optimum ACs at 4.0 percent VTM were established from the previous gyratory results. These new optimum ACs were used to determine comparative air voids for 50-blow Marshall specimens and 65-gyration specimens (see Table 5). The air voids of the Marshall specimens were considerably higher, 1.6 to 1.8 percent, than the air voids of the gyratory specimens for three of the four mixtures (see Figure 4). More asphalt cement would have been required in three of the Type A mixtures to achieve 4.5 percent air voids according to the Marshall method.

Table 5. 50-Blow Marshall and 65-Gyration Gyratory Volumetric Test Data for Typical SM-9.5A Mixtures

	Superior Paving Corp.		Virginia Paving Company		Branscome Inc.		Lee Hy Paving Corporation	
	Marshall	Gyratory	Marshall	Gyratory	Marshall	Gyratory	Marshall	Gyratory
% AC	5.8	5.8	6.0	6.0	5.5	5.5	5.0	5.0
% VTM	5.7	4.1	4.3	4.0	6.4	4.8	5.9	4.1
% VMA	18.9	18.0	18.4	18.8	18.0	17.1	16.6	14.8
% VFA	69.7	77.1	76.7	78.8	64.2	71.8	64.2	72.4

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

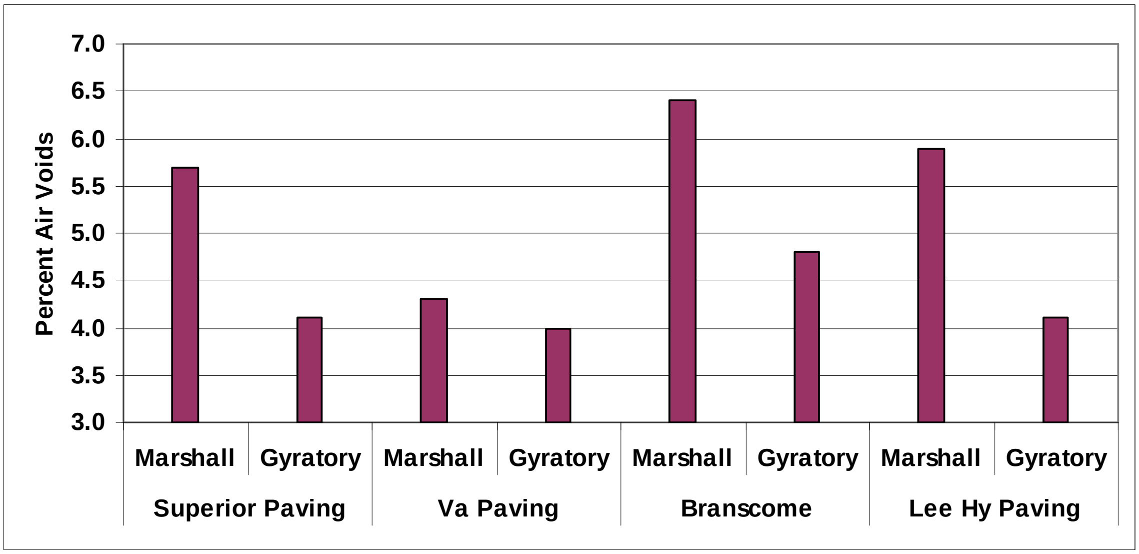

Figure 4. Comparison of Air Voids Between Marshall and Gyratory Compactive Efforts

Effect of Compaction Temperature on Air Voids

The next phase of laboratory testing was designed to determine if mixture design criteria, such as compaction temperature, affected the optimum AC. The effect of compaction temperature was investigated by compacting specimens at the laboratory compaction temperatures used during the two time periods, pre-Superpave and Superpave, and comparing the projected asphalt content at the design void level. Figures 5 and 6 show the compaction curves

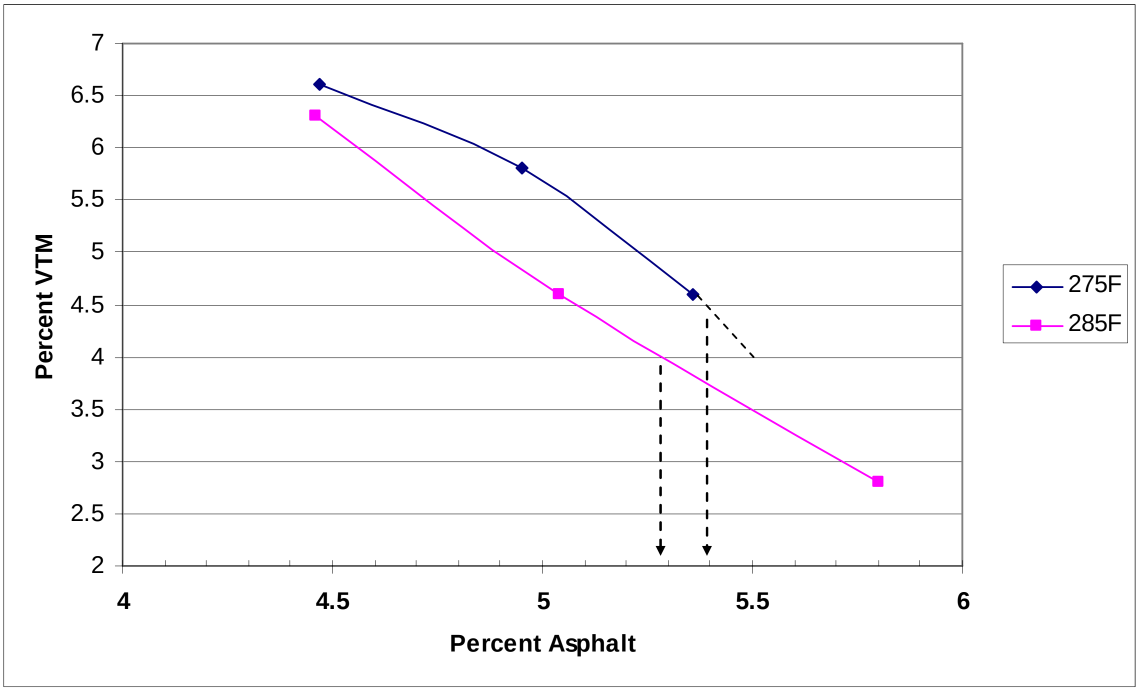

Figure 5. Typical Compaction Curves at Different Temperatures for Mixture Containing PG 64-22 Binder. VTM = voids total mix.

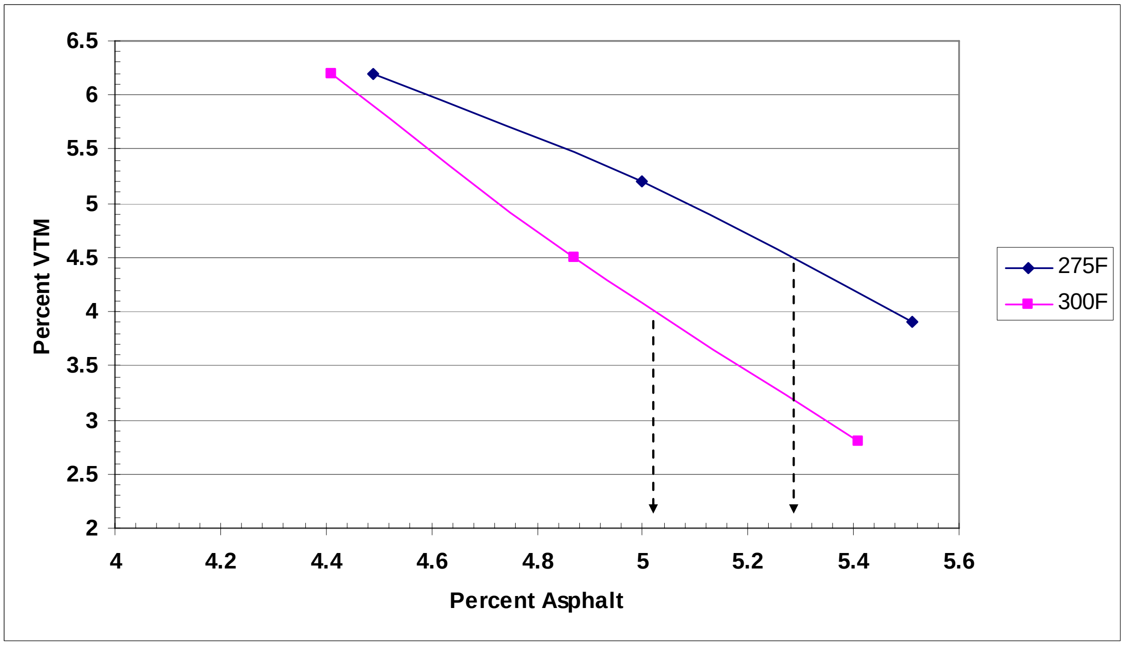

Figure 6. Typical Compaction Curves at Different Temperatures for Mixture Containing PG 70-22 Binder. VTM = voids total mix.

developed for one of the mixtures. It illustrates the difference in the optimum AC determined at the different temperatures. The lower laboratory compaction temperature of 275°F for both PG 64-22 and PG 70-22 binders was used for the time period prior to Superpave. Another factor that influenced the optimum AC was the design air void content, which was 4.5 percent and 4.0 percent for the time periods prior to Superpave and during Superpave, respectively.

The difference in optimum AC for each of the four mixtures determined at the two temperatures is listed in Table 6. Three of the four mixtures showed negligible change in the optimum AC for the PG 64-22 binder; however, the temperature difference was only 10°F. Two of the four mixtures showed an optimum AC that was 0.2 to 0.3 percent less for the present Superpave mixtures using the PG 70-22 binder. The fourth mixture was an anomaly in that it indicated that a higher optimum AC was developed for the higher compaction temperature. The results were checked for accuracy, and the reason for the anomaly could not be explained.

Table 6. Superpave Optimum Asphalt Content Minus Pre-Superpave Optimum Asphalt Content

Binder	Superior Paving Corp.	Virginia Paving Company	Branscome Inc.	Lee Hy Paving Corporation
PG 64-22	0	+0.3	0	-0.1
PG 70-22	0	+0.4	-0.2	-0.3

DISCUSSION

VDOT’s asphalt mixture design history revealed three primary changes in the last 20 years concerning nominal 3/8 in surface mixtures. The S-5 mixture was eliminated and replaced with the SM-2 mixture, which contained slightly more +0.5 in material. When necessary, additional stability was incorporated by using various laboratory mixture design compactive efforts and stiffer binders. The adoption of the nationally developed Superpave mixture design system probably provided the most change over this time period when new binder specifications were introduced in addition to quite different laboratory compactive equipment and related mixture design criteria. Although follow-up specification changes have been made by VDOT since the adoption of the Superpave system, it was still suspected that additional changes were needed to adjust the design asphalt content of the resultant SM-9.5 mixture.

It was thought that an examination of the properties of the three basic mixture types (i.e., S-5, SM-2, and SM-9.5) produced over an approximate 20-year time period might shed light on whether design changes were needed for current mixtures. Since the SM-9.5 mixture is the surface mixture currently used most often, it was chosen for comparison with the previous mixtures. VDOT's asphalt database containing quality assurance acceptance test results for asphalt content and gradation was examined. In the majority of VDOT districts, the asphalt content of SM-9.5 mixtures was equal to or slightly more than the asphalt content of older SM-2 mixtures. Statewide, the average asphalt content of the two types of mixtures was the same. In retrospect, the production results of the SM-12.5 mixtures should also have been examined since their production gradations seemed to compare more closely with those of the previous SM-2 mixtures. Considering the fact that the production SM-9.5 mixtures were slightly finer than the SM-2 mixtures, more asphalt should probably have been contained in the SM-9.5 mixtures, but it was not.

Although mixture designs were available for only a few S-5 mixtures, the statewide average asphalt content of the S-5 mixtures was slightly less than the asphalt content of the other two mixture types. Past data did not reveal that the asphalt content had been decreased since the adoption of Superpave. Changes to VDOT mixture design soon after Superpave adoption may have prevented discernable differences. The gradation and asphalt content for the small sample of S-5 mixtures were approximately the same as for the current SM-9.5 mixtures.

In the laboratory experiment involving volumetric results, two of four mixtures could have sustained an additional 0.5 percent asphalt; however, the other two mixtures would have been too dense. Comparison of 50-blow Marshall and 65-gyration specimens revealed that more asphalt cement would have been required for the Marshall specimens to achieve satisfactory air voids in three of the four cases. This observation would seem to indicate that mixtures designed by the Marshall method should have had more asphalt cement than those mixtures designed by the gyratory method. The experiment involving compaction temperatures indicated that there could be an 0.2 to 0.3 percent difference in the designed optimum AC for some but not all mixtures.

CONCLUSIONS

- The asphalt content of SM-2 mixtures and current SM-9.5 mixtures was not significantly different.

- Some mixtures may be able to perform satisfactorily with more asphalt; however, the performance of other mixtures may be unsatisfactory if more asphalt is included.

- For a majority of the mixtures investigated, mixtures designed by the Marshall method would contain slightly more asphalt cement.

- VDOT's current design procedure may result in less asphalt cement in some mixtures containing PG 70-22 binder.

RECOMMENDATION

1. *Considering the difference in production gradations between the SM-9.5 mixtures and SM-2 mixtures, VTRC should look at the asphalt contents of production SM-12.5 mixtures.* Because changes have occurred since the adoption of Superpave, the data should possibly be divided into intervals encompassing certain design/gradation changes. Possible additional laboratory research to include more mixtures would also be beneficial.

COSTS AND BENEFITS ASSESSMENT

The purpose of this study was potentially to increase the durability and service life of current surface mixtures that were suspected of being deficient in asphalt cement content. The scope of the study prevented a definite conclusion; however, the results justify additional research that may lead to future beneficial mixture design changes.

ACKNOWLEDGMENTS

Appreciation is expressed to the asphalt contractors named in the report who supplied the materials and job-mix designs that were used in the projects. In addition, Todd Rorrer of VDOT's Materials Division and Richard Schreck of the Virginia Asphalt Association provided some of the production and mixture design data that were analyzed. Thanks are extended to the project panel consisting of W. R. Bailey III, David Lee, Haroon Shami, and Richard Schreck for their guidance in the planning and their suggestions during the conduct of the research. Moreover, Trenton Clark and Alex Apeagyei helped review the final report. Special thanks go to Troy Deeds and Aaron Dupont of the VTRC laboratory staff who conducted the testing for the study.

REFERENCES

1. Virginia Asphalt Association. http://www.vaasphalt.org/. Accessed June 27, 2008.

2. McDaniel, R.S. *Current Superpave Mixture Design Practice: Survey of the User-Producer Regions*. Circular Number E-C124. Transportation Research Board of the National Academies, Washington, D.C., 2007.

3. Zhou, F., Hu, S., Scullion, T., Mikhail, M., and Walubita, L.F. A Balanced HMA Mixture Design Procedure for Overlays. *Journal of the Association of Asphalt Paving Technologists,* Vol. 76, 2007, pp. 823-850.

4. Maupin, G.W., Jr. *Additional Asphalt to Increase the Durability of Virginia's Superpave Surface Mixtures.* VTRC 03-R15. Virginia Transportation Research Council, Charlottesville, 2003.

5. McGhee, K.K. *A Cost Comparison Methodology for Selecting Appropriate Hot-Mixture Asphalt Materials.* VTRC 07-R31. Virginia Transportation Research Council, Charlottesville, 2007.

6. Asphalt Research Advisory Committee. Meeting Minutes. Virginia Transportation Research Council, Charlottesville, May 29, 2008.

7. Virginia Department of Transportation. *Road and Bridge Specifications.* Richmond, 2007. http://www.virginiadot.org/business/resources/const/2007SpecBook.pdf . Accessed September 30, 2010.