FINAL REPORT

ADDITIONAL ASPHALT TO INCREASE THE DURABILITY OF VIRGINIA'S SUPERPAVE SURFACE MIXES

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DISCLAIMER

ABSTRACT

Although Superpave has been successful in preventing rutting, many believe that the design asphalt content needs fine-tuning to produce durable mixes. This investigation used various laboratory tests to test samples of field surface mixes (12.5 mm and 9.5 mm) to predict changes in mix properties as extra asphalt was added. Permeability, 50-blow Marshall volumetrics, rutting, and fatigue tests were used. An analysis tool using gyratory compaction was also used to predict what the level of pavement voids would have been had higher asphalt contents been used.

For most of the mixes, properties improved as the asphalt content was increased. The asphalt content could have been increased as much as 0.5 percent in most of the mixes with no harmful effects. It is reasonable to expect that the beneficial effects would increase the life of a surface mix by approximately 5 percent.

The Virginia Department of Transportation (VDOT) uses approximately 2 million tons of asphalt in surface overlays per year at a cost of approximately $35 per ton. The cost of adding 0.5 percent more asphalt would be approximately $1 per ton. With an estimated increased service life of 5 percent, VDOT would save approximately $1.5 million per year.

The researcher recommended that the effects of increasing the design asphalt content of Superpave mixes be explored and tested in the field.

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INTRODUCTION

The Marshall asphalt concrete design system, which Virginia used until 1997, was developed for a limited number of traffic loadings and is not logically adaptable to the severe traffic conditions encountered today. Superpave is a new asphalt concrete design system developed in the early 1990s to meet existing traffic loading and environmental conditions. Much of the Superpave system is rationally based from an engineering viewpoint and does not rely on empirical relationships, as did the Marshall system. Although the Superpave system was intended to be mechanistically based, it still relies on particular empirical relationships that need refinement.

Superpave uses a gyratory compactor to compact specimens to verify that the proper combination of aggregates has been used and determines the proper asphalt content in the mix design phase. The compactive effort (number of gyrations) used is specified by the design procedure and depends on the level of traffic and expected high air ambient temperature. The compactive effort is supposed to produce laboratory specimens with the void content that will be reached in the pavement after several years of traffic. The compactive effort was set by the early developers on a limited set of data and modified by an expert task group associated with Superpave; however, the specified effort is somewhat arbitrary. An NCHRP study[1] in progress is supposed to verify that the specified number of gyrations is correct for various levels of traffic. In the meantime, a great deal of mix is still being placed while that work is being completed. The design compactive effort directly affects the resultant design asphalt content.

Although Superpave mixes have generally been very resistant to rutting, there has been some concern about durability because of the low asphalt content.[2] In fact, some user agencies have changed the original Superpave design system to try to incorporate more asphalt cement into the mixture. Since the adoption of Superpave, Virginia has lowered the number of gyrations to try to raise the design asphalt content and increase durability.

A question still remains concerning whether even more asphalt could be added to increase durability. The designers need confidence that recent changes in the specified number of gyrations will yield satisfactory mixes with respect to rutting and durability, and, more important, whether the mixes need and can tolerate more asphalt.

PURPOSE AND SCOPE

The purpose of this investigation was to determine whether more asphalt would increase the durability of Virginia's Superpave mixes without any detrimental effects. Various laboratory tests were performed on samples of mixtures collected from paving projects in Virginia

METHODS

Experimental Plan

Nine mixes, five 12.5 mm and four 9.5 mm mixes, were sampled at hot-mix asphalt plants at the end of the Virginia Department of Transportation's (VDOT) 2001 construction season and taken to the laboratory for modification and testing. Specifications were modified slightly in 2002 to produce slightly finer mixes, and the compactive effort for designated D and E mixes was changed from 75 to 65 gyrations. Currently, the major difference between D and E mixes is that PG70-22 is required for D mixes and PG76-22 is required for E mixes. An attempt was made to select mixes for the laboratory work that conformed closely to the gradations that were adopted for 2002 and are still in effect so that the results would reflect testing of mixes now being used.

The gradations and asphalt contents of the nine mixes are listed in Table 1, and the gradations are very close to or within the 2002 specification limits. Six of the mixes met the new gradation specification requirements. The other three mixes had only one sieve outside the 2002 specification, and that sieve was less than 4 percentage points from the specification limits. Six of the nine mix design gradations were still current in 2002, and the remaining three mixes were redesigned in accordance with the normal procedure for the particular contractor furnishing the mixes. Therefore, the mixes tested should have been similar to the mixes now being used. An attempt was also made to verify that the asphalt contents of the D mixes sampled were similar to the design asphalt content that would have resulted had 65 gyrations been used.

Table 1. Gradations of Mixes (% Passing)

Sieve, mm	2002 Spec		12.5 mm Mixes					9.5 mm Mixes			
	12.5 mm	9.5 mm	1082	1084	1089	1093	1101	1081	1086	1091	1098
19	100		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
12.5	95-100	100	98.5	97.8	97.5	95.8	96.9	97.2	99.7	99.3	99.9
9.5	<90	90-100	87.5	82.0	83.2	87.1	87.7	86.5	90.8	93.6	95.9
4.75		<90	52.6	54.3	54.8	61.8	66.7	53.6	57.9	54.9	56.0
2.36	34-58	38-67	33.3	36.6	37.9	42.2	47.0	32.8	42.5	30.9	38.8
1.18			24.8	24.4	27.7	28.0	34.3	23.8	34.0	20.3	30.7
0.6			19.8	18.2	22.0	18.7	24.2	18.8	25.9	14.7	25.3
0.3			13.0	11.8	16.3	12.9	14.7	12.6	16.0	9.9	13.5
0.075	2-10	2-10	5.5	5.7	5.8	7.2	7.1	5.6	6.3	4.9	6.1
% AC			5.9	5.1	5.8	6.2	5.4	6.3	5.6	5.0	5.7

The mixes were modified by adding 0, 0.5, and 1 percent additional asphalt, and then various tests were performed to predict whether additional asphalt changed properties that indicated a possible improvement in durability. The laboratory tests performed included density (air voids), permeability, rutting, and fatigue (Table 2). Cores were also taken from the pavement to determine the pavement density being achieved in the field. Rutting tests were included to verify that the additional asphalt would not result in rutting failures.

Table 2. Number of Laboratory Tests Performed for Each Mix

Type of Test	Without Additional Asphalt	With 0.5% Additional Asphalt	With 1.0% Additional Asphalt
Compaction effort	9	-----	-----
Pavement voids prediction	3	3	3
Permeability	3	3	-----
Rut	3	3	3
Fatigue	3	3	3*
Marshall	3	3	3
Total	33	12	12*

*Fatigue tests with 1.0% additional asphalt were performed on only five of the nine mixes.

Tests

Air Voids

The first step in the investigation was to determine the laboratory compactive effort that yielded the same air voids that had been achieved in the field for each mix. The Superpave gyratory compactor (SGC) was used to compact the laboratory specimens. Each mix was compacted at several levels of effort, the air voids were determined, and the number of gyrations producing the same level of field voids was selected as illustrated for one of the mixes in Figure 1. Most of the compactive efforts used were those believed to produce void levels equal to the field voids. However, one additional higher compactive design level was available for the plot.

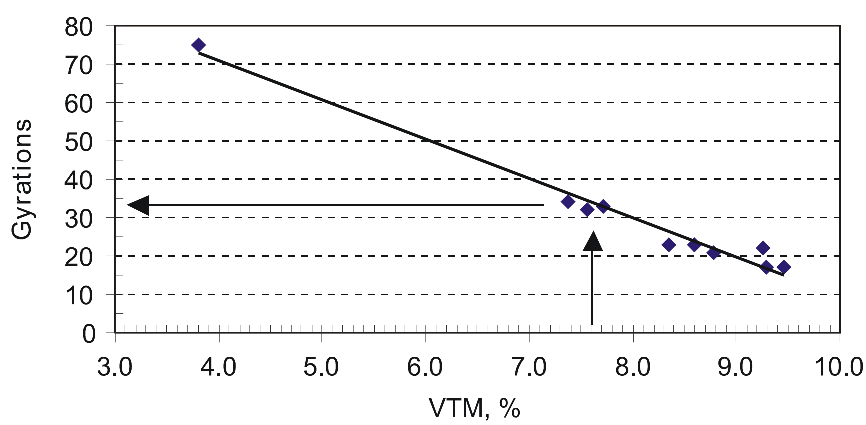

Figure 1. Determination of Laboratory Compactive Effort to Duplicate Pavement Voids

Specimens were made at the selected compactive level, and voids were measured to predict the void level of the mixes if more asphalt was added. The same specimens were used to perform permeability tests. Voids were also measured on specimens compacted with the Marshall hammer using a 50-blow compactive effort because VDOT had a great deal of experience with the Marshall design method.

Permeability

The same specimens used to predict pavement voids were also tested for permeability. A reduction in permeability by adding asphalt would be beneficial because it would lessen the chance of stripping. Permeability tests were performed in accordance with VTM-120, Virginia Test Method for Measurement of Permeability of Bituminous Paving Mixtures Using a Flexible Wall Permeameter,[3] which mimics very closely a provisional ASTM procedure. The test used a simple flexible wall falling head permeameter to test specimens that had been saturated with water.

Rutting

Rutting tests were performed in accordance with VTM-110, Virginia Test Method for Determining Rutting Susceptibility Using the Asphalt Pavement Analyzer,[3] to ensure that mixes were not only durable but also resistant to rutting. The Asphalt Pavement Analyzer (APA) was used to test 3 x 5 x 12 in beams. Each beam was subjected to 8,000 cycles at a test temperature of 120 °F and a wheel load of 120 lb.

Fatigue

Flexural beam fatigue tests were performed according to AASHTO Provisional Standard TP8-94, Standard Test Method for Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Loading.[4] The test utilized 2 x 2.5 x 14.7 in beams tested at 20 °C at a repeated sinusoidal mode of loading using a strain level of 600 $\mu\varepsilon$ on the outer surface of the beam. Each beam was sawed with a water-cooled saw to the required dimensions before testing. As specified by the test method, failure was defined as a 50 percent decrease in the beam stiffness.

RESULTS

Voids

Predicted Pavement Voids

As indicated previously, specimens were compacted using the number of gyrations on the SGC that yielded the pavement density measured on cores taken from the road. The number of gyrations determined from the type of plots illustrated in Figure 1 and used to compact the specimens are listed in Table 3. The wrong number of gyrations was used for mix 1093; therefore, the results are invalid for the predicted pavement voids and permeability phases of this investigation, which used the same specimens.

Table 3. Pavement Voids and Number of Gyrations Used to Compact Specimens

Mix ID	Target Pavement Air Voids, %	Number of Gyrations
12.5 mm Mixes		
1082	10.3	18
1084	8.4	16
1089	9.0	16
1093	6.7	21
1101	9.9	20
9.5 mm Mixes		
1081	10.1	18
1086	7.6	33
1091	7.4	55
1098	7.5	24

Figure 2 shows the predicted pavement voids of four 12.5 mm mixes with 0, 0.5, and 1.0 percent additional asphalt. Each 0.5 percent of additional asphalt decreased voids approximately 1.5 percent. The same magnitude of decrease in pavement air voids is predicted in Figure 3 for the 9.5 mm mixes. A 1.5 to 3.0 percent decrease in air voids would be beneficial for the durability of the mixes because it would decrease aging and the penetration of rainwater.

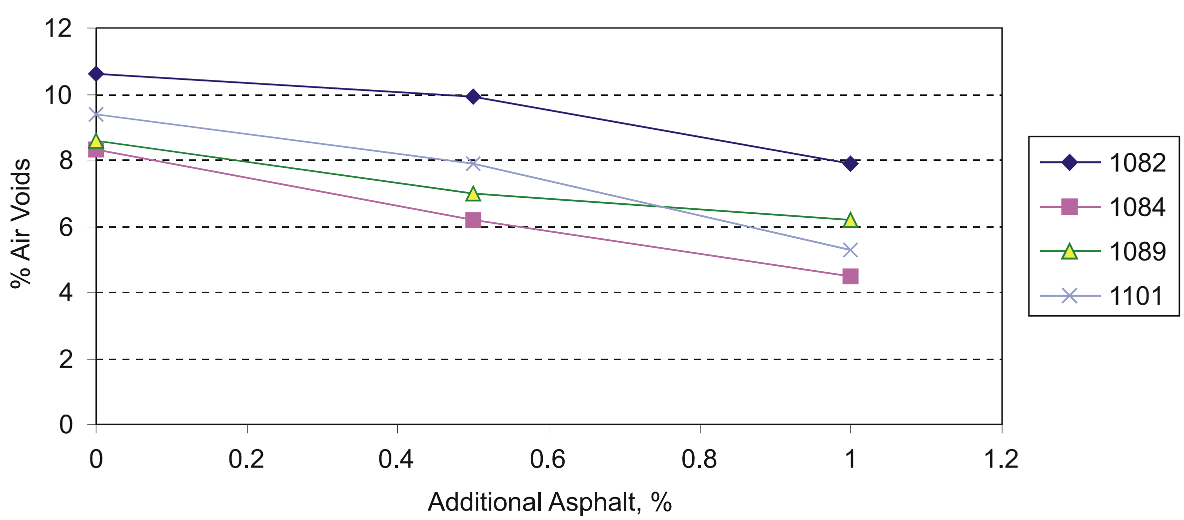

Figure 2. Predicted Pavement Air Voids for 12.5 mm Mixes

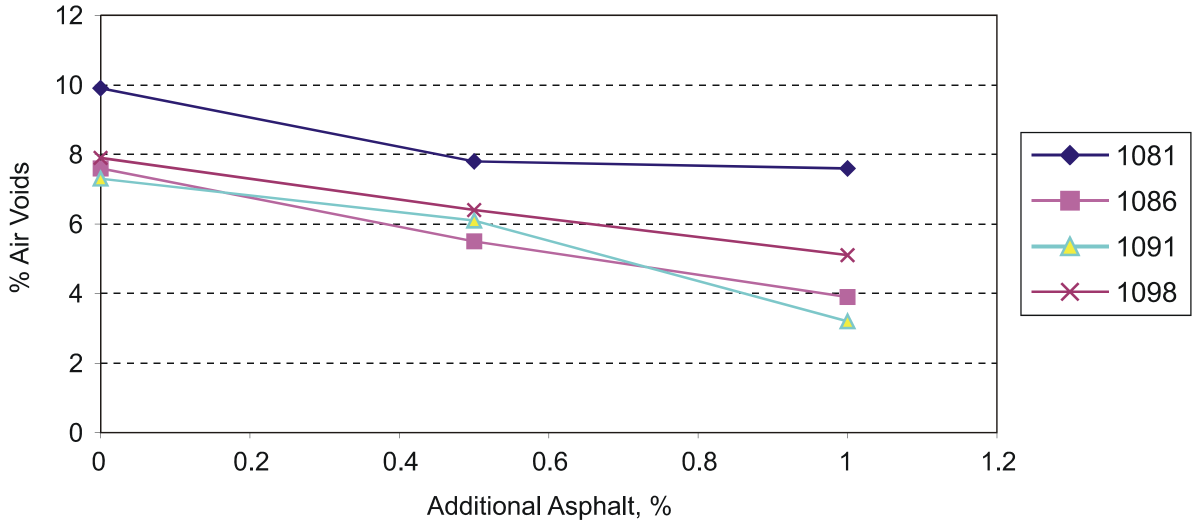

Figure 3. Predicted Pavement Air Voids for 9.5 mm Mixes

To minimize required maintenance, the contractors for the design-build-warranty project on Route 288 near Richmond, Virginia are targeting pavement voids at around 6 percent.[5] The low voids help prevent premature aging and entrance of water, which results in stripping. The mixes could have used 0.5 percent additional asphalt, and several could have tolerated as much as 1.0 percent.

Estimated Design Asphalt Content at 65 Gyrations

An analysis of voids data was used to verify that the asphalt content of the mixes tested was consistent with the present designs currently being done at 65 gyrations. As stated previously, each mix was compacted at various numbers of gyrations to obtain the laboratory compaction level that matched the field voids. In addition, volumetric data were obtained for specimens compacted at the design number of gyrations, which was 65 or 75 gyrations depending on whether the mix was an A or D designation, respectively. The plots in Figure 1 were used to estimate what the void level would have been at 65 gyrations for the D mixes. Also, the design asphalt content at 65 gyrations and 4 percent voids for the D mixes was estimated from a formula used in the Superpave design procedure:

$$P_{b,\,est} = P_{bi} - (0.4(4 - V_a))$$

where

$P_{b,\,est}$ = estimated asphalt content at 65 gyrations

P_{bi} = known asphalt content of mix

V_a = % air voids of mix at 65 gyrations obtained from the plot (Figure 1), These estimates would be considered to be within about 0.2 percent of the actual design asphalt content at 65 gyrations. These results and sample results and design values are listed in Table 4. The asphalt contents of the 12.5 mm mixes appeared to be very close to estimated design asphalt contents with the exception of that of mix 1101; therefore, these mixes are considered to be representative of mixes being produced currently. However, mix 1101 should have contained considerably more asphalt for good performance. The asphalt content of most mixes was slightly higher than cited design values, possibly so that the contractor could achieve the required pavement density.

The estimated design asphalt content at 65 gyrations for the 9.5 mm mixes were also very close to the actual asphalt content with the exception of mix 1091. Therefore, these mixes are also very representative of mixes currently being produced. Mix 1091 should have contained more asphalt.

Table 4. Estimated Design Asphalt Content at 65 Gyrations

Mix ID	Sample	Mix Design		At 65 Gyrations	
	P_{bi}, % AC	Number of Gyrations	% AC	V_a, Estimated % Air Voids of Sample	$P_{b,\,est}$ Estimated Design % AC at 4% Voids
12.5 mm					
1082	5.9	75	5.7	4.4	6.1
1084	5.1	75	4.9	3.4	4.9
1089	5.8	65	5.7	3.4	5.6
1093	6.2	65	6.0	2.7	5.7
1101	5.4	75	5.3	5.5	6.0
9.5 mm					
1081	6.3	75	6.0	4.4	6.5
1086	5.6	75	5.6	4.6	5.8
1091	5.0	65	5.4	6.2	5.9
1098	5.7	75	5.5	4.1	5.7

Marshall Voids

The voids of Marshall specimens with 0, 0.5, and 1.0 percent additional asphalt compacted by the 50-blow effort are shown in Figures 4 and 5. The design criterion for air void content is usually 4.0 percent. The 50-blow effort was usually used for roads with low traffic; therefore, the design air voids for D mixes used under moderately high traffic should probably be slightly higher than 4.0.

The range of percent voids for the 12.5 mm mixes with no additional asphalt cement was 4.8 to 7.3, which would be considered high if 4.0 percent is considered to be the design target value. The range of voids for the specimens with 0.5 percent additional asphalt was 3.2 to 4.7, which would be considered reasonable for good performance. Most of the voids for the mixes with 1.0 percent additional asphalt would be considered too low for good performance. Without question, mix 1101 could have contained 0.5 percent or more additional asphalt. It is not clear whether D mixes 1082 and 1084, which formally were designed with 75 blows and placed under high traffic conditions, could have tolerated at least 0.5 percent of additional asphalt.

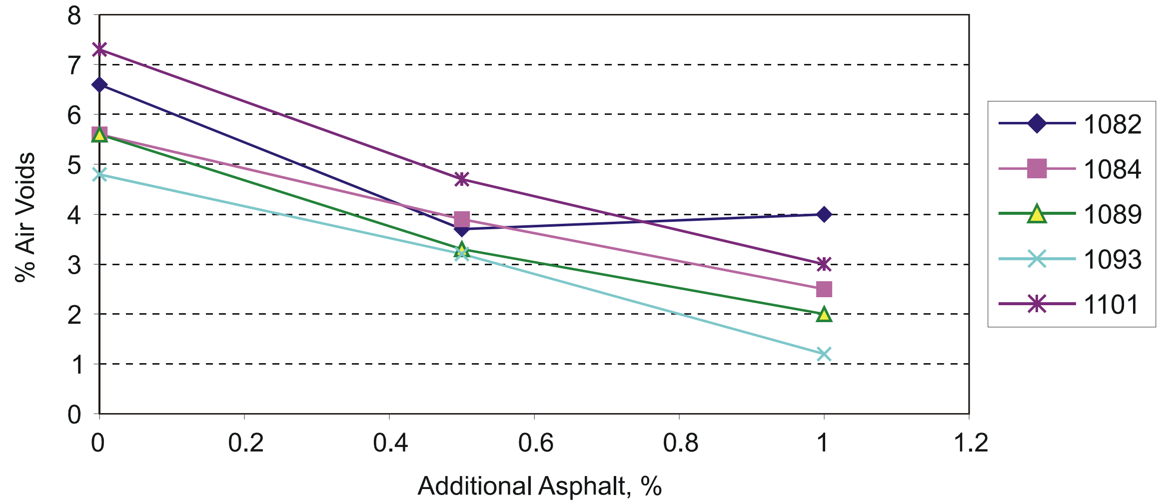

Figure 4. Air Voids of 50-blow Marshall Specimens for 12.5 mm Mixes

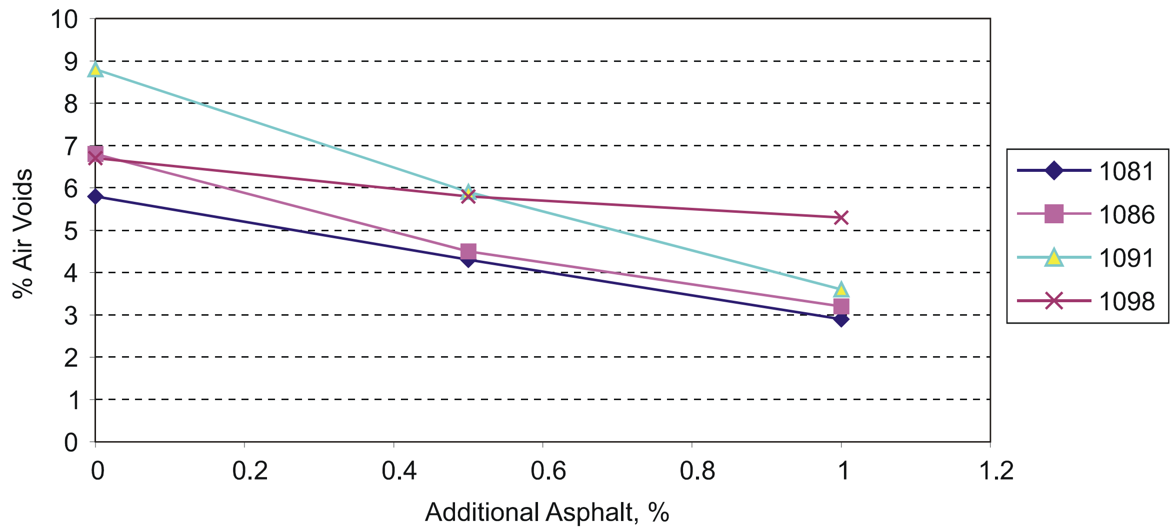

Figure 5. Air Voids of 50-blow Marshall Specimens for 9.5 mm Mixes

The range of voids for the 9.5 mm mixes with no additional asphalt cement was 5.8 to 8.8 percent, which would also be considered high. The range of voids with 0.5 percent additional asphalt cement was 4.3 to 5.9, which is still slightly high. According to the Marshall results, the 9.5 mm mixes could probably have contained 0.5 percent or more additional asphalt.

Permeability

Permeability results are shown in Figures 6 and 7. VDOT has tentatively set a value of 125×10^{-5} cm/sec as the maximum allowable permeability for new mix designs in 2004. Two mixes with no additional asphalt in each of the 12.5 mm and 9.5 mm mix groups had a permeability greater than the acceptable value of 125×10^{-5} cm/sec. When 0.5 percent asphalt

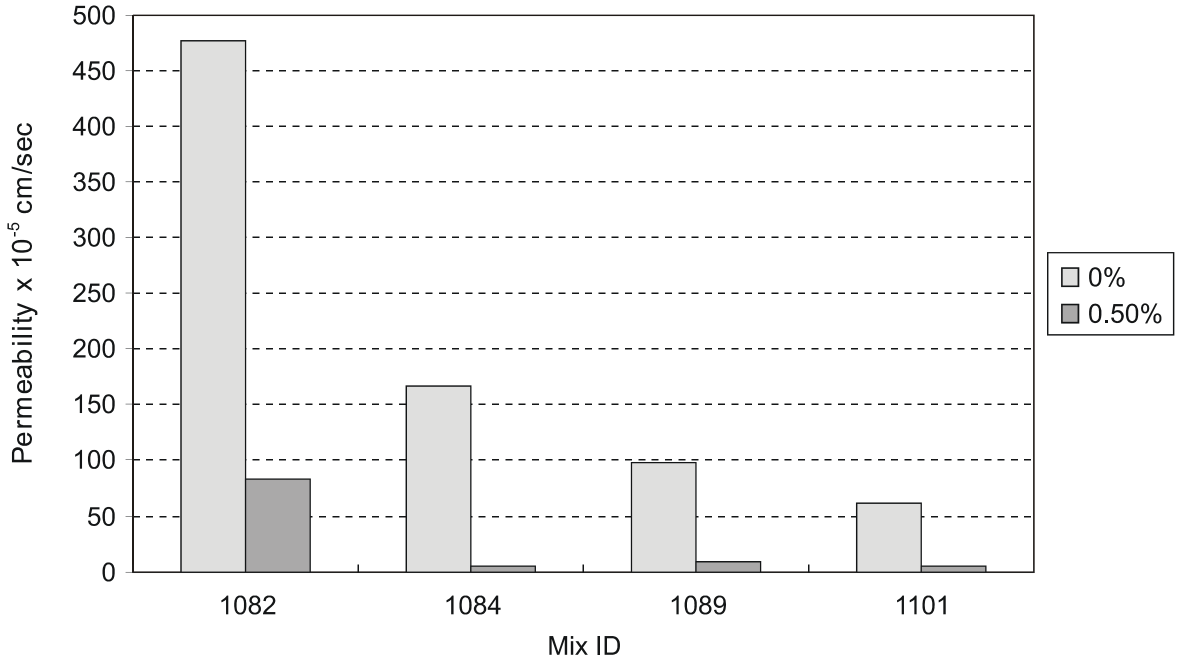

Figure 6. Permeability Before and After Adding Asphalt to 12.5 mm Mixes

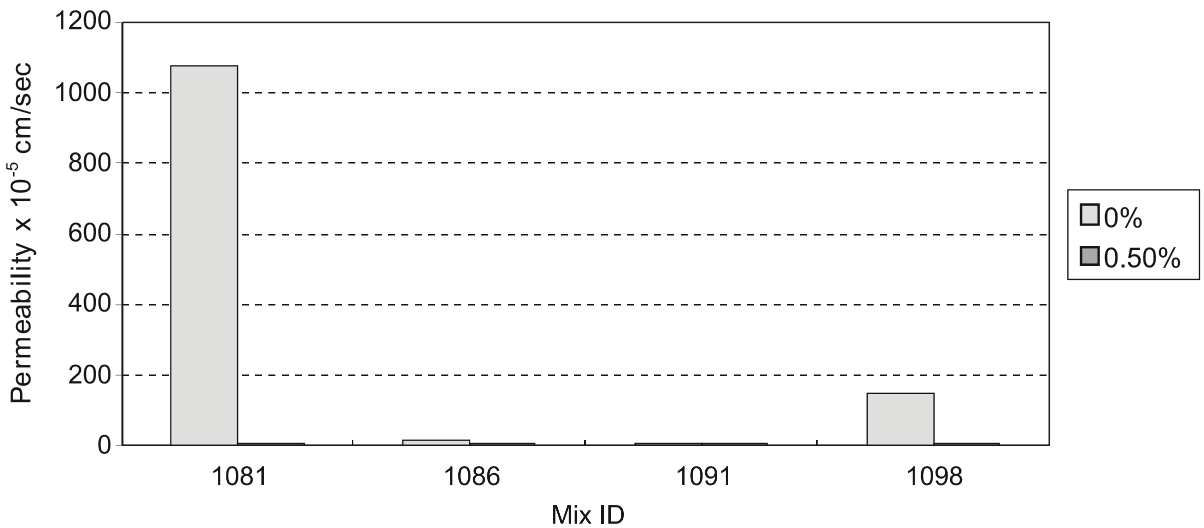

Figure 7. Permeability Before and After Adding Asphalt to 9.5 mm Mixes

was added, the permeability dropped below the maximum acceptance value and was even near 0 (almost impermeable) in most cases. Therefore, it is obvious that an additional 0.5 percent of asphalt would be very beneficial for permeability. The permeability is low enough with 0.5 percent additional asphalt so that little would be gained by adding more than 0.5 percent.

Rutting Tests

The results of the rutting tests and acceptance criteria for VDOT are shown in Table 5. An attempt was made to compact the specimens containing no added asphalt to approximately 8 percent air voids as specified by the VDOT test method. However, the specimens containing additional asphalt were made to have reduced voids to somewhat reflect the voids that would have resulted had more asphalt been added in the field. None of the test results, even for the specimens containing additional asphalt, reflected values greater than the allowable maximum values. It also appears that additional asphalt did not increase rutting for some mixes and decreased it slightly for some when 1.0 percent asphalt was added. This is an indication that the mixes did not contain enough asphalt to decrease shear strength and substantially increase rutting.

Table 5. Results of Rutting Tests

Mix ID	Rutting, mm/Void Content, %			
	Maximum Allowable, mm	Additional Asphalt, %		
		0.0	0.5	1.0
12.5 mm Mixes				
1082	5.5	1.3 / 7.4	2.9 / 6.6	2.3 / 5.6
1084	5.5	1.1 / 6.9	2.8 / 6.2	1.9 / 3.9
1089	7.0	0.9 / 6.9	2.9 / 5.8	3.8 / 4.4
1093	7.0	4.2 / 8.1	4.9 / 6.3	4.2 / 3.3
1101	5.5	2.4 / 8.4	2.2 / 7.2	3.6 / 5.1
9.5 mm Mixes				
1081	5.5	1.6 / 7.6	2.7 / 6.7	1.2 / 2.0
1086	5.5	1.2 / 7.5	2.1 / 6.6	1.8 / 5.4
1091	7.0	2.4 / 8.8	2.5 / 7.0	3.2 / 6.5
1098	5.5	1.5 / 7.8	2.0 / 6.3	2.7 / 5.2

Fatigue Tests

The results of the fatigue tests are shown in Figures 8 and 9. Not all mixes were tested with 1.0 percent additional asphalt because of a lack of material. An attempt was made to manufacture the beam specimens containing no additional asphalt to match typical pavement voids (8.0 percent) and decrease voids slightly in the beams containing additional asphalt to simulate the pavement voids that would have been achieved.

For the 12.5 mm mixes, the average air voids were 7.4, 6.6, and 7.5 percent containing 0, 0.5, and 1.0 percent additional asphalt, respectively. The voids target was lower than the 7.5 percent attained for the beams containing 1.0 percent additional asphalt; therefore, the author believes that the fatigue life would have been slightly higher if the lower target voids had been achieved. Figure 8 shows a definite trend for an increase of fatigue life as asphalt content is increased. The increases were slight at 0.5 percent for all four mixes but substantially higher at 1.0 percent for three of the mixes.

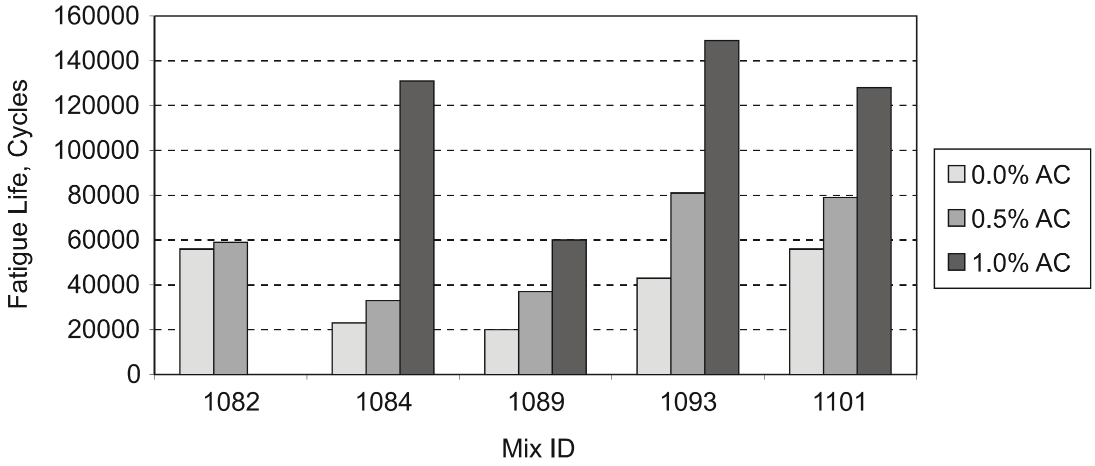

Figure 8. Effect of Additional Asphalt on Fatigue Life of 12.5 mm Mixes

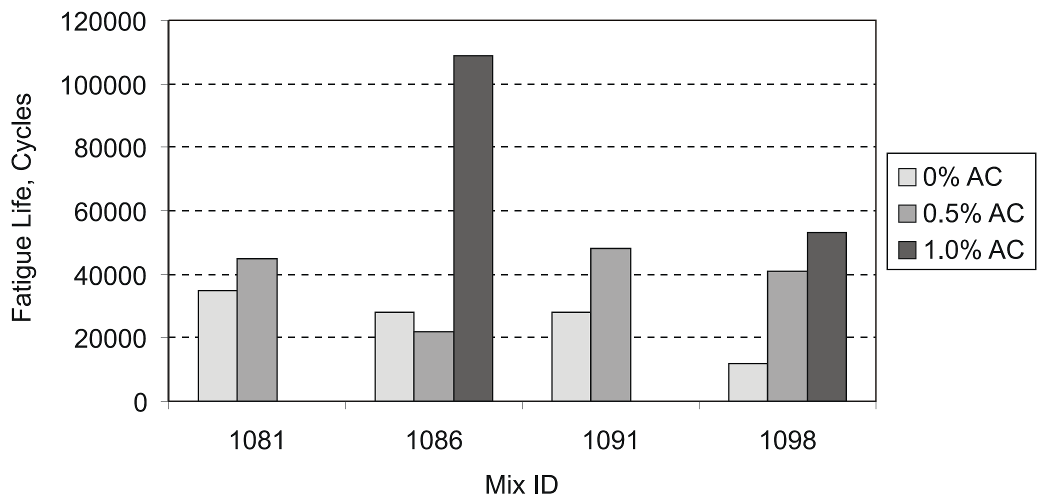

Figure 9. Effect of Additional Asphalt on Fatigue Life of 9.5 mm Mixes

For the 9.5 mm mixes, the air voids were 8.1, 7.4, and 6.45 percent for the mixes containing 0.0, 0.5, and 1.0 percent additional asphalt, respectively. There was a slight increase in fatigue life at 0.5 percent for three of the four 9.5 mm mixes shown in Figure 9. One of the two mixes tested with 1.0 percent additional asphalt showed a significant increase in fatigue life.

Laboratory fatigue results should be viewed as relative comparisons between mixes and not as being directly related to field fatigue results. However, the results of these tests indicate that some fatigue benefit would likely be obtained if 0.5 to 1.0 percent asphalt could be added to all of the mixes sampled. Additional amounts below 0.5 percent would be of questionable benefit.

SUMMARY AND CONCLUSIONS

Table 6 indicates how various test properties were influenced and whether the mix was satisfactory at the two levels of additional asphalt. Predicted pavement voids decreased as expected with the addition of 0.5 percent asphalt and remained at a safe beneficial level at around 6 percent for both the 12.5 mm and 9.5 mm mixes. Only three of the eight mixes were at a safe void level with the addition of 1.0 percent asphalt.

Table 6. Summary of Results

Mix ID	Predicted Pavement Voids		50-blow Marshall Voids		Perm.	Fatigue		Rutting	
	0.5%	1.0%	0.5%	1.0%	0.5%	0.5%	1.0%	0.5%	1.0%
12.5 mm									
1082	D/S	D/S	D/S	D/S	D/S	NC	---	I/S	I/S
1084	D/S	D/U	D/S	D/U	D/S	NC	I	I/S	I/S
1089	D/S	D/S	D/U	D/U	D/S	I	I	I/S	I/S
1093	----	----	D/U	D/U	----	I	I	I/S	NC/S
1101	D/S	D/S?	D/S	D/U	D/S	I	I	NC/S	I/S
9.5 mm									
1081	D/S	D/S	D/S	D/U	D/S	NC	---	I/S	NC/S
1086	D/S	D/U	D/S	D/U	D/*	NC	I	I/S	I/S
1091	D/S	D/U	D/S	D/U	D/*	NC	---	NC/S	I/S
1098	D/S	D/U	D/S	D/S	D/S	I	NC	I/S	I/S

Perm. = permeability; NC = no change; I = increase; D = decrease; S = Satisfactory; U = Unsatisfactory;
* = practically impermeable with no additional asphalt.

The benefit of reducing the pavement voids to a level around 6 percent is obvious. Warranty projects planned and designed by contractors that are responsible for upkeep are resulting in mixes that can be compacted in the field to a 6 percent air void level. To minimize required maintenance, the contractors for the design-build-warranty project on Route 288 near Richmond, Virginia, are targeting pavement voids around 6 percent.[5] The low voids help prevent premature aging and the entrance of water that results in stripping.

Seven of the nine mixes were reasonably close to the design standard of 4 percent voids for a 50-blow Marshall compactive effort when 0.5 percent asphalt was added, and these mixes were considered to be satisfactory. Only two of the mixes were satisfactory when 1.0 percent asphalt was added.

The permeability of all mixes was considered acceptable when 0.5 percent asphalt was added. In fact, after asphalt was added, seven of the eight mixes tested were nearly impermeable. Therefore, there was a tremendous benefit in reducing permeability when only 0.5 percent asphalt was added.

There was a trend for fatigue life to increase as the asphalt content was increased; however, the increase was only slight. Some of the mixes showed a significant increase when 1.0 percent asphalt was added, but that amount could probably not be tolerated because the mix would become too dense. The overall results indicate that the improvement of fatigue life is not large when 0.5 percent asphalt is added but that there would probably be a slight benefit for four of the nine mixes. There are no defined limits for satisfactory performance for fatigue.

Rutting did not appear to be a problem, even with the addition of 1.0 percent asphalt. The rutting acceptance criteria and testing conditions were developed with a limited amount of data by Virginia. National task groups are considering more stringent values; therefore, it is uncertain whether these test results may be relied upon to ensure good field performance.

Generally, the investigation revealed that as much as 0.5 percent asphalt could have been added to the mixes tested with beneficial results. The production of mixes with less air voids decreased permeability, which decreased the likelihood of moisture damage. Pavement voids were also decreased to an ideal level of around 6 percent by adding 0.5 percent asphalt.

It is reasonable to expect that the beneficial effects would increase the life of a surface mix approximately 5 percent. VDOT uses approximately 2 million tons of asphalt in surface overlays per year at a cost of approximately $35 per ton. Although the cost of 0.5 percent additional asphalt would be approximately $1 per ton, an estimated increased service life of 5 percent would save VDOT approximately $1.5 million per year.

RECOMMENDATION

The Asphalt Section of VDOT's Materials Division should explore ways to incorporate additional asphalt in surface mixes. The increase could be accomplished by adjusting the number of gyrations or the design air content. In addition, short test sections should be constructed to prove that the increases will lead to satisfactory performance in the field. This could be accomplished by simply increasing the asphalt content for several truckloads of mix on selected jobs and evaluating the rutting performance of the pavement.

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