NCAT Report 02-04

DEVELOPMENT OF MIX DESIGN CRITERIA FOR 4.75 MM SUPERPAVE MIXES - FINAL REPORT

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February 2002

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TABLE OF CONTENTS

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BACKGROUND

Within the Superpave mix design system there are mix design criteria for 9.5 to 37.5 mm nominal maximum aggregate size (NMAS) mixes. Many agencies have expressed an interest in using a 4.75 mm NMAS mix because such a mix should result in a very smooth riding surface, be used for thin lift applications, correct surface defects (leveling), decrease construction time, provide a use for manufactured screening stockpiles, and provide a very economical surface mix for low traffic volume facilities.

Past experience with thin hot mix asphalt (HMA) overlays has been positive. In Maryland, these mixes are used as part of a preventive maintenance program and have shown excellent rutting and cracking resistance. Maryland's thin HMA overlay mixes generally contain about 65 percent manufactured screenings and 35 percent natural sand. Gradation requirements for these mixes are shown in Table 1. Based on Table 1, the gradation can have either a 4.75 mm or 9.5 mm NMAS gradation. Typical lift thicknesses in the field are between 19 and 25 mm.

Table 1. Maryland Design Specifications for 4.75 mm Mixtures (*1*)

Grading Requirements	
% Passing 9.5 mm Sieve	100
% Passing 4.75 mm Sieve	80 - 100
% Passing 2.36 mm Sieve	36 - 76
% Passing 0.075 mm Sieve	2 - 12
Design Requirements	
Range for Asphalt Content, %	5.0 - 8.0
Design Optimum Air Voids, %	4.0

The Georgia DOT has used a 4.75 mm NMAS-like mix for over 30 years for low volume roads and leveling purposes (*2*). Good performance has been provided by the mix, provided it is placed in thin lifts (approximately 25 mm max.). These Georgia mixes have been primarily comprised of screenings with a small amount of No. 89 sized stone resulting in approximately 60 to 65 percent passing the 2.36 mm (No. 8) sieve and an average of about 8 percent dust (Table 2). A graph of the typical gradations used in Maryland and Georgia is provided in Figure 1.

The Georgia mix is currently designed using the Superpave gyratory compactor with a N_{design} of 50 gyrations. Design air voids range from 4 to 7 percent. With these mixes, a higher design air void content is sometimes used to allow a lower binder content for economic considerations, without reducing the mix durability. These mixes are not as open to water and air at the same air void level as other larger NMAS mixes.

Recent research at NCAT has been conducted to evaluate the effectiveness of using 100 percent processed aggregate screenings for HMA mixes (*4*). The primary focus of this research was to develop a mix which could utilize large amounts of processed aggregate screenings that have accumulated due, in part, to the increased use of coarse-graded mixes.

Table 2. Georgia Design Specifications for 4.75 mm Mixtures (3)

Grading Requirements	
% Passing 12.5 mm Sieve	100
% Passing 9.5 mm Sieve	90 - 100
% Passing 4.75 mm Sieve	75 - 95
% Passing 2.36 mm Sieve	60 - 65
% Passing 0.30 mm Sieve	20 - 50
% Passing 0.075 mm Sieve	4 - 12
Design Requirements	
Range for Asphalt Content, %	6.0 - 7.5
Design Optimum Air Voids, %	4.0 - 7.0
% Aggregate Voids Filled with Asphalt	50 - 80

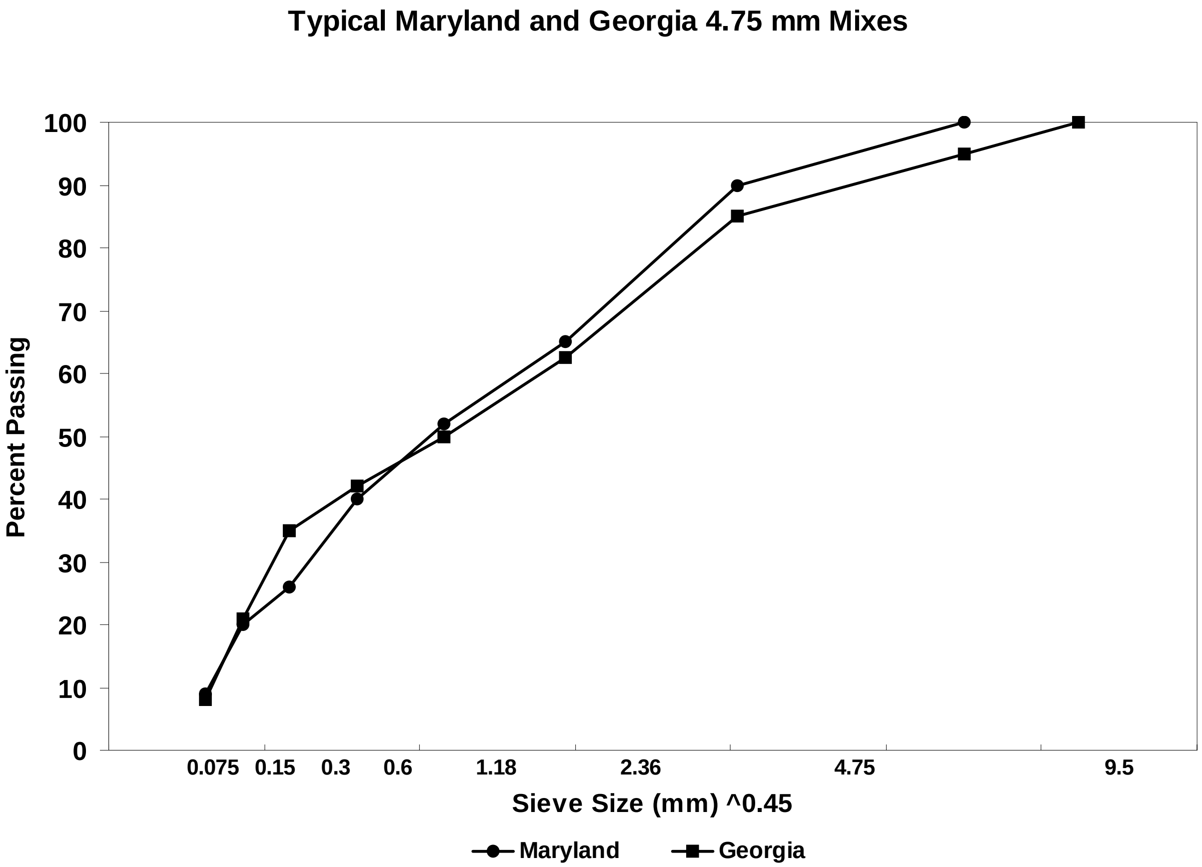


Figure 1. Mid-Band Gradations for the Maryland and Georgia Mixes

Granite and limestone screenings, whose gradations are shown in Table 3, were designed in NCAT's research using the Superpave gyratory compactor at a N_{design} = 100 gyrations for 4, 5, and 6 percent air voids. Both of the mixes had 4.75 mm NMAS gradations, with the granite mix being considerably finer than the limestone.

Table 3. Screening Study Gradations

Sieve Size (mm)	Percent Passing	
	Granite M-10's	Limestone 821's
9.5	100.0	100.0
4.75	98.7	91.6
2.36	81.8	68.5
1.18	65.7	45.3
0.6	52.3	30.3
0.3	38.1	21.4
0.15	24.1	15.5
0.075	14.4	12.0

The volumetric properties and rut testing (Asphalt Pavement Analyzer) results for mixes using these two aggregates are shown in Table 4. The granite mixes had significantly higher binder contents than the limestone mixes, possibly due to the increased fineness and rougher surface texture of the granite. Based on rut testing shown in Table 4, it generally appears that the screening mixes have the potential to provide good rut resistance.

Based upon past field and lab experience, it is evident that 4.75 mm mixes can be used successfully for certain applications. However, there needs to be a set of standard mix design criteria established for their use, much like the Superpave mix criteria for 9.5 to 37.5 mm nominal maximum size mixes.

Table 4. Test Results for Screening Mixes Using Two Aggregate Types

Mix	Air Voids	Effective Binder (%)	VMA (%)	VFA (%)	Dust/ Binder	Rut Depth (mm)
Granite M-10's	4	7.63	21.0	81.9	1.89	8.77
Limestone 821's		3.55	12.2	68.5	3.38	4.00
Granite M-10's	5	7.18	21.0	77.1	2.00	5.45
Limestone 821's		3.15	12.1	61.2	3.81	3.22
Granite M-10's	6	6.63	21.8	71.4	2.17	5.53
Limestone 821's		2.79	12.9	50.4	4.30	3.65

OBJECTIVES

The objective of this study was to develop mix design criteria for 4.75 mm nominal maximum aggregate size mixes. Criteria targeted in the research were gradation controls and volumetric property requirements (air voids, VMA, VFA, and dust-to-binder ratio).

TEST PLAN

Two commonly used aggregate types were utilized in this study: granite and limestone. For each of the two aggregates, three general gradation shapes were evaluated: coarse (passing below the maximum density line), medium (passing near the maximum density line), and fine (passing above the maximum density line). These general gradation shapes are illustrated in Figure 2 and represent the practical ranges that could be produced in the field.

For each of the three gradation shapes, three dust (passing 0.075 mm sieve) contents were evaluated: 6, 9 and 12 percent. The varying dust contents were investigated to evaluate the effect of dust on the volumetrics and rutting resistance of these 4.75 mm NMAS mixes. Additionally, different stockpiles used to blend 4.75 mm NMAS mixes will likely have varying degrees of dust.

When designing 4.75 mm NMAS mixes, the design air voids could be increased from the Superpave standard of 4 percent, and still provide an acceptable performing mix. This was evaluated by designing mixes to 4 and 6 percent air voids. As mentioned previously, the 4.75 mm NMAS mixes used by Georgia DOT have a range of design air voids from 4 to 7 percent and have provided good stability and durability performance in the field.

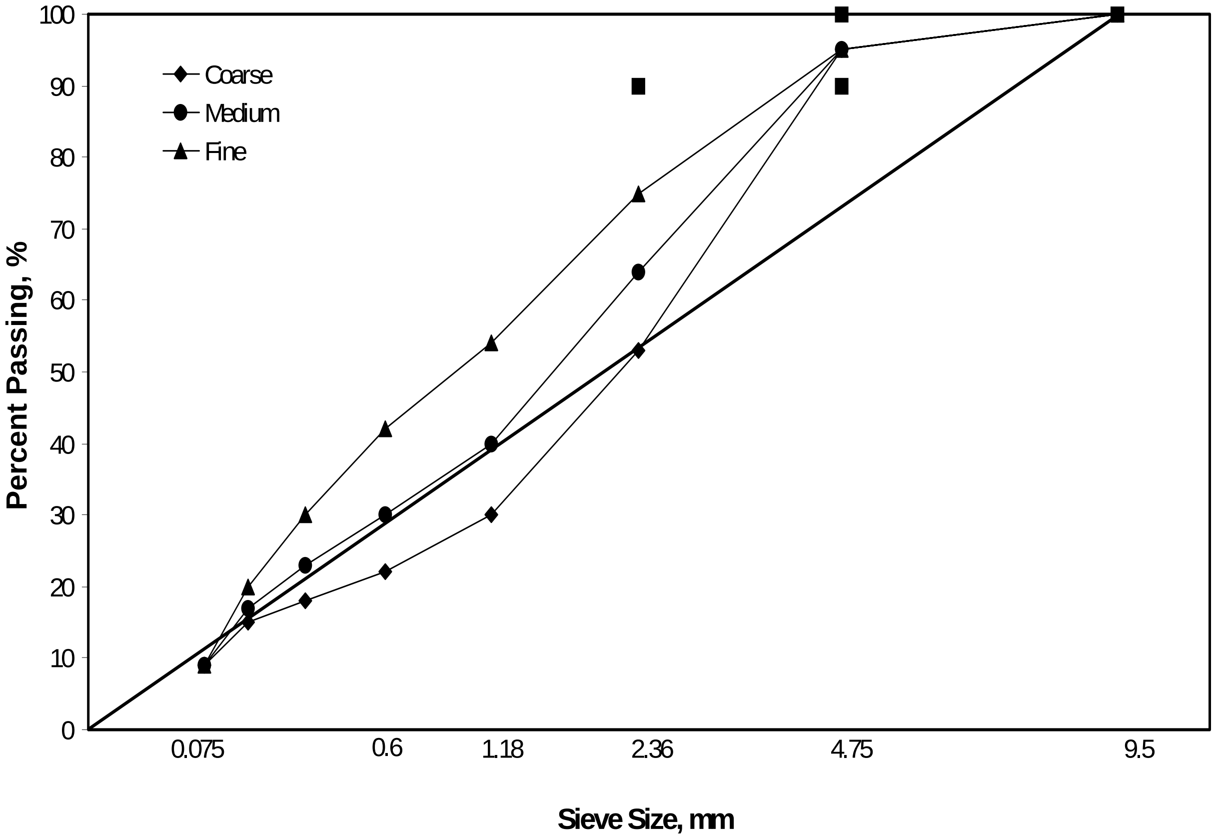


Figure 2. General Gradation Shapes Used in Study

The design compactive effort (N_{design}) used in this study was 75 gyrations which corresponds to an equivalent single axle load (ESAL) range of 0.3 to 3 million under current Superpave specifications (AASHTO PP28-00). A PG 64-22 (that also meets requirements for a PG 67-22) was used for all the mixes.

Thus, for the study, there were a total of 36 designed mixes (2 aggregate types * 3 general gradation shapes * 3 dust contents * 2 design air void levels = 36 total mixes). For each mix, the volumetric properties (VMA, VFA, and dust to effective binder ratio), and gyratory compaction parameters (% G_{mm} @ $N_{initial}$) were evaluated to determine the degree of variation resulting from the various study parameters.

In order to evaluate the stability of each mix, rut testing was conducted with the Asphalt Pavement Analyzer (APA). Test conditions included in this research were a test temperature of 64°C, wheel load of 534 N (120 lbs), and hose pressure of 827 kPa (120 psi). Samples used in the rut testing were cylindrical samples that were normal mix design size samples (. 115 mm height) compacted at the appropriate binder content (4 or 6 percent design air voids) to the design number of gyrations.

TEST RESULTS AND ANALYSIS

Table 5 presents the results of testing on the two aggregates used in this study: granite and limestone. Both aggregates have similar absorptive characteristics; however, the limestone has a slightly higher specific gravity (bulk and apparent). The granite had a higher fine aggregate angularity value.

Table 5. Aggregate Properties

Property	Procedure	Granite	Limestone
Bulk Specific Gravity	AASHTO T84	2.663	2.714
Apparent Specific Gravity	AASHTO T84	2.707	2.758
Water Absorption, %	AASHTO T84	0.6	0.6
Fine Aggregate Angularity, %	AASHTO T304	49.0	46.0

Tables 6 and 7 present the results of mix designs conducted on the 36 mixes. Results are provided for optimum binder content, voids in mineral aggregate (VMA), voids filled with asphalt (VFA), % G_{mm}@N_{ini}, effective binder content, dust-to-effective binder ratio, and film thickness.

Optimum binder contents ranged from a low of 4.2 percent to a high of 8.0 percent (Figure 3). On average the granite mixes had a higher optimum binder content (average of 5.9 percent) than the limestone mixes (average of 5.4 percent). The higher optimum binder contents for the granite mixes are likely the result of the granite aggregates having more surface texture than the limestone aggregates. As the percent passing the 0.075 mm sieve ($P_{0.075}$) increased, optimum binder content decreased. Mixes having 6 percent $P_{0.075}$ had an average optimum binder content of 6.2 percent followed by the 9 percent $P_{0.075}$ and 12 percent $P_{0.075}$ (5.6 and 5.1 percent optimum binder content, respectively). Increasing the $P_{0.075}$ by 3 percent reduced optimum binder content by about 0.5 percent on average. Optimum binder content was also affected by the general gradation shape. Mixes having a fine gradation had the highest average optimum binder content (6.0 percent) followed by the coarse gradation (5.7 percent) and medium gradation (5.2 percent). It was not unexpected that mixes utilizing the medium gradation would have the lowest average optimum binder content as this gradation fell near the maximum density line below the 1.18 mm

Table 6. Results of Mix Designs Conducted on Granite Aggregate

Gradation	Dust Content, %	Design Air Void Level, %	Total Binder Content, %	VMA, %	VFA, %	$\%G_{mm}$@ N_{ini}	Eff. Binder Content, %	Dust-to-Eff. Binder Ratio	Film Thickness, :m
Coarse	6.0	4	6.7	18.2	78.0	87.3	6.2	0.97	8.87
		6	6.0	18.5	67.6	85.8	5.5	1.09	7.81
	9.0	4	6.2	17.0	76.5	87.2	5.7	1.58	7.15
		6	5.4	17.2	65.1	85.2	4.9	1.84	6.09
	12.0	4	5.8	16.2	75.3	87.0	5.4	2.22	6.03
		6	5.0	16.5	63.6	85.1	4.6	2.61	5.09
Medium	6.0	4	6.2	17.5	77.1	88.8	5.8	1.03	7.23
		6	5.6	17.7	66.1	87.2	5.2	1.15	6.44
	9.0	4	5.7	15.9	74.8	88.5	5.2	1.73	5.76
		6	5.0	16.3	63.2	86.7	4.5	2.00	4.95
	12.0	4	5.2	14.9	71.5	88.0	4.8	2.61	4.78
		6	4.7	15.6	60.2	86.2	4.3	2.93	4.26
Fine	6.0	4	8.0	20.8	80.8	89.9	7.5	0.80	8.10
		6	7.0	20.4	70.6	88.0	6.5	1.08	6.95
	9.0	4	6.8	18.4	78.2	89.2	6.3	1.42	6.10
		6	5.9	18.2	67.0	87.5	5.4	1.67	5.18
	12.0	4	5.8	16.2	75.3	89.5	5.3	2.26	4.65
		6	5.1	16.5	63.6	87.7	4.6	2.61	4.01

Table 7. Results of Mix Designs Conducted on Limestone Aggregate

Gradation	Dust Content, %	Optimum Air Void Level, %	Total Binder Content, %	VMA, %	VFA, %	$\%G_{mm}$@ N_{ini}	Eff. Binder Content, %	Dust-to-Eff. Binder Ratio	Film Thickness, μm
Coarse	6.0	4	6.1	17.7	77.4	86.0	5.8	1.03	8.25
		6	5.5	18.1	66.9	84.0	5.2	1.15	7.35
	9.0	4	5.8	16.5	75.8	86.2	5.3	1.70	6.62
		6	5.2	16.9	64.5	84.6	4.7	1.91	5.83
	12.0	4	5.6	14.9	73.2	85.7	5.1	2.61	5.68
		6	4.8	14.4	58.3	84.0	4.3	3.43	4.75
Medium	6.0	4	5.7	16.5	75.8	86.9	5.3	1.13	6.57
		6	5.0	16.7	64.1	85.8	4.6	1.30	5.66
	9.0	4	5.3	15.4	74.0	86.5	4.8	1.88	5.30
		6	4.6	15.5	61.3	85.3	4.1	2.20	4.49
	12.0	4	4.8	14.2	71.8	86.3	4.3	2.79	4.27
		6	4.2	14.7	59.2	85.5	3.7	3.24	3.65
Fine	6.0	4	6.8	18.5	78.4	88.1	6.3	0.95	6.72
		6	6.0	18.5	67.6	86.5	5.5	1.09	5.81
	9.0	4	6.0	16.6	75.9	87.8	5.4	1.67	5.19
		6	5.2	16.6	63.9	86.4	4.6	1.96	4.38
	12.0	4	5.2	15.4	74.0	87.6	4.8	2.50	4.19
		6	4.6	15.7	61.8	86.1	4.2	2.86	3.64

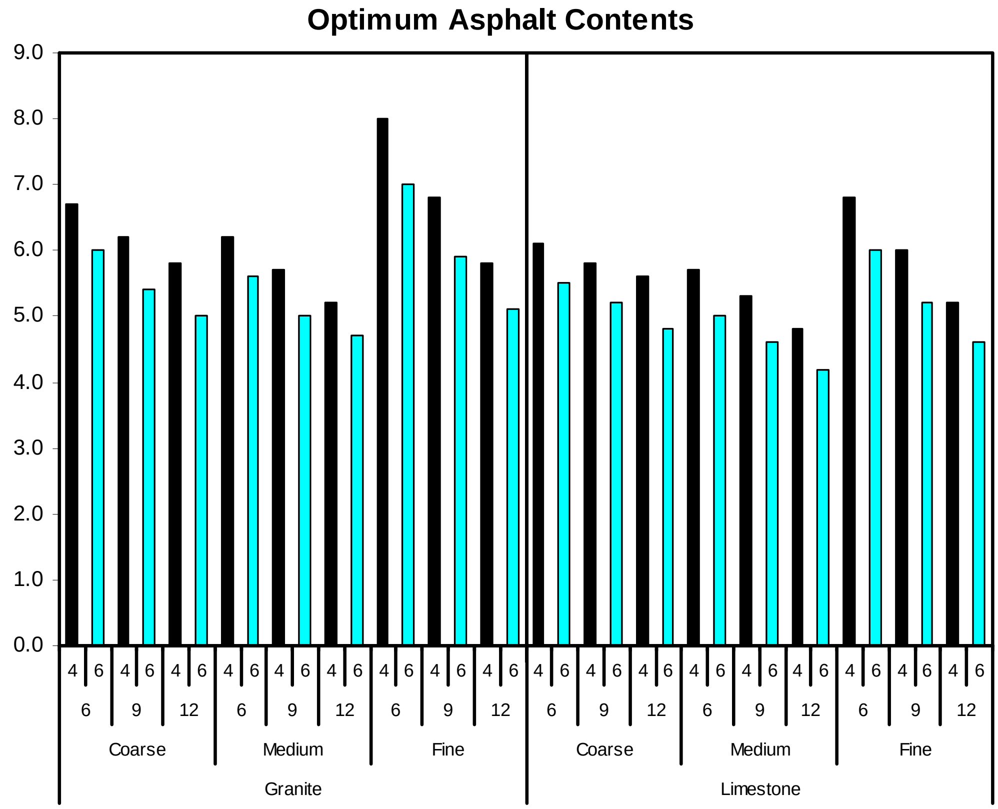


Figure 3 Range in Optimum Binder Contents

(No. 16) sieve. Also as expected, the mixes designed at 4 percent air voids had a higher average optimum binder content (6.0 percent) than the mixes designed at 6.0 percent air voids (5.3 percent). The 2.0 percent range in design air voids, therefore, resulted in about 0.7 percent difference in optimum binder content.

Voids in mineral aggregate (VMA) values for the individual mixes ranged from a high of 20.8 percent to a low of 14.2 percent (Figure 4). As expected, VMA at optimum binder content was affected by the aggregate type, $P_{0.075}$ content, and gradation shape. Design air voids did not appear to significantly affect the overall average VMA values. It was noted during the mix designs that in most cases the VMA curves were relatively flat. The granite mixes had about 1 percent higher VMA (on average) than the limestone mixes (17.3 percent to 16.3 percent, respectively). As the $P_{0.075}$ content increased, the average VMA values decreased. The 6 percent $P_{0.075}$ mixes had an average VMA of 18.3 percent followed by the 9 percent $P_{0.075}$ (16.7 percent VMA) and 12 percent $P_{0.075}$ (15.4 percent VMA). The medium gradation produced the lowest average VMA values (15.9 percent) which was not unexpected since the gradation approached the maximum density line. Fine gradations produced mixes with the highest average VMA values (17.7 percent) while the average VMA value for the coarse gradations was between the fine and medium gradations (16.8 percent).

Percent theoretical maximum density at the initial number of gyrations ($\%G_{mm}@N_{ini}$) ranged from a low of 84.0 percent to a high of 89.9 percent (Figure 5). The $\%G_{mm}@N_{ini}$ values were most affected by aggregate type, gradation shape, and design air void content. Collectively, the granite mixes provided a higher $\%G_{mm}@N_{ini}$ value (87.5 percent) than did the limestone mixes (86.1 percent). This was likely due to the higher overall optimum binder contents for the granite

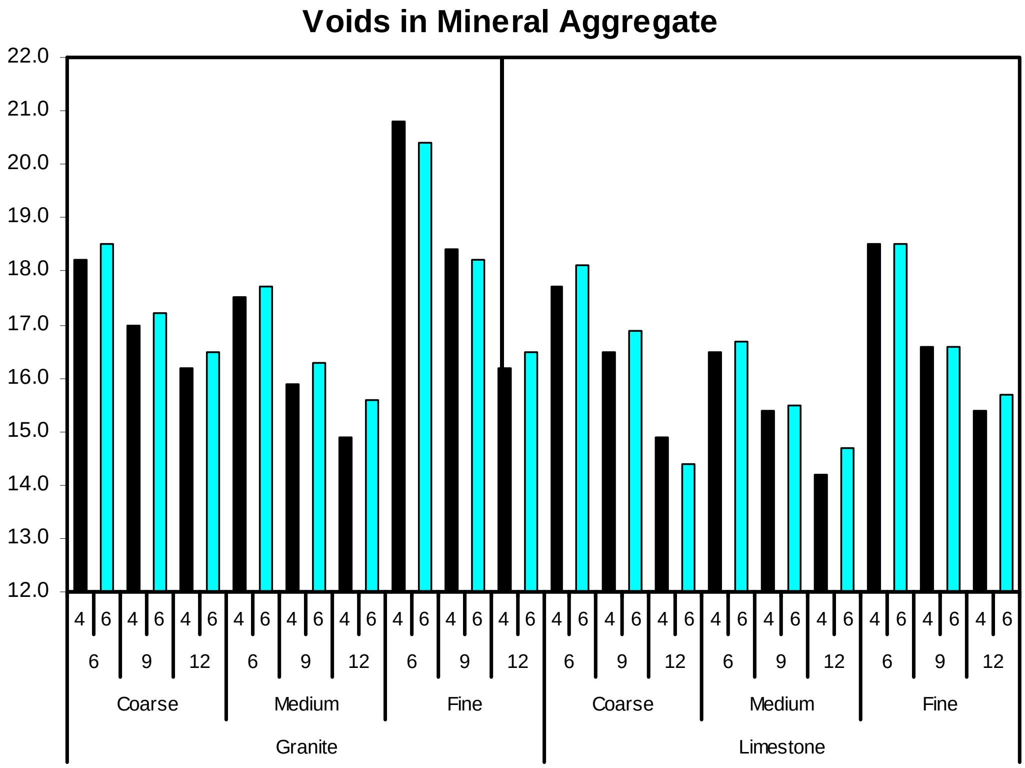


Figure 4. Range in Voids in Mineral Aggregate Values

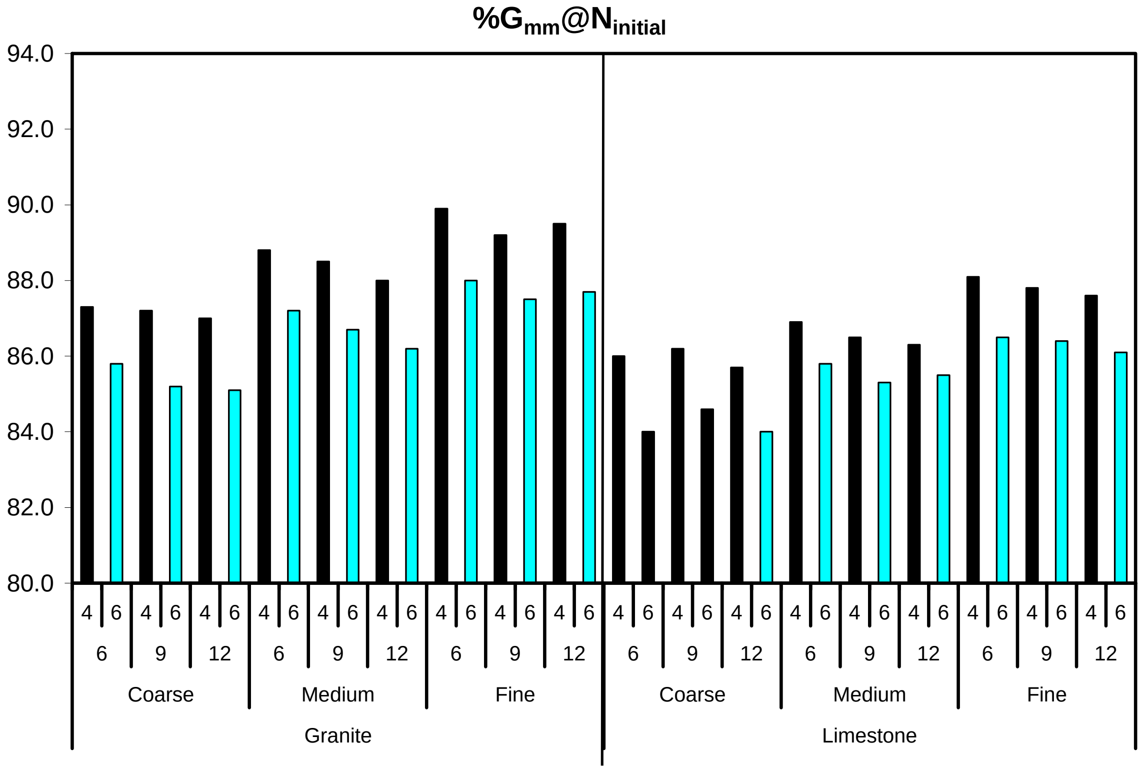


Figure 5. Range in %G_{mm}@N_{ini} Values

mixes. The increased binder contents for the granite mixes aided in the early compaction of the granite mixes (higher $\%G_{mm}@N_{ini}$ values). Coarse gradations provided the lowest average $\%G_{mm}@N_{ini}$ values (85.7 percent) followed by the medium gradation (86.8 percent) and fine gradations (87.9 percent). As the design air void content increased (optimum binder content decreased), the average $\%G_{mm}@N_{ini}$ values decreased. As shown on Figure 5, none of the 36 mixes failed the $\%G_{mm}@N_{ini}$ maximum requirement for mix designs (90.5 percent maximum) conducted at 75 gyrations.

Binder film thicknesses ranged from 3.64 to 8.87 microns for the 36 mixes (Figure 6). It should be pointed out that these film thickness values can not be directly compared to historical film thickness values presented in the literature (6 to 10 microns). Because of the relative fineness of these mixes (small NMAS and high $P_{0.075}$ contents), typical film thicknesses for these mixes were expected to be relatively lower. However, the mixes did not appear "dry" in the laboratory. All four of the main factors in the experiment (aggregate type, $P_{0.075}$, gradation shape, and design air void content) affected film thickness. As expected, $P_{0.075}$ had the greatest effect on film thickness. Mixes having 6 percent $P_{0.075}$ had the largest average film thickness at 7.15 microns while the 9 and 12 percent $P_{0.075}$ mixes had average film thicknesses of 5.59 and 4.46 microns, respectively. This was expected because $P_{0.075}$ has the greatest effect on the calculated aggregate surface area (5) used in calculating film thickness. This data suggests that increases of 3 percent $P_{0.075}$ resulted in an average decrease in film thickness of about 1.5 microns. Film thickness data also showed that the mixes having a coarse gradation provided the largest film thickness (average film thickness of 6.51 microns). Mixes utilizing the medium gradation had the lowest average film thickness at 5.28 microns and mixes utilizing the fine gradation fell in the middle at an average film thickness of 5.41 microns. Mixes designed to 4 percent air voids provided an average film thickness of 6.16 microns while mixes designed to 6 percent air voids had an average film thickness of 5.3 microns.

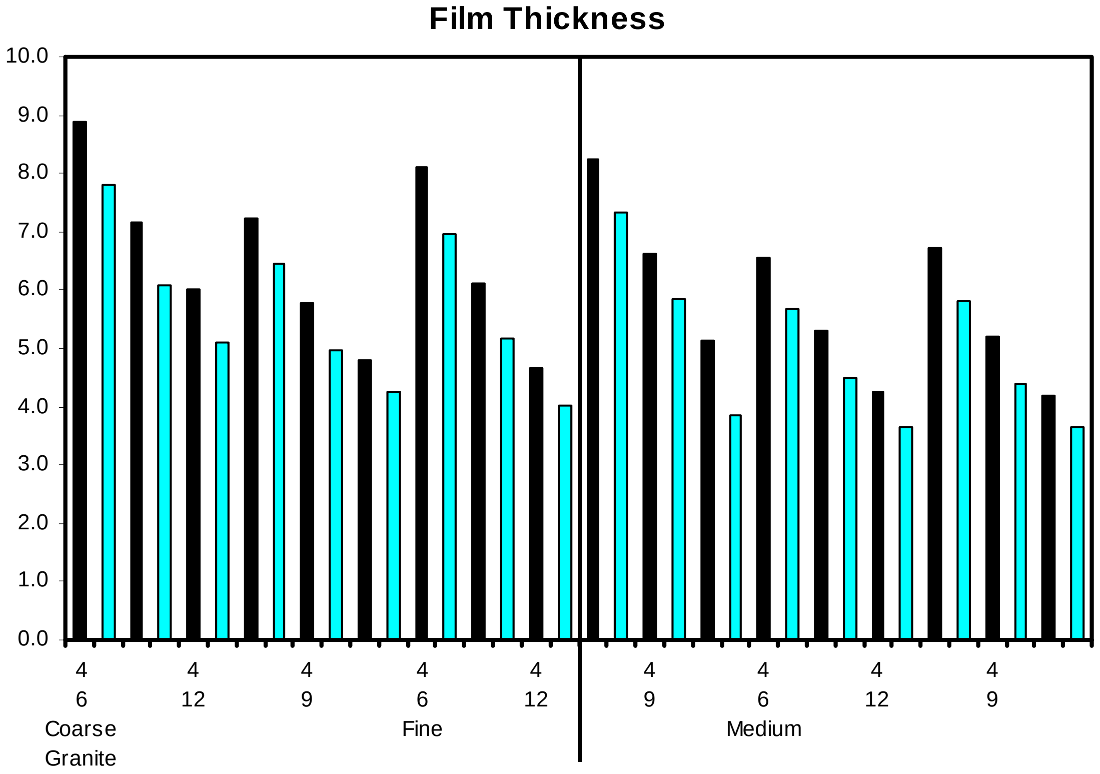


Figure 6. Range in Asphalt Binder Film Thicknesses

Because a 4.75 mm NMAS-type mix has historically been considered a maintenance or low volume roadway type mix, little performance testing data (durability or rutting) is available. Both Georgia and Maryland indirectly address the durability side of performance by specifying a maximum percentage passing the 0.075 mm (No. 200) sieve and a minimum binder content. From the specified values for each state (Tables1 and 2), a maximum dust-to-effective binder ($P_{0.075}/P_{be}$) ratio was calculated from both sets of specifications. Based upon Georgia's specification, a maximum $P_{0.075}/P_{be}$ ratio of 2.0 was calculated while from the Maryland specification a maximum $P_{0.075}/P_{be}$ ratio of 2.4 was determined. (Both of these calculated maximum $P_{0.075}/P_{be}$ ratios assume no binder absorption by utilizing the minimum total binder content.) The average of these two maximum $P_{0.075}/P_{be}$ ratios is 2.2.

Within the Superpave mix design system, the durability of mixtures is generally controlled with both VMA and $P_{0.075}/P_{be}$ ratio. Additionally, some states evaluate the calculated film thickness of mixes to provide a durability index. Figure 7 presents the relationships between VMA and $P_{0.075}/P_{be}$ ratio and film thickness and $P_{0.075}/P_{be}$ ratio. Data from all 36 mixes are reflected in Figure 7 for both VMA and film thickness. Both of the relationships shown in Figure 7 have reasonably high coefficients of determination (R^2) as both are above 0.7. Statistically, both relationships also have a significant correlation (p-values of 0.000 for both). However, these relationships may vary somewhat if other aggregate types are utilized.

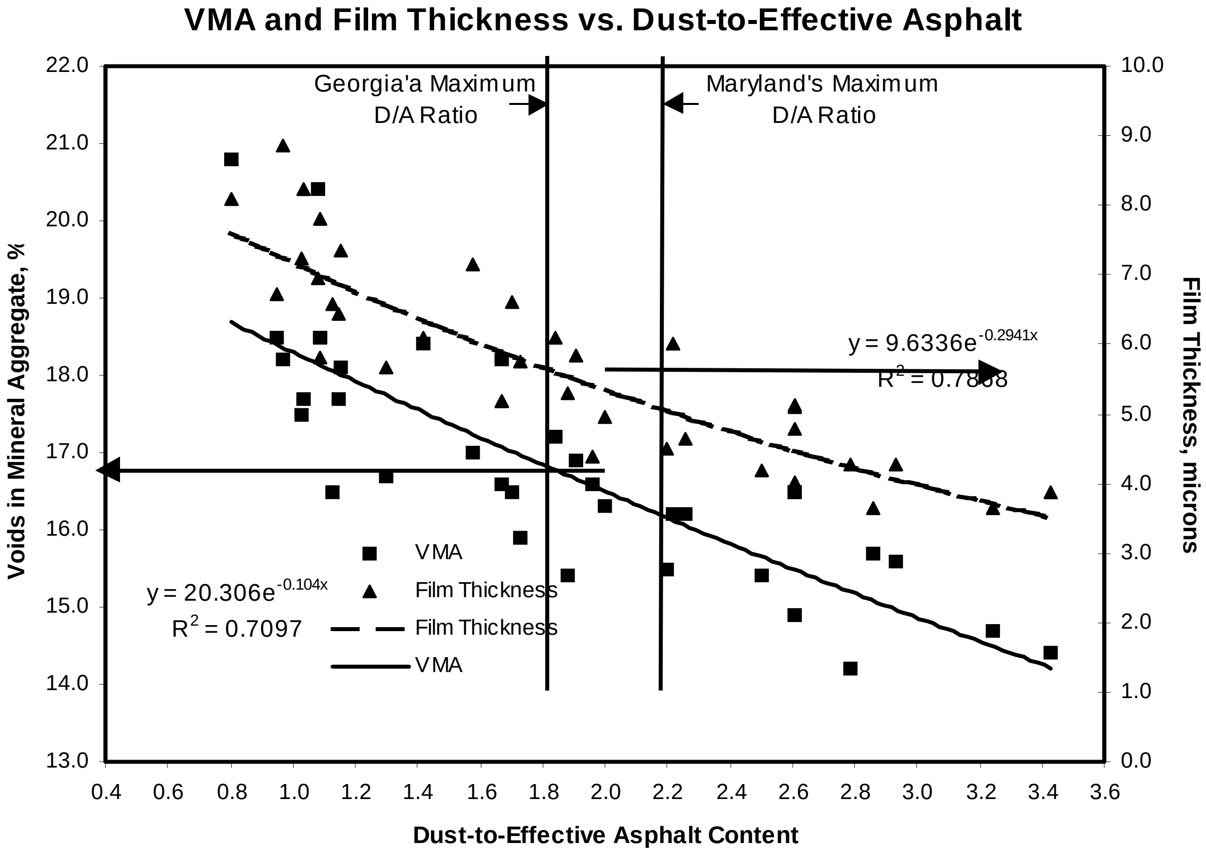


Figure 7. Relationship Between Durability Measures

The relationship between VMA and $P_{0.075}/P_{be}$ ratio shown in Figure 7 was utilized to evaluate a minimum criteria for VMA. Using the average maximum $P_{0.075}/P_{be}$ ratio of 2.2 (as discussed above), a minimum VMA criteria would be 16 percent. This minimum VMA value is interesting in that it follows the current logic of the Superpave mix design system. Within the Superpave mix design system, minimum VMA criteria increases by 1 percent as the NMAS decreases (Table 8). For example, the minimum Superpave VMA criteria for 12.5 mm NMAS mixes is 14.0 percent, while the minimum criteria for 9.5 mm NMAS mixes is 15.0 percent. This concept of increasing VMA criteria for decreasing NMAS can be traced back to McLeod (6). Figure 7 and Table 8 both suggest that a minimum VMA criteria of 16 percent for 4.75 mm NMAS mixes is reasonable. Figure 7 also indicates that at a $P_{0.075}/P_{be}$ ratio of 2.2 and VMA value of 16 percent the average binder film thickness would be about 5 microns. This 5 micron film thickness seems low based upon the literature (where 6 to 10 microns is typically suggested), but may be reasonable for the relatively fine mixes used in this study.

Table 8. Minimum Superpave VMA Criteria (AASHTO PP28)

NMAS, mm	VMA criteria, %
37.5	11.0
25.0	12.0
19.0	13.0
12.5	14.0
9.5	15.0

Another mix design criteria within the Superpave mix design system is $\%G_{mm}@N_{ini}$. As shown in Figure 5, none of the mixtures evaluated within this study failed the $\%G_{mm}@N_{ini}$ criteria of 90.5 percent maximum for the design compactive effort (N_{des} = 75). This can likely be explained in that two high quality, quarried materials were used within the study. Since the incorporation of some natural, rounded sand was not included in this study, an evaluation of $\%G_{mm}@N_{ini}$ was not conducted.

Tables 9 and 10 provide the Asphalt Pavement Analyzer rut depth data for the 36 mixes evaluated in this study. Figure 8 illustrates all of the rut depth data. Initial analysis of this APA rut depth data was performed by conducting an analysis of variance (ANOVA) to evaluate the effect of the main factors (aggregate type, gradation shape, dust content, and design air voids) and any interactions between the main factors on rut depth. Results of the ANOVA are presented in Table 11.

As shown in Table 11, all four of the experiment’s main factors significantly affected rut depths. On average, the granite mixes had larger rut depths (9.1 mm) than did the limestone mixes (8.3 mm). This was likely caused by the higher optimum binder contents for the granite mixes. The coarse gradations provided higher rut depths (10.14) than did the fine gradations (9.72 mm) or the medium gradations (6.29 mm). As expected, decreasing $P_{0.075}$ contents led to higher rut depths. Mixes having 6 percent $P_{0.075}$ had the highest average rut depths (10.4 mm), followed by the 9 percent $P_{0.075}$ mixes (8.5 mm) and the 12 percent $P_{0.075}$ mixes (7.24 mm). This was not unexpected because the mixes with lower $P_{0.075}$ contents had collectively higher optimum binder contents. On average, the mixes designed at 4 percent air voids had higher rut depths (9.13 mm) than the mixes designed at 6 percent air voids (8.30 mm). Again, this is likely due to the higher optimum binder contents for mixes designed at 4 percent air voids.

Table 9. Results of Asphalt Pavement Analyzer Testing on Granite Mixes

Gradation	Dust Content, %	Design Air Void Level, %	Total Binder Content, %	VMA, %	Dust-to-Eff. Binder Ratio	Film Thickness, μm	Rut depth, mm
Coarse	6.0	4	6.7	18.2	0.97	8.87	8.22
		6	6.0	18.5	1.09	7.81	7.51
	9.0	4	6.2	17.0	1.58	7.15	10.07
		6	5.4	17.2	1.84	6.09	6.98
	12.0	4	5.8	16.2	2.22	6.03	9.39
		6	5.0	16.5	2.61	5.09	6.91
Medium	6.0	4	6.2	17.5	1.03	7.23	8.61
		6	5.6	17.7	1.15	6.44	7.14
	9.0	4	5.7	15.9	1.73	5.76	6.78
		6	5.0	16.3	2.00	4.95	5.65
	12.0	4	5.2	14.9	2.61	4.78	6.92
		6	4.7	15.6	2.93	4.26	6.16
Fine	6.0	4	8.0	20.8	0.80	8.10	21.82
		6	7.0	20.4	1.08	6.95	16.39
	9.0	4	6.8	18.4	1.42	6.10	12.77
		6	5.9	18.2	1.67	5.18	13.48
	12.0	4	5.8	16.2	2.26	4.65	6.46
		6	5.1	16.5	2.61	4.01	5.40

Table 10. Results of Asphalt Pavement Analyzer Testing on Limestone Mixes

Gradation	Dust Content, %	Optimum Air Void Level, %	Total Binder Content, %	VMA, %	Dust-to-Eff. Binder Ratio	Film Thickness, μm	Rut depth, mm
Coarse	6.0	4	6.1	17.7	1.03	8.25	10.04
		6	5.5	18.1	1.15	7.35	14.77
	9.0	4	5.8	16.5	1.70	6.62	13.47
		6	5.2	16.9	1.91	5.83	11.33
	12.0	4	5.6	14.9	2.61	5.68	13.56
		6	4.8	14.4	3.43	4.75	11.97
Medium	6.0	4	5.7	16.5	1.13	6.57	6.32
		6	5.0	16.7	1.30	5.66	6.75
	9.0	4	5.3	15.4	1.88	5.3	6.26
		6	4.6	15.5	2.20	4.49	4.31
	12.0	4	4.8	14.2	2.79	4.27	5.25
		6	4.2	14.7	3.24	3.65	5.36
Fine	6.0	4	6.8	18.5	0.95	6.72	8.79
		6	6.0	18.5	1.09	5.81	8.6
	9.0	4	6.0	16.6	1.67	5.19	6.67
		6	5.2	16.6	1.96	4.38	6.68
	12.0	4	5.2	15.4	2.50	4.19	5.39
		6	4.6	15.7	2.86	3.64	4.33

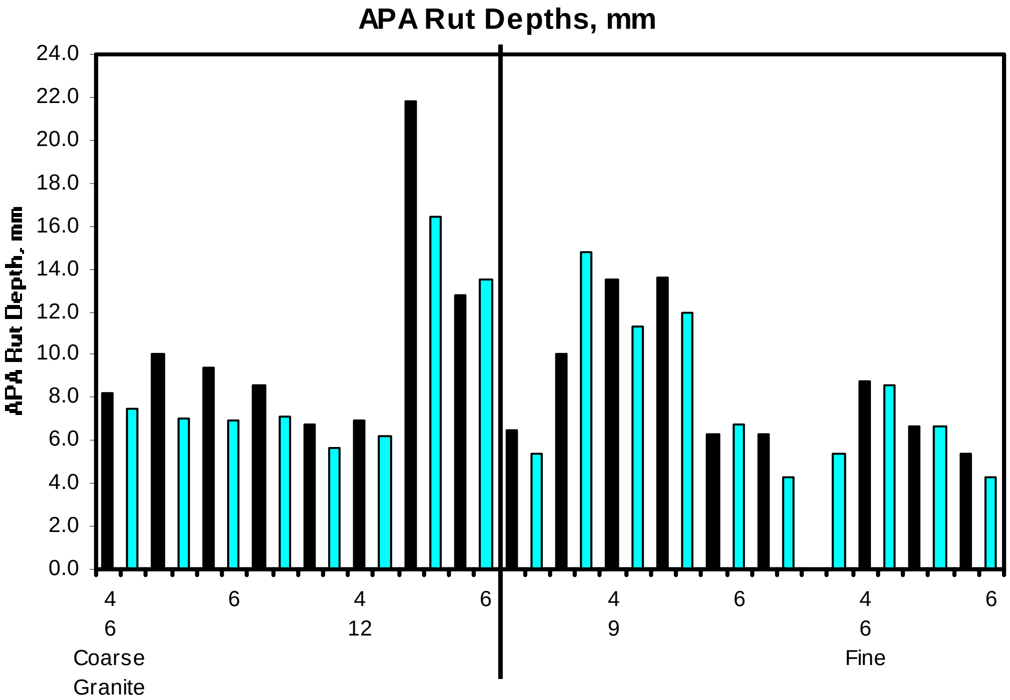


Figure 8. Results of Asphalt Pavement Analyzer Testing

Interestingly in Table 11, a large number of two-factor interactions were also significant. Figure 9 illustrates the interaction between aggregate type and gradation shape. This figure shows that for the coarse gradation, the limestone mixes had the highest average rut depths while for the fine gradation the granite mix had the highest average rut depths. Mixes with both aggregate types had somewhat similar rut depths for the medium gradation. For the coarse gradation, the higher average rut depth for the limestone mixes is likely due to less surface texture on the aggregate. Recall from Table 5 that the fine aggregate angularity value for the limestone was 46 percent while the granite aggregate had a value of 49 percent. This would indicate the granite aggregate has more surface texture than the limestone aggregate. Because of the nature of the coarse gradation shape, there tends to be more particle-to-particle contact than the other gradation shapes. For the fine gradation, the likely cause of higher rutting in the granite mixes was higher optimum binder contents. The granite mix with a fine gradation and 6 percent $P_{0.075}$ content designed at 4 percent air voids had a binder content of 8.0 percent. This is 1.2 percent higher than the optimum binder content for the companion limestone mix. The excessive optimum binder content was the probable cause of the higher rutting in the granite mixes.

Another interaction that significantly affected laboratory rut depths was the interaction between aggregate type and dust content (Figure 10). As expected, Figure 10 shows that rut depths generally decreased as the percentage of dust increased. There are two probable explanations for this interaction: one is related to binder content and the other is related to particle surface texture. Referring to Tables 9 and 10, the granite-fine gradation-6 percent dust mixes had very high rut depths (21.8 and 16.4 mm for the two design air void contents) compared to the companion limestone mixes (8.8 and 8.6 mm for the two design air void contents). These granite combinations had over 1 percent more binder than did the companion limestone combinations. If the fine gradation is neglected, the average rut depths for the two aggregate types at 6 percent dust are somewhat similar at 7.9 mm for the granite and 9.5 for the limestone mixes.

Table 11. Results of Analysis of Variance for Rut Depths

Source	F-statistic	p-value	Significant?[1]
Aggregate	18.35	0.000	Yes
Gradation	166.09	0.000	Yes
Dust	94.62	0.000	Yes
Design Air Voids (VTM)	19.14	0.000	Yes
Aggregate*Gradation	264.36	0.000	Yes
Aggregate*Dust	22.49	0.000	Yes
Aggregate*VTM	10.37	0.002	Yes
Gradation*Dust	68.49	0.000	Yes
Gradation*VTM	0.85	0.433	No
Dust*VTM	1.42	0.249	No
Aggregate*Gradation*Dust	22.57	0.000	No
Aggregate*Gradation*VTM	0.60	0.552	No
Aggregate*Dust*VTM	16.06	0.000	Yes
Gradation*Dust*VTM	11.43	0.000	Yes
Aggregate*Gradation*Dust*VTM	1.30	0.278	No

[1] Level of Significance of 95 percent

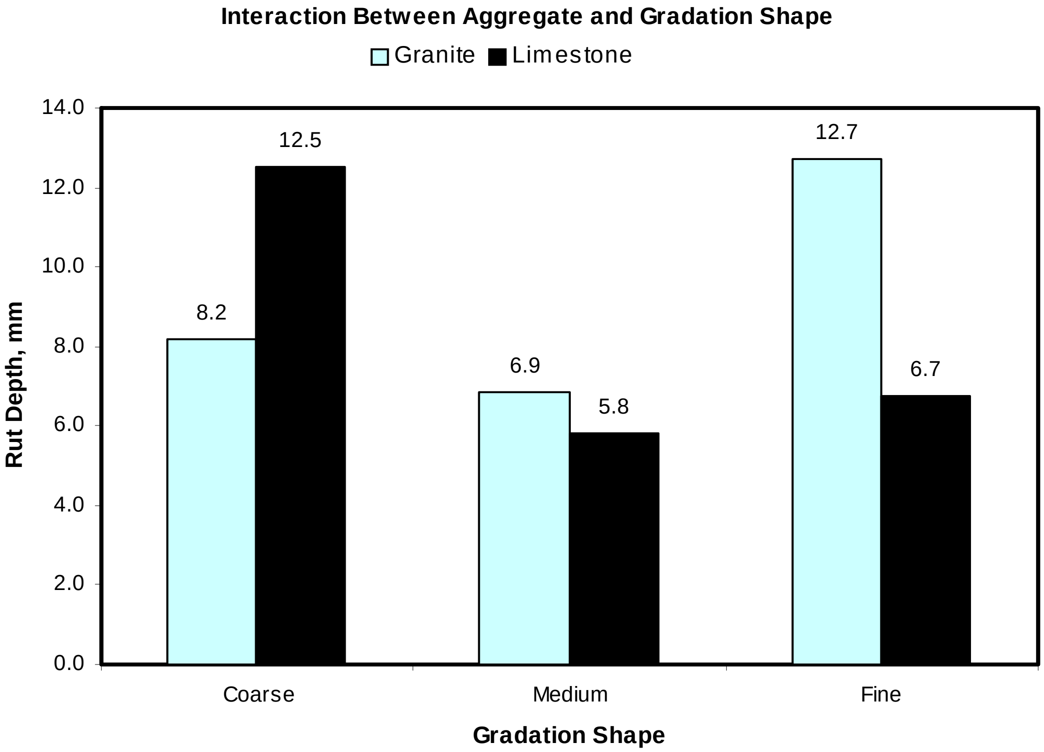


Figure 9. Interaction Between Aggregate Type and Gradation Shape

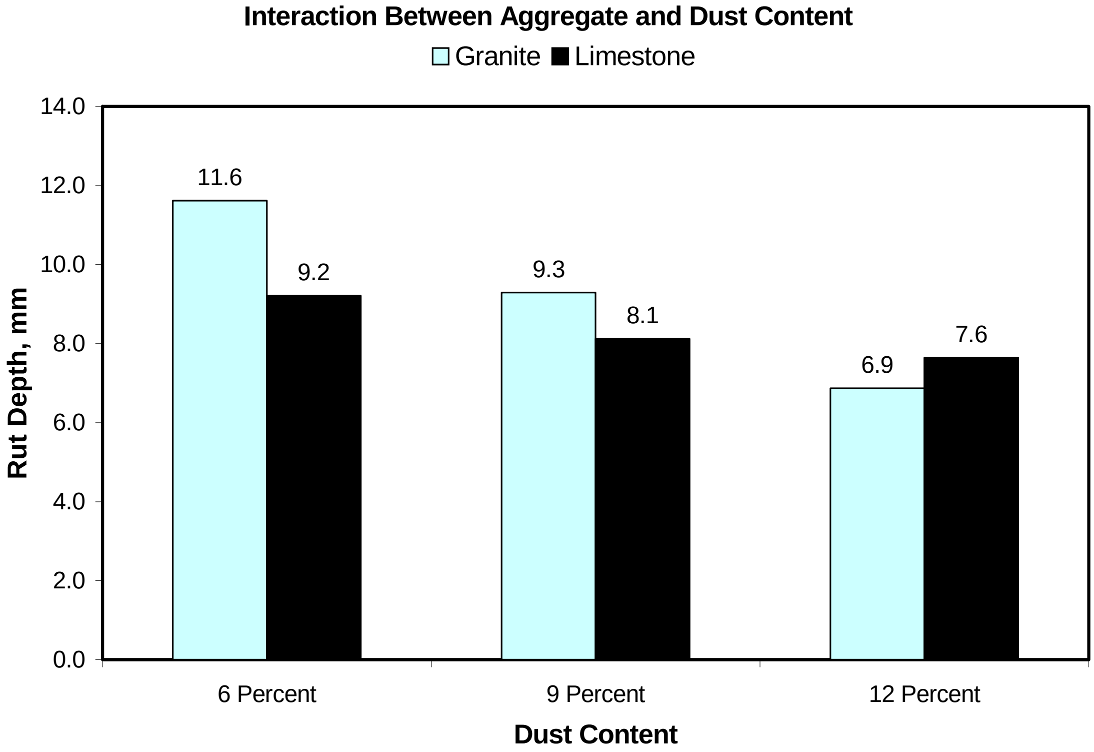
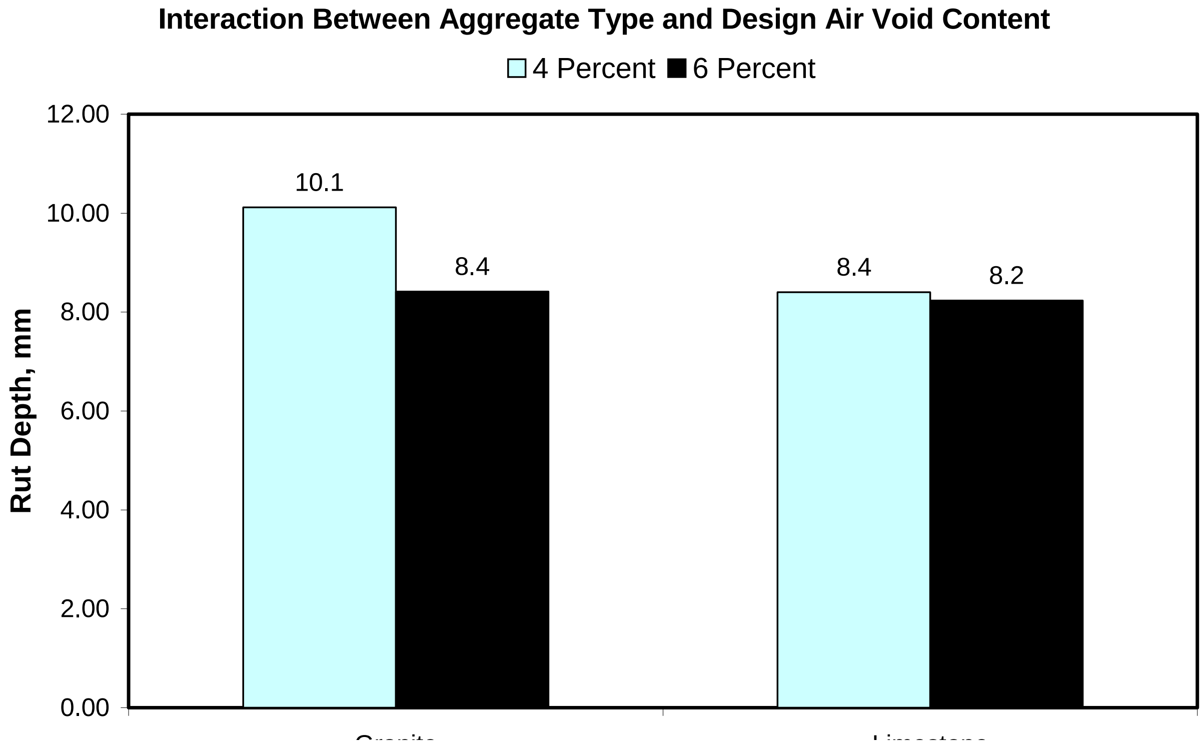


Figure 10. Interaction Between Aggregate Type and Dust Content

Secondly, for the 12 percent dust content mixes aggregate shape and surface texture likely cause the differences between rut depths. The average optimum binder contents for the granite and limestone mixes are 0.4 percent different (5.3 percent for granite mixes and 4.9 percent for limestone mixes). Even though the granite mixes have slightly higher binder contents, the granite mixes also provided lower rut depths. The higher angularity and surface texture of the granite aggregate offset the slightly higher binder contents.

Another interaction shown significant by the ANOVA was the interaction between aggregate type and design air void content. Figure 11 shows that there was a greater difference between average rut depths at 4 and 6 percent design air voids for the granite mixes than for the limestone mixes. This difference is again probably due to the very high rut depths obtained for the granite-fine gradation-6 percent dust mixes. At 4 percent design air voids, the rut depth was over 5 mm higher than the 6 percent design air void mix (21.8 to 16.4 mm). If these granite-fine gradation-6 percent dust mixes (both design air void contents) are removed, then the rut depths for the granite mixes are similar (0.1 mm difference). Again, these differences were the result of an excessive binder content problem.

The final two-way interaction that was shown significant in Table 11 was the interaction between gradation and dust content. Figure 12 illustrates the average rut depths for gradation shape-dust content combinations. This figure shows that there was little difference in average rut depths for the coarse or medium gradations, but there was large differences in average rut depths for the fine gradation. Interestingly, the coarse gradation utilized in this study falls within the SMA gradation band for 4.75 mm mixes recommended within NCHRP 9-8, “Designing Stone Matrix Asphalt Mixtures” (7). The results shown in Figure 12 seem to support the existence of an aggregate skeleton having stone-on-stone contact as there was little difference in average rut depths for the coarse gradation mixes, no matter the dust content. For the fine gradation mixes,



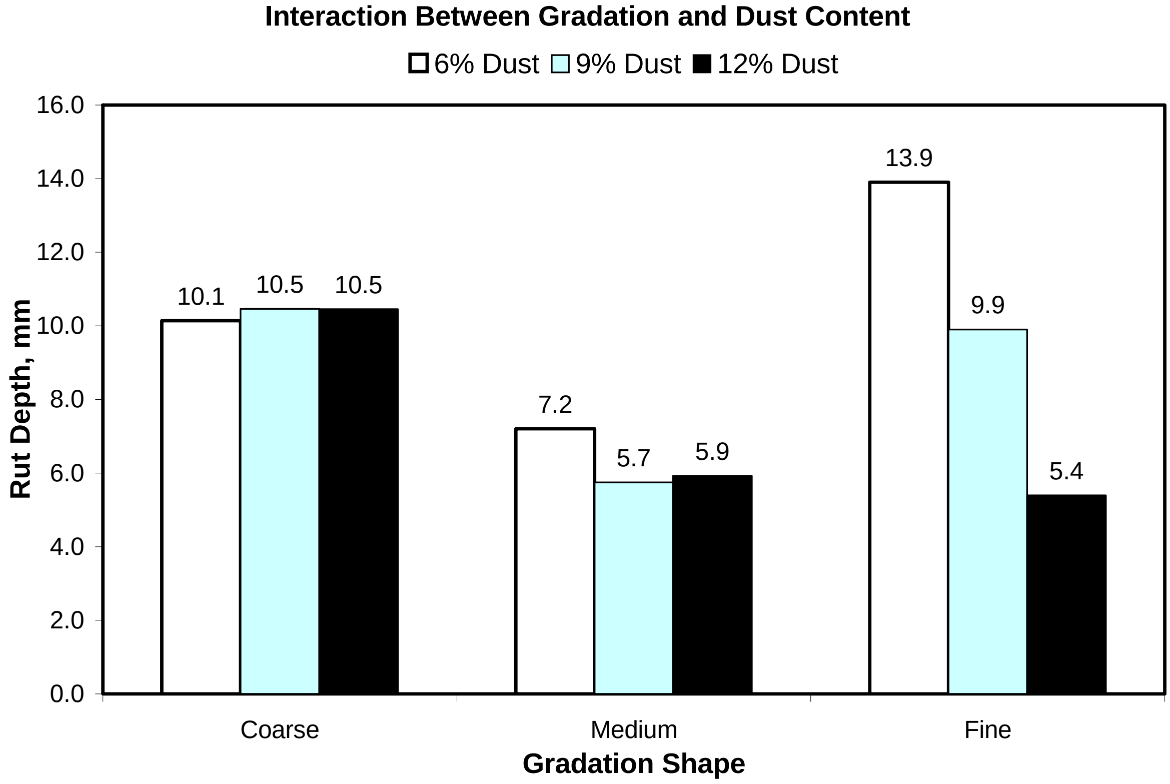


Figure 12. Interaction Between Gradation Shape and Dust Content

there was a large difference in average rut depths between the 6 percent dust mixes and 12 percent dust mixes. This was likely due to a wide range of optimum binder contents between the three dust contents (1.8 percent difference). Mixes having a fine gradation and designed with 6 percent dust had an average optimum binder content of 7.0 percent while the mixes designed at 12 percent dust had an average optimum binder content of 5.2 percent. The coarse and medium gradations had much smaller optimum binder content ranges with respect to the dust contents (0.8 and 0.6 percent, respectively).

Based upon these discussions of the significant two-way interactions, in order to ensure a stable mixture the optimum binder content may need to be limited. Within the Superpave mix design system, optimum binder content is controlled by VMA, voids filled with asphalt (VFA) and/or with the $P_{0.075}/P_{be}$ ratio.

In order to evaluate the need for a maximum optimum binder content, some type of critical rut depth was needed. During the second phase of National Cooperative Highway Research Program (NCHRP) Project 9-17, "Accelerated Laboratory Rutting Tests: Asphalt Pavement Analyzer," NCAT developed tentative criteria for critical rut depths in the APA (8). Testing during NCHRP Project 9-17 was conducted on both beams and cylinders at the same test temperature as was utilized in this study. However, there was one difference between the testing conducted during NCHRP Project 9-17 and this study. During NCHRP Project 9-17, cylindrical samples were compacted to 4 percent air voids at a height of 75 mm.. For this study, APA testing was conducted on mix design height samples compacted at optimum binder content to the design number of gyrations. This was done within this study because of the two design air void contents (4 and 6 percent). Regardless of the differences in sample height and air voids, the criteria developed during NCHRP Project 9-17 will be utilized. Criteria developed were based upon traffic level in ESALs: 2, 3, 5, 10, and 30 million. Since the design compactive level utilized in this study was 75 gyrations (0.3 to 3 million ESALs), the criteria corresponding to 3 million ESALs was utilized in comparing the rut resistance of different mixes (9.5 mm).

The relationship between APA rut depth and VMA is illustrated in Figure 13. Based upon the trend line, the relationship is not strong ($R^2 = 0.37$); however, the relationship is significant (p-value = 0.002). Therefore, a maximum value for VMA is plausible to prevent high rut potential mixes. Based upon the critical rut depth of 9.5 mm, a maximum VMA value would be 18 percent. This, in essence, would be a 2 percent range for VMA, if 16 percent were the minimum value. Limiting VMA to no more than 2 percent above the minimum value has also been recommended by the WesTrack Forensic Team (*9*).

VFA, in essence, puts a control on the allowable VMA that a mixture can have and, thus, binder content. However, within this study two different design air void contents (to define a range) were utilized. Figure 14 shows the relationship between rut depths and VFA for both design air void contents. This figure shows that a single VFA criterion to ensure a stable mixture is likely not implementable if a design range of air voids is utilized. The acceptable range would be too large (63 percent to 78 percent assuming a minimum VMA of 16 percent, maximum VMA of 18 percent, and a design air void content range of 4 to 6 percent).

Using this critical APA rut depth along with the data presented in Figure 15, a minimum $P_{0.075}/P_{be}$ ratio would be 1.2. This criteria may be too stringent in that 7 data points fall below the critical rut depth and below a $P_{0.075}/P_{be}$ ratio of 1.2. Possibly a criteria should be a $P_{0.075}/P_{be}$ ratio of 0.9 or 1.0 minimum along with some type of torture test to ensure stability.

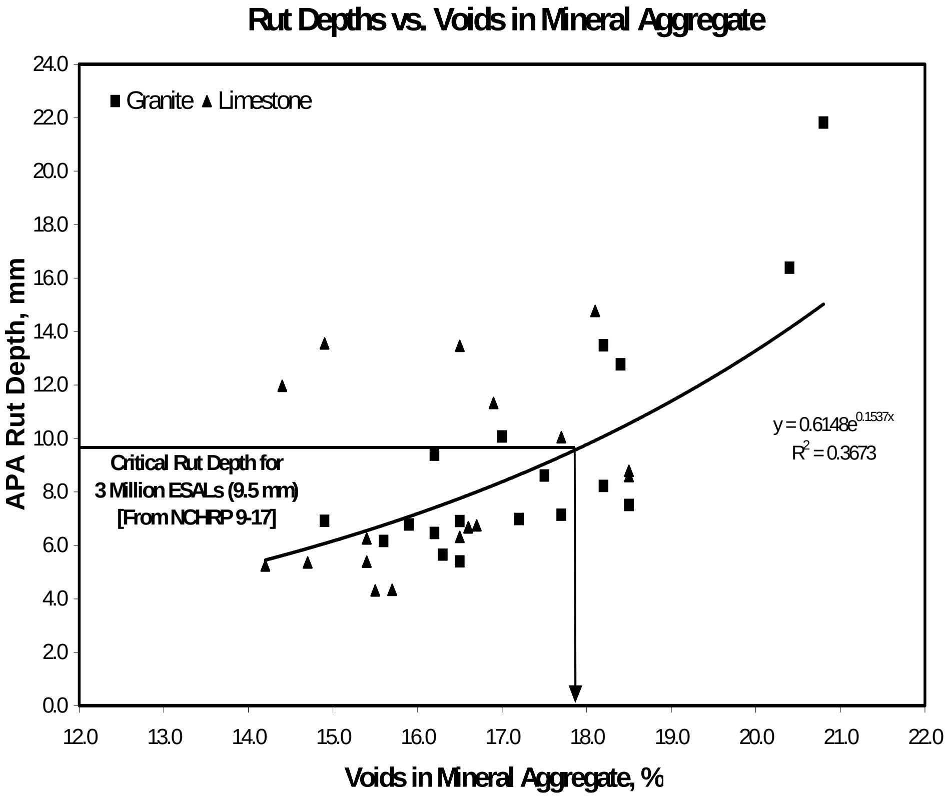


Figure 13. Relationship Between APA Rut Depths and Voids in Mineral Aggregate

DISCUSSION ON DEVELOPMENT OF CRITERIA

Within AASHTO MP2-01, "Standard Specification for Superpave Volumetric Mix Design," there are requirements for asphalt binder, combined aggregate properties, gradation, and volumetrics (*10*). Within this section, criteria for each of these requirements are discussed based upon the work in this study and, where needed, justification provided. A draft standard for the Superpave design of 4.75 mm NMAS is provided in Appendix A. The draft standard includes all of the traffic categories utilized in AASHTO MP2-01 to provide latitude to agencies. It is possible that some agencies intend to only utilize a 4.75 mm NMAS mix for low traffic volume applications (e.g., little or no trucks). Some agencies may utilize this mix type for pavements that will experience truck traffic.

Asphalt Binder Requirements

As for typical Superpave mix designs, a performance-graded (PG) binder meeting the requirements of AASHTO MP1-01, "Performance Graded Asphalt Binder," should be utilized (*10*). The LTTPBind software should be used to select the appropriate grade of binder at the desired reliability. Guidance is provided within AASHTO MP2-01 for recommendations concerning bumping of binder grades. One possible modification for the less than 0.3 million ESAL traffic level (N_{des}=50) would be to increase the high temperature grade by one equivalent grade (6°C) if traffic is standing. Within MP2-01, it states "*Consideration should be given* to *increasing the high temperature grade* ..." Because of the higher binder contents associated with

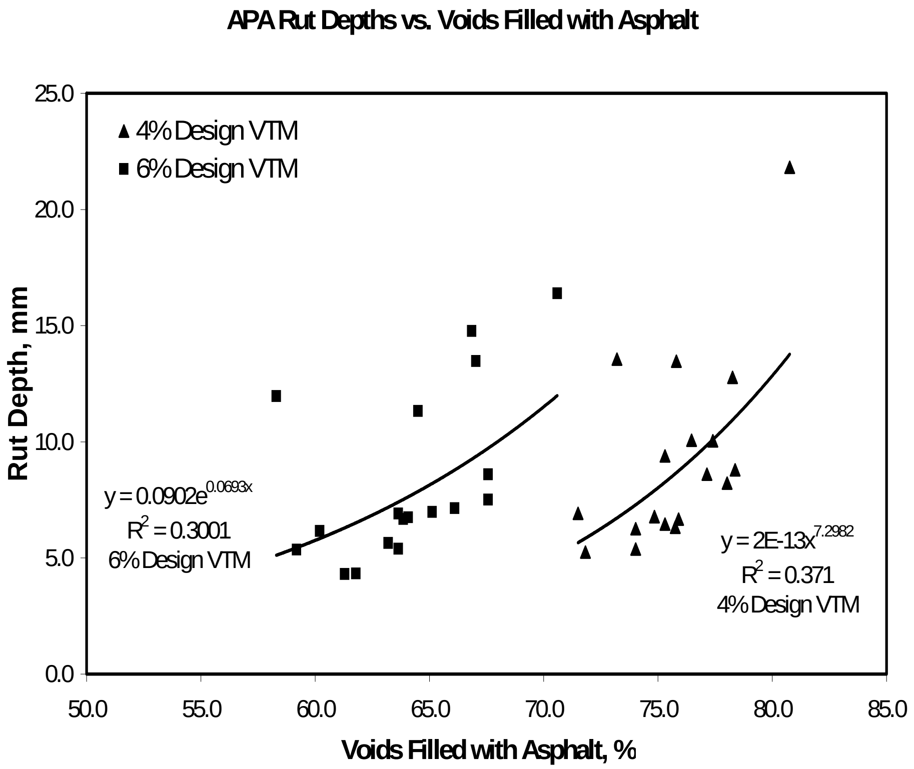


Figure 14. Relationship Between APA Rut Depths and VFA (By Design Air Void Content)

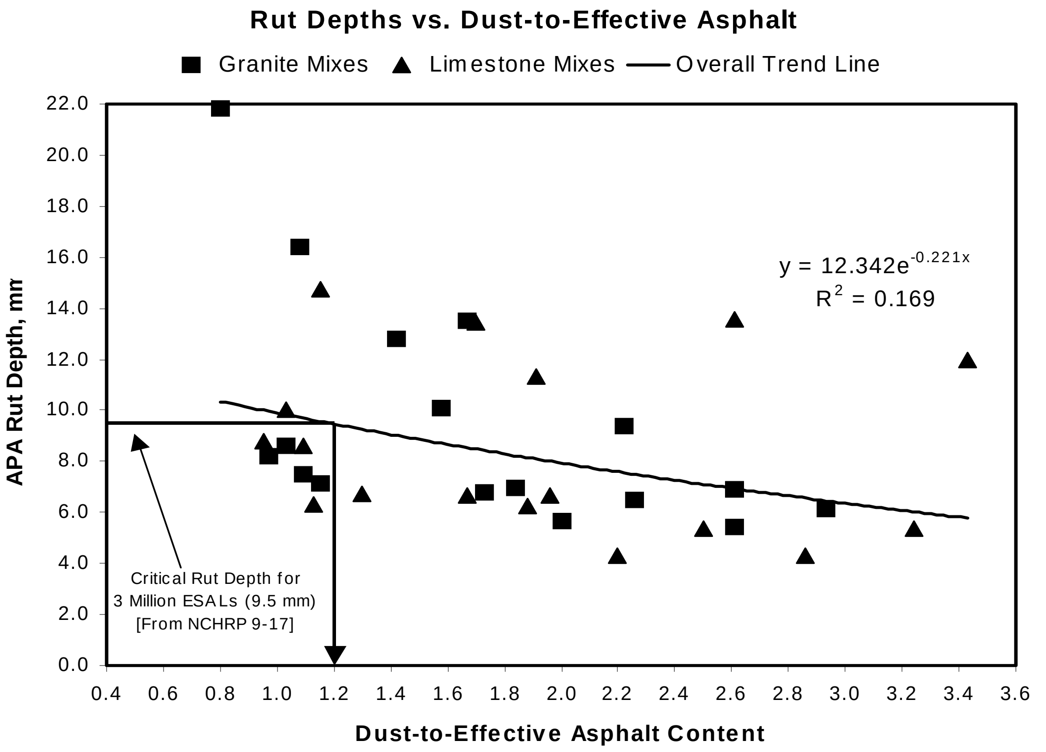


Figure 15. Relationship Between APA Rut Depth and Dust-to-Asphalt Ratio

4.75 mm NMAS mixes, requiring a stiffer binder when traffic is standing may ensure good performance.

Aggregate Requirements

Obviously, only fine aggregate stockpiles (e.g., No. 89, M10, etc.) can be used to blend a 4.75 mm NMAS gradation. AASHTO MP2-01 provides fine aggregate quality requirements such as fine aggregate angularity (FAA) and sand equivalency. A possible modification to these requirements would be to require a FAA value of 40 percent for the less than 0.3 million design ESAL traffic range. This would typically prevent 100 percent rounded, smooth particles with very low FAA values from making up the entire aggregate blend. Another possible modification would be to require a FAA value of 43 for the 0.3 to 3 million design ESAL traffic range. This would ensure that some portion of the gradation blend would be angular aggregates. These suggested actions are not based upon work conducted within this study. No specific evaluation was conducted on FAA requirements. However, they should be considered when developing a standard on the design of 4.75 mm NMAS mixes.

Gradation Requirements

Gradation requirements under the Superpave mix design system provide control points for the maximum aggregate size, the NMAS, an intermediate aggregate size, and the 0.075 mm sieve. For gradations larger than a 4.75 mm NMAS, the intermediate size control points are on the 2.36 mm sieve. This is probably too large for a 4.75 mm NMAS gradation. Vavrik et al (*11*) have suggested that the primary control sieve for a 4.75 mm NMAS gradation should be the 1.18 mm (No. 16) sieve.

Within this study, the percent passing the 1.18 mm sieve ranged from 30 to 54 percent. These limits appear reasonable. Mixtures within this range were successfully designed and shown to be rut resistant. However, as with any designed mixture some type of performance test should be included. For the limestone mixes designed with 30 percent passing the 1.18 mm sieve, rut depths were relatively high. However, the companion granite mixes performed well in the lab. For the granite mixes designed with 54 percent passing the 1.18 mm sieve, rut depths were high while the limestone mixes had lower rut depths.

For this study, the percent passing the 0.075 mm sieve ($P_{0.075}$) ranged from 6 to 12 percent. The 6 percent $P_{0.075}$ is higher than the minimum specified by Maryland (2 to 12 percent) or Georgia (4 to 12 percent). VMA values for the mixes designed with 6 percent $P_{0.075}$ ranged from 16.5 to 20.8. Over half of these mixes had a VMA value above 18 percent, which based on Figure 13 may be a maximum value limit.

The recently completed NCHRP Project 9-14, "Investigation of the Restricted Zone in the Superpave Aggregate Gradation Specification," recommended removing any restricted zone requirements from the Superpave mix design system (*12*). Therefore, no restricted zone requirement is needed.

Volumetric Properties

AASHTO MP2-01 provides requirements for $\%G_{mm}@N_{ini}$, $\%G_{mm}@N_{design}$ (design air voids), $\%G_{mm}@N_{max}$, VMA, VFA, and $P_{0.075}/P_{be}$ ratio. For $\%G_{mm}@N_{ini}$ and VFA, requirements change based upon the traffic level. Figure 5 indicated that none of the mixes used in this study failed the $\%G_{mm}@N_{ini}$ requirement of 90.5 percent maximum. However, as stated previously high quality aggregates were used in this study. Therefore, for the design ESAL level targeted in this study (0.3 to < 3 million ESALs) the $\%G_{mm}@N_{ini}$ criteria in AASHTO MP2-01 seems reasonable. This suggests that the remaining $\%G_{mm}@N_{ini}$ criteria in AASHTO MP2-01 may also be reasonable.

Under the current Superpave mix design system, only one design air void content is utilized: 4 percent. Within this study, both 4 and 6 percent design air voids were used. Based upon the research in this study, a range of design air void contents would be reasonable. However, from a regional standardization of a 4.75 mm NMAS mix design system, it would be more implementable to select a single design air void content, especially until experience is gained with this mixture type. Validity could be given to selecting 4, 5, or 6 percent air voids for design. Solely from the standpoint of incorporating the 4.75 mm NMAS mix design system into AASHTO MP2-01, a single design air void content of 4 percent would be selected. However, since the research indicated that high optimum binder contents led to high rut depths, selection of 4 percent design air voids means that a maximum VMA value should probably be used. This would prevent excessive binder contents.

As stated above, a 16 percent minimum VMA requirement appears reasonable (Figure 7 and Table 8). If a design air void content of 4 percent is selected, this would ensure an effective volume of binder of 12 percent. A maximum VMA criteria should also be considered for mixtures to be designed at 75 gyrations or more. Based on Figure 13, a maximum value of 18 percent appears reasonable. This also matches the recommendations from WesTrack (9) that indicated VMA should be limited to no more than 2 percent above the minimum value. Mixtures designed at 50 gyrations are typically placed on pavements with little or no truck traffic. Therefore, the primary distress to be designed against is aging of the binder binder (and subsequent cracking). For this type of distress, high binder contents are desired. Therefore, a maximum VMA value is likely not needed.

With the incorporation of a single design air void content (4 percent) and an acceptable range for VMA (16 to 18 percent), a VFA criteria is indirectly applied. The acceptable range for VFA would be 75 to 78 percent. Again, this would be for mixtures designed at 75 gyrations or higher. A maximum VFA criteria of 80 percent may be reasonable for mixes designed at 50 gyrations. If a range of design air void contents (4 to 6 percent) is incorporated into the mix design procedure, a requirement for VFA is not needed. Figure 14 showed that a very wide range of VFA values could be encountered that performed well with respect to rutting.

Within AASHTO MP2-01, the allowable range for $P_{0.075}/P_{be}$ ratio is 0.6 to 1.2. There is a note, however, that allows $P_{0.075}/P_{be}$ ratios of 0.8 to 1.6 if the gradation passes below the boundaries of the restricted zone. The upper limit suggested previously within this report was 2.2 which was arbitrarily selected based upon Maryland and Georgia mix design criteria. Results of this study did not indicate that this value is inappropriate. For the lower limit, Figure 15 (APA rut depth versus $P_{0.075}/P_{be}$ ratio) suggested that a minimum $P_{0.075}/P_{be}$ ratio of 1.2 may be warranted. However, Figure 15 did not depict a strong relationship. Seven mixes had $P_{0.075}/P_{be}$ ratios between 0.95 and 1.2 that performed well with respect to rutting. By contrast, three mixes had $P_{0.075}/P_{be}$ ratios below 1.2 that showed a high potential for rutting. Therefore, a minimum $P_{0.075}/P_{be}$ ratio requirement of 0.9 appears reasonable.

CONCLUSIONS

Many agencies have expressed an interest in using a 4.75 mm NMAS mix because using such a mix could result in a very smooth riding surface, be used for thin lift applications, correct surface defects (leveling), decrease construction time, and provide a use for manufactured screening stockpiles. The objective of this study was to develop Superpave mix design criteria for a 4.75

mm NMAS mixture. The following conclusions were obtained from the research conducted to meet the project objectives:

- Mixes having a 4.75 mm NMAS can be successfully designed in the laboratory.
- Optimum binder contents of designed mixes were affected by aggregate type, gradation shape, dust content, and design air void content.
- Voids in mineral aggregate values were affected by aggregate type, gradation shape, and dust content.
- The primary cause of excessive laboratory rutting was high optimum binder contents.
- A good relationship existed between VMA and $P_{0.075}/P_{be}$ ratio. However, this relationship may vary somewhat when different aggregate types are used. Based upon the relationship and mix design criteria from Maryland and Georgia, a minimum VMA criteria of 16 percent appears reasonable. For mixes designed at 75 gyrations and above, a maximum VMA value of 18 percent is rational.

RECOMMENDATIONS

Based upon the findings in this study, Superpave mix design criteria are recommended for a 4.75 mm NMAS mixture. A draft AASHTO standard for the mix design system is provided in Appendix A. It is likely that the proposed standard should be incorporated into the AASHTO MP2 standard. Following are recommended design criteria for 4.75 mm NMAS Superpave mixes:

- Gradations for 4.75 mm NMAS mixes should be controlled on the 1.18 mm (No. 16) and 0.075 mm (No. 200) sieves. On the 1.18 mm sieve, the gradation control points are recommended as 30 to 54 percent. On the 0.075 mm sieve, the control points are recommended as 6 to 12 percent.
- An air void content of 4 percent be used during mix design.
- For all traffic levels, a VMA minimum limit of 16 percent be utilized.
- For mixes designed at 75 gyrations and above, a maximum VMA criteria of 18 percent should be utilized to prevent excessive optimum binder contents.
- For mixes designed at 50 gyrations, no maximum VMA criteria should be utilized.
- For mixes designed at 75 gyrations and above, VFA criteria should be 75 to 78 percent.
- For mixes designed at 50 gyrations, VFA criteria should be 75 to 80 percent.
- $\%G_{mm}@N_{ini}$ values currently specified in AASHTO MP2-01 for the different traffic levels are recommended.
- Criteria for dust-to-effective binder ratio are recommended as 0.9 to 2.2.

It is also recommended that the mix design procedure be refined in the laboratory and field validated. Laboratory refinement of the procedure is recommended in the following areas:

1. Minimum VMA criteria and $P_{0.075}/P_{be}$-Ratio Requirements: Laboratory work is needed to evaluate the aging characteristics of 4.75 mm NMAS mixes designed with the draft mix design system. The minimum criteria of 16 percent was selected based upon Maryland and Georgia minimum binder contents and gradation specifications on similar mixes. Included within this work should be an evaluation of the maximum $P_{0.075}/P_{be}$ ratio requirement.
2. Maximum VMA criteria: High optimum binder contents were identified as the primary cause of excessive laboratory rutting. For this reason, a maximum VMA criteria of 18 percent was recommended. This value needs to be validated in the laboratory by designing numerous mixes with a wide range of aggregate types to further evaluate the relationship between VMA and rut resistance.
3. $\%G_{mm}@N_{ini}$ criteria: Within this study, two high quality aggregates were utilized. None of the 36 mixes designed failed the $\%G_{mm}@N_{ini}$ criteria for a 75 gyration design

(90.5 percent). Additional work needs to be conducted that incorporates various percentages of natural, rounded sand to evaluate the applicability of $\%G_{mm}@N_{ini}$ requirements within the mix design system.

4. Aggregate Properties: Both of the aggregates used in this study had FAA values in excess of 45 percent. Additional refinement needs to be conducted to evaluate the desired FAA values for different design levels. Research is also needed to quantify an acceptable aggregate toughness and resistance to abrasion.
5. To avoid excessive binder contents, field work should verify if 4.75 mm NMAS mixes can be designed at a single air void level (e.g., 4 percent) and result in satisfactory performance or if a design air void range criteria is needed.
6. Use of Polymer Modified Binders: Within a refinement study, some polymer modified binders should be included to evaluate any enhanced performance.

Field validation of the refined mix design system would entail working with state and local agencies to construct a number of pilot projects. Selected projects should encompass a number of different applications to determine where 4.75 mm NMAS mixtures are applicable. Data should be gathered during the production of these pilot projects to recommend acceptable tolerances on volumetric properties. The performance of these mixtures should be monitored over a time period to provide data on their overall performance. Based upon the results of the laboratory refinement and field validation, guidelines should be developed on the design, production, construction, and allowable applications of a 4.75 mm NMAS Superpave mix.

ACKNOWLEDGMENTS

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APPENDIX A

Draft AASHTO Standard
for
Standard Specification for Superpave Volumetric Mix Design of 4.75 mm NMAS Mixtures

1. Scope

1.1 This specification for Superpave volumetric mix design of 4.75 mm nominal maximum aggregate size mixes uses binder, aggregate, and mixture properties to produce a hot-mix asphalt (HMA) job-mix formula.

1.2 This standard specifies minimum quality requirements for binder, aggregate, and HMA for Superpave volumetric mix designs.

1.3 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. ASTM Standards:

2.1 AASHTO Standards:

T11	Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
T27	Sieve Analysis of Fine and Coarse Aggregates
T176	Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
T283	Resistance of Compacted Bituminous Mixture to Moisture Induced Damage
T304	Uncompacted Void Content of Fine Aggregate
MP1	Performance Graded Asphalt Binder
PP28	Superpave Volumetric Design for Hot-Mix Asphalt (HMA)
TP2	Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures
TP4	Preparing and Determining the Density of Hot-Mix Asphalt Specimens by Means of the Superpave Gyratory Compactor

2.2 Other References:

"LTPP Seasonal Asphalt Concrete Pavement Temperature Models, FHWA-RD-97-103," September, 1998.

The Asphalt Institute Manual MS-2, "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types."

3. Terminology

3.1 HMA - Hot-Mix Asphalt

3.2. Design ESALs - Design equivalent (80kN) single-axle loads

Discussion-Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. For pavements designed for more or less than 20 years, determine the design ESALs for 20 years when using this standard.

3.3 Air voids (V_a) - The total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the compacted paving mixture (Note 1).

Note 1-Term defined in the Asphalt Institute Manual MS-2, "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types."

3.4 Voids in the Mineral Aggregate (VMA)-the volume of the intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective binder content, expressed as a percent of the total volume of the specimen (Note 1).

3.5 Voids Filled With Asphalt (VFA) - The percentage of the VMA filled with binder (the effective binder volume divided by the VMA).

3.6 Dust-to-Binder Ratio ($P_{0.075}/P_{be}$) - By mass, the ratio between the percent of aggregate passing the 0.075 mm (No. 200) sieve ($P_{0.075}$) and the percent effective binder content (P_{be}).

3.7 Nominal Maximum Aggregate Size (NMAS) - One size larger than the first sieve that retains more than 10 percent aggregate (Note 2).

3.8 Maximum Aggregate Size - One size larger than the nominal maximum aggregate size (Note 2).

Note 2-The definitions given in Subsections 3.7 and 3.8 apply to Superpave mixes only and differ from the definitions published in other AASHTO standards.

4. **Significance and Use**-This standard may be used to select and evaluate materials for 4.75 mm NMAS Superpave volumetric mix designs.

5. Binder Requirements

5.1 The binder shall be a performance-graded (PG) binder, meeting the requirements of MP1, which is appropriate for the climate and traffic-loading conditions at the site of the paving project or as specified by the contract documents.

5.1.1 Determine the mean and the standard deviation of the yearly, 7-day-average, maximum pavement temperature, measured 20 mm below the pavement surface, and the mean and the standard deviation of the yearly, 1-day-minimum pavement temperature, measured at the pavement surface, at the site of the paving project. These temperatures can be determined by use of the LTPPBind software or be supplied by the specifying agency. If the LTPPBind software is used, the LTPP high and low temperature models should be selected in the software when determining the binder grade. Often, actual site data is not available, and representative data from the nearest weather station will have to be used.

5.1.2 Select the design reliability for the high and low temperature performance desired. The design reliability required is established by agency policy.

Note 3-The selection of design reliability may be influenced by the initial cost of the materials and the subsequent maintenance costs.

5.1.3 Using the pavement temperature data determined, select the minimum required PG binder that satisfies the required design reliability.

5.2 If traffic speed or the design ESALs warrant, increase the high temperature grade by the number of grade equivalents indicated in Table 1 to account for the anticipated traffic conditions at the project site.

6. Combined Aggregate Requirements

6.1 Size Requirements

6.1.1 Nominal Maximum Size-The combined aggregate shall have a nominal maximum aggregate size of 4.75 mm.

6.1.2 Gradation Control Points-The combined aggregate shall conform to the gradation requirements specified in Table 2 when tested according to T11 and T27.

6.2 Fine Aggregate Angularity Requirements-The aggregate shall meet the uncompacted void content of fine aggregate requirements, specified in Table 3, measured according to T304, Method A.

6.3 Sand Equivalent Requirements-The aggregate shall meet the sand equivalent (clay content) requirements, specified in Table 3, measured according to T176.

7. HMA Design Requirements

7.1 The binder and aggregate in the HMA shall conform to the requirements of Sections 5 and 6.

7.2 The HMA design, when compacted in accordance with TP4, shall meet the relative density, VMA, VFA, and dust-to-binder ratio requirements specified in Table 4. The initial, design, and maximum number of gyrations are specified in PP28.

7.3 The HMA design, when compacted according to TP4 at 7.0 ± 1.0 percent air voids and tested in accordance with T283 shall have a tensile strength ratio of at least 0.80.

Table A-1. Binder Selection on the Basis of Traffic Speed and Traffic Level

Design ESALs[1] (million)	Adjustment to the High Temperature Grade of the Binder[5]		
	Traffic Load Rate		
	Standing[2]	Slow[3]	Standard[4]
<0.3	1	-	-
0.3 to <3	2	1	-
3 to <10	2	1	-
10 to <30	2	1	[6]
$30	2	1	1

(1) The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.
(2) Standing traffic-where the average traffic speed is less than 20 km/h.
(3) Slow traffic-where the average traffic speed ranges from 20 to 70 km/h.
(4) Standard traffic-where the average traffic speed is greater than 70 km/h.
(5) Increase the high temperature grady by the number of grade equivalents indicated (one grade is equivalent to 6°C). Use the low temperature grade as determined in Section 5.
(6) Consideration should be given to increasing the high temperature grade by one grade equivalent.

Note 4-Practically, PG binders stiffer than PG 82-XX should be avoided. In cases where the required adjustment to the high temperature binder grade would result in a grade higher than a PG 82, consideration should be given to specifying a PG 82-XX and increasing the design ESALs by one level (e.g., 10 to <30 million increased to 30 million).

Table A-2. Aggregate Gradation Control Points

Sieve Size (mm)	Nominal Maximum Aggregate Size-Control Point (Percent Passing)	
	4.75 mm	
	Min	Max
12.5	100	100
9.5	95	100
4.75	90	100
1.18	30	54
0.075	6	12

Table A-3. Superpave Aggregate Consensus Property Requirements

Design ESALs[1] (million)	Uncompacted Void Content of Fine Aggregate (Percent), minimum		Sand Equivalent (Percent), minimum
	#100 mm	>100 mm	
<.03	40	40	40
0.3 to <3	43	40	40
3 to <10	45	40	45
10 to <30	45	40	45
$30	45	45	50

(1) The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

Note 5-If less than 25 percent of a construction lift is within 100 mm of the surface, the lift may be considered to be below 100 mm for mixture design purposes.

Table A-4. Superpave HMA Design Requirements

Design ESALs[1] (million)	Required Relative Density (Percent of Theoretical Maximum Specific Gravity)			Voids in the Mineral Aggregate (VMA) (Percent), minimum[2]	Voids Filled With Asphalt (VFA) (4) Range (Percent)	Dust-to-Binder Ratio Range
	$N_{initial}$	N_{design}	N_{max}			
<0.3	#91.5	96.0	#98.0	16.0 min.	75-80	0.9 - 2.2
0.3 to <3	#90.5			16.0 - 18.0	75 - 78	
3 to <10	#89.0					
10 to <30						
$30						

(1) Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

Note 6 - Mixtures designed for design ESAL levels above 0.3, a maximum VMA value of 18 percent should be considered. Mixtures having more than 18 percent VMA may be prone to rutting.