NCAT Report 03-05

4.75 MM NMAS STONE MATRIX ASPHALT (SMA) MIXTURES

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Michael H. Huner

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National Center for Asphalt Technology
NCAT
AUBURN UNIVERSITY

277 Technology Parkway - Auburn, AL 36830

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Hongbin Xie
Graduate Research Assistant
National Center for Asphalt Technology
Auburn University, Alabama

L. Allen Cooley, Jr.
Senior Geotechnical/Pavements Engineer
Burns Cooley Dennis, Inc.
Ridgeland, Mississippi
(Formerly, National Center for Asphalt Technology)

Michael H. Huner
District Engineer
Asphalt Institute
Franklin, Tennessee
(Formerly, National Center for Asphalt Technology)

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ABSTRACT

The use of 4.75 mm nominal maximum aggregate size (NMAS) hot mix asphalt has recently become a more attractive alternative to highway engineers because these mixes have the potential to be used within a preventative maintenance program. The primary reason for this attractiveness is that these mixes can be placed in thin lifts.

Because of the recent research and experiences in developing 4.75 mm NMAS SMA mixes, a study was needed to further refine the design of 4.75 mm NMAS SMA mixes. Specifically, the fraction passing the 0.075 mm sieve and the currently specified draindown basket were evaluated.

Based upon the test results and analyses, SMA mixes having a 4.75 mm NMAS can sometimes be successfully designed having gradations with aggregate fractions passing the 0.075 mm sieve less than the currently specified 12 percent. Gradations with aggregate fractions passing the 0.075 mm sieve of 9 percent can be utilized as long as all other requirements are met.

Draindown tests conducted using a wire mesh basket with 2.36 mm openings produced test results with less draindown than tests conducted with a wire mesh basket having 6.3 mm openings. It was concluded that the difference in draindown results between the two basket types was related to the amount of mix that could fall through the different mesh size openings.

KEY WORDS: Stone matrix asphalt (SMA), 4.75 mm NMAS, mix design, rutting

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4.75 MM NMAS STONE MATRIX ASPHALT (SMA) MIXTURES

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BACKGROUND

Stone Matrix Asphalt (SMA) has been used successfully in the United States for over 10 years since its first introduction in 1991. To date, SMA has been proven to be a rut-resistant mix. The most commonly used nominal maximum aggregate sizes (NMAS) for SMA in the U.S. have been 19.0 and 12.5 mm. Some projects have, however, been placed that had a 9.5 mm NMAS with successful experience (*1*).

In 1999, the National Center for Asphalt Technology (NCAT) completed a National Cooperative Research Program (NCHRP) study to develop mix design criteria for SMA mixes (*2*). Within this document, mix design criteria along with gradation requirements were provided for SMA mixes having a range of NMAS from 25.0 to 4.75 mm. Based upon this NCHRP study, a recommended gradation band was developed for 4.75 mm NMAS mixes (Table 1).

Table 1. Recommended 4.75 mm NMAS SMA Gradation Bands, Percent Passing by Volume (*1*)

Sieve (mm)	9.5	4.75	2.36	1.18	0.6	0.30	0.075
Lower	100	90	28	22	18	15	12
Upper	100	100	65	36	28	22	15

In 2001, the NCAT reported on the potential of using SMA for thin overlays (*3*). The purpose of this study was to evaluate whether SMA mixes having a 4.75 mm NMAS gradation could be designed and how they compared to more conventional NMAS SMA mixes. The gradation band utilized for this study was identical to the recommendations shown in Table 1.

Both Maryland and Georgia DOTs have used 4.75 NMAS dense-graded mixes for preventive maintenance programs, low volume roads, and leveling purposes (*4*). Recently, the NCAT conducted a study on 4.75 NMAS Superpave designed mixes (*4*) and a concept study for screening (fine aggregate stockpiles) mixes (*5*). These screening mixes also had 4.75 mm NMAS gradations. Table 2 and Figures 1 and 2 summarize the gradation bands used in Maryland, Georgia, and the NCAT study. And Table 3 summarizes the design requirements for those mixes.

Based upon the previous studies, mixes having a 4.75 mm NMAS can be designed successfully. These types of mixes have the potential to be used within a preventative maintenance program because they can be placed in thin lifts. Because of the success of previous work and experiences in developing 4.75 mm NMAS SMA mixes, a study was needed to further refine the design of 4.75 mm NMAS SMA mixes.

Table 2. Gradations Used in Previous Studies (*3, 4*).

	Grading Requirements % passing sieve								
Sieve (mm)	12.5	9.5	4.75	2.36	1.18	0.6	0.30	0.15	0.075
Maryland		100	80-100	36-76	--	--	--	--	2-12
Georgia DOT	100	90-100	75-95	60-65	--	--	20-50	--	4-12
4.75mm Superpave	100	95-100	90-100	--	30-54	--	--	--	6-12
Screening mixes*		100	91.6-98.7	68.5-81.8	45.3-65.7	30.3-52.3	21.4-38.1	15.5-24.1	12.0-14.4

* No gradation recommendations were provided; values represent gradations studied.

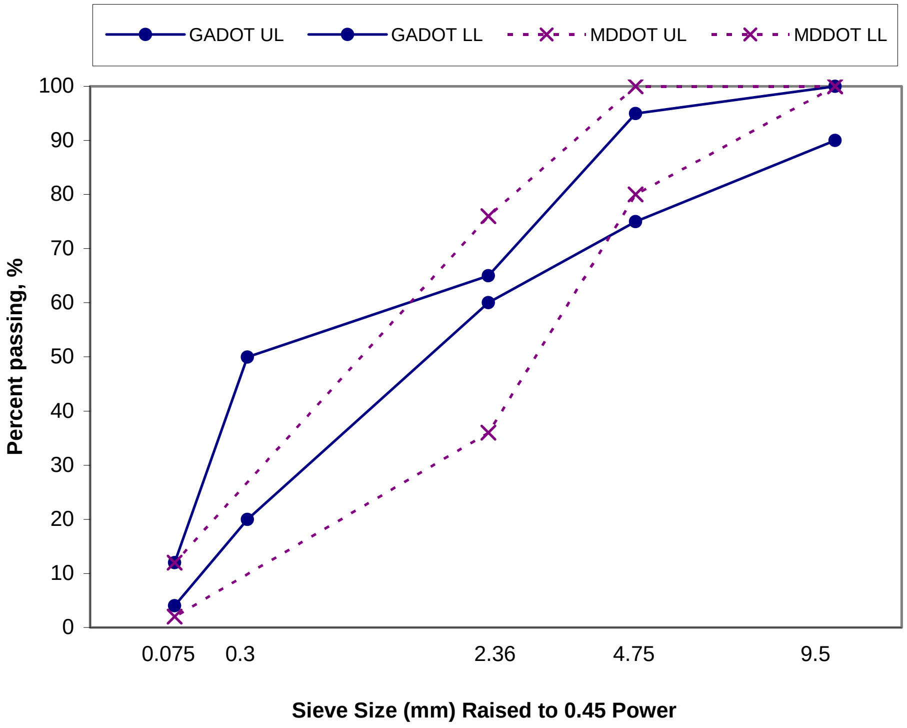

Figure 1. Georgia and Maryland DOT Gradation Limits

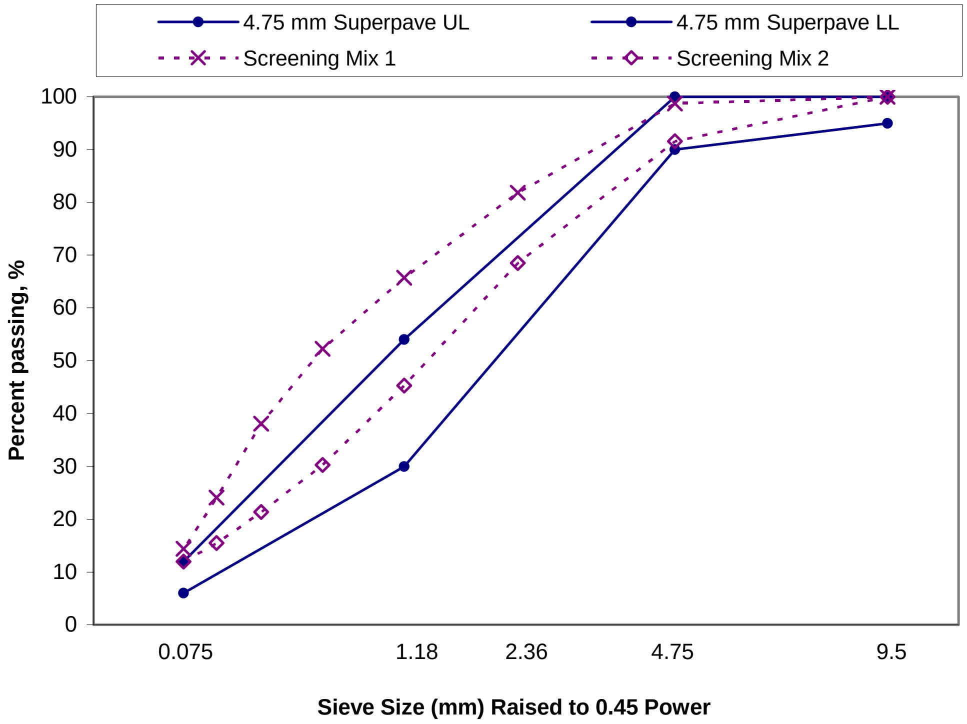

Figure 2. 4.75 mm Superpave Gradation Limits and Two Screening Mixes Gradations (*4, 5*)

Table 3. Design Requirements (*4, 5*)

	Asphalt content (%)	Design air voids (%)	VMA (%)	VFA (%)	Dust to Binder Ratio	Effective Volume of Binder, %
Maryland	5.0-8.0	4.0	--	--	--	--
Georgia DOT	6.0-7.5	4.0-7.0	--	50-80	--	--
4.75mm Superpave	--	4.0	16.0-18.0	75-80	0.9-2.2	--
Screening mixes	--	4.0-6.0	--	67-80	--	12 min

Two primary issues needed further evaluation: gradation requirements for the percent passing 0.075 mm sieve and the use of the currently standardized draindown basket. There was some concern that the 0.075 mm sieve requirements (Table 1) were too high for some aggregate types and, therefore, needed further evaluation. Draindown is an important part of the SMA design procedure. AASHTO T 305-97 specifies a 6.3 mm mesh for draindown basket. If an SMA has a 4.75 mm NMAS, essentially all of the aggregate fraction will pass through this sized cloth. Therefore, a different sized sieve cloth needs to be evaluated for 4.75 mm NMAS mixes.

OBJECTIVE

The objective of this research study was to further refine the design of 4.75 mm NMAS SMA. Specifically, the fraction passing the 0.075 mm sieve and the requirements for the draindown basket were evaluated.

RESEARCH APPROACH

The research approach entailed designing four different SMA mixes having a 4.75 mm NMAS. Two aggregates were included in this evaluation: granite and limestone. These two aggregates were also utilized in NCATs work on 4.75 mm NMAS Superpave designed mixes (*4*). A single gradation was used in this study except that two fractions passing the 0.075 mm sieve were investigated: 9 and 12 percent. The 12 percent was selected because it met the lower gradation requirements from the aforementioned NCHRP study (*2*) for 4.75 mm NMAS SMA mixes (Table 1). The 9 percent was evaluated to determine the potential for lower dust contents in 4.75 mm NMAS SMA mixes. The target gradation is presented in Table 4 and illustrated in Figure 3.

Table 4. 4.75 mm SMA Gradation Used in This Study

	Grading Requirements % passing sieve							
Sieve (mm)	9.5	4.75	2.36	1.18	0.6	0.30	0.15	0.075
4.75 mm SMA	100	90	28	22	18	15	13	9 and 12

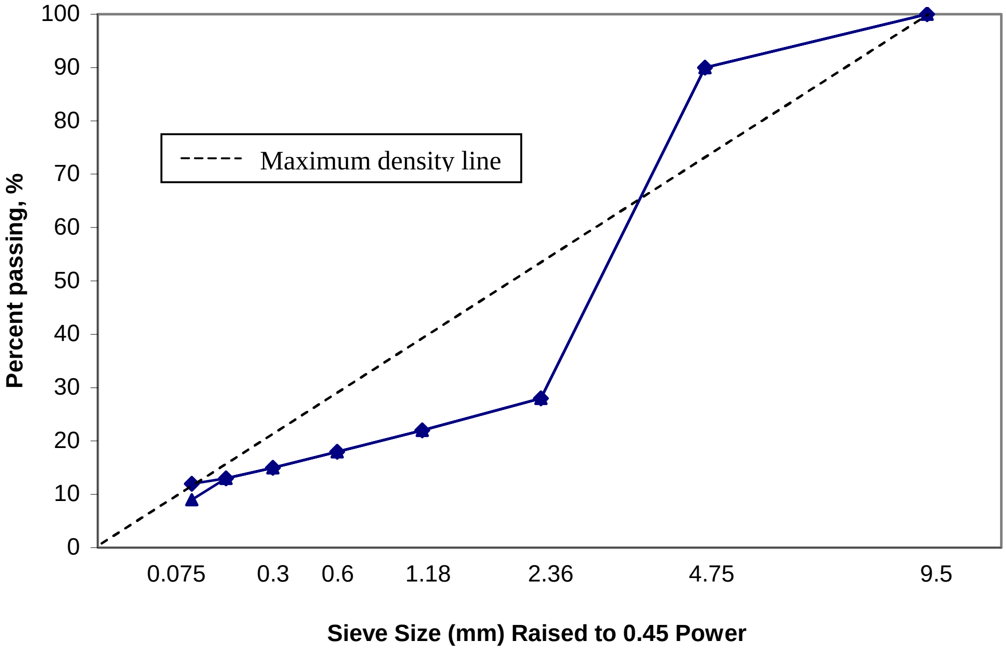

Figure 3: Gradation Used in This Study

When designing any 4.75 mm NMAS mix, there is a concern about excessively high optimum binder contents because of the high surface area of the gradation and potentially high VMA values. To combat this potential problem, the design air voids could be increased from the standard of 4 percent and still provide an acceptable performing mix. Thus in this study, 4 and 6 percent design air voids were utilized.

A constant compactive effort was used for all designs. The design compactive effort (N_{design}) was 75 gyrations. A PG 64-22 asphalt binder meeting Superpave high temperature requirements above 67 ºC was used for all the mixes. Thus, for the study, there were a total of 8 designed mixes (2 aggregate types * 2 dust contents * 2 design air void levels). For each mix, the volumetric properties, such as voids in mineral aggregate (VMA), voids filled with asphalt (VFA), voids in coarse aggregate (VCA) were determined and evaluated.

In order to evaluate the stability of each mix, rut tests were conducted with the Asphalt Pavement Analyzer (APA). APA conditions included in this research study 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 Superpave gyratory samples that were normal mix design sized samples (height is 115± 5 mm) compacted at the appropriate binder content to the design number of gyrations.

The draindown characteristics were evaluated using two different baskets: the standard 6.3 mm wire cloth and a 2.36 mm wire cloth. Figure 4 shows the difference between two different baskets.

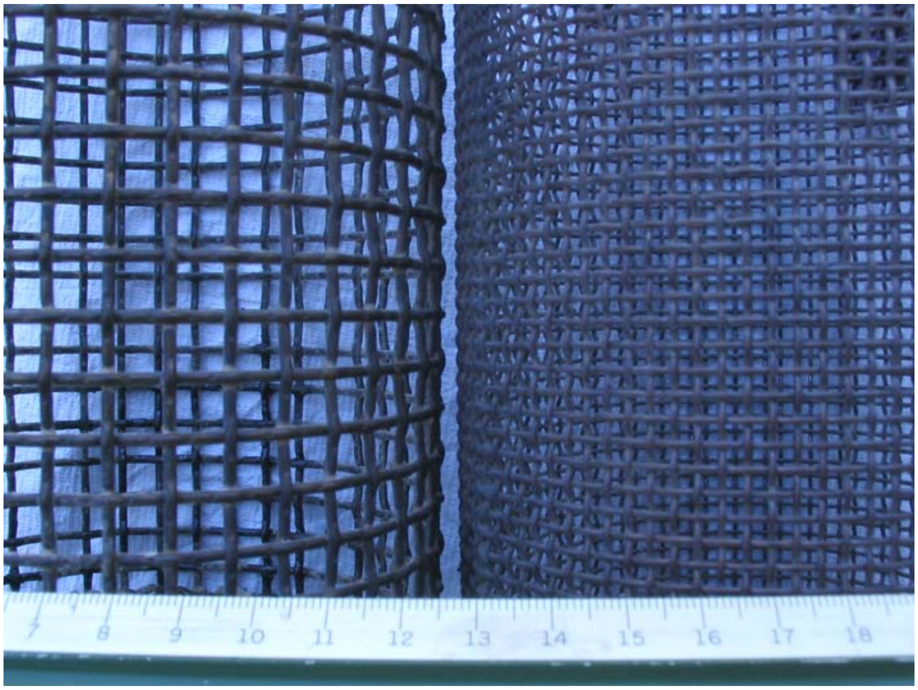

Figure 4. Basket with Two Different Sizes of Screening

Only two mixes were evaluated for draindown tests. Each aggregate type was blended to meet the gradation having 9 percent passing the 0.075 mm sieve at a design air void content of 4 percent. These mixes were selected because they should be the most susceptible to draindown as they should have the highest optimum binder content. A test temperature of 175ºC was used during all draindown testing. Two replicates of each mix were tested.

MATERIALS AND METHODS

Materials

Aggregates

Two commonly used aggregate types were utilized in this study: granite and limestone. Aggregate properties are summarized in Table 5. Both aggregates had similar bulk specific gravity values; however, the limestone had a slightly higher absorption value (1.0 percent compared to 0.6 percent). The granite had a higher fine aggregate angularity value (49 percent) than did the limestone (46 percent).

Table 5. Aggregate Properties

Properties	Procedure	Granite	Limestone
Bulk Specific Gravity	AASHTO T84	2.669	2.666
Apparent Specific Gravity	AASHTO T84	2.713	2.741
Water Adsorption, %	AASHTO T84	0.6	1.0
L.A. Abrasion, %	AASHTO T96	36.4*	26.4
Flat & Elongated, 3:1, %	ASTM D4791	33.1	28.5
Fine Aggregate Angularity, %	AASHTO T304	49.0	46.0

* Although AASHTO recommends using aggregates with maximum 30 percent L.A. abrasion loss for SMA mixtures, a number of states, such as Virginia and Georgia, allow using aggregate with a higher L.A. abrasion value up to 45 percent in SMA mixtures.

Mineral Filler

The filler material used in this study was marble dust. This mineral filler has been used in a number of NCAT studies on SMA.

Fiber

Fibers were not incorporated into the SMA mixes. Because of the high surface area associated with the 4.75 mm NMAS and the normal dust contents for SMA studied, draindown was not perceived as a potential problem. Results of the draindown tests should either validate this assumption or prove it false.

Binder

A PG 64-22 asphalt binder was used in all the mixes. The primary purpose for utilizing the non-modified PG-64-22 binder was to better evaluate the aggregate structure within the mixtures. A polymer modified binder may mask the effect of the aggregate structure. The asphalt binder properties are summarized in Table 6 below.

Table 6. Asphalt Binder Properties

Test	Temperature (°C)	Test Result	Requirement
Unaged DSR, G*/sinδ (kPa)	67	1.078	1.00 min
RTFO Aged DSR, G*/sinδ (kPa)	67	2.279	2.20 min
PAV Aged DSR, G*/sinδ (kPa)	25	4752	5000 max
PAV Aged BBR, Stiffness (MPa)	-12	226	300 max
PAV Aged BBR, m-value	-12	0.325	0.300 min

Test Methods

Voids in Coarse Aggregate (VCA)

For 4.75 mm NMAS SMA, the definition of coarse aggregate fraction has a somewhat different meaning than with other traditional NMAS mixtures. Coarse aggregate is typically defined as the material coarser than the 4.75 mm sieve. However, for a 4.75 mm NMAS gradation, basically all of the aggregate particles pass through the 4.75 mm sieve. From the gradation curve shown in Figure 2, the 1.18 mm sieve was the breakpoint of the gradation studied. This means that the largest fraction of aggregate was retained on the 1.18 mm sieve. Vavrik et al (*6*) have suggested that the primary control sieve for a 4.75 mm NMAS gradation should be the 1.18 mm sieve. Therefore, the aggregates larger than the 1.18 mm sieve were considered the coarse aggregate fraction.

The 1.18 mm and larger aggregates were used to conduct the unit weight and voids test (AAHTO T19) to determine the voids in coarse aggregate (VCA) in the dry rodded condition (VCA_{DRC}). The VCA_{DRC} results were compared with VCA values for the compacted mix (VCA_{MIX}) to determine the existence of coarse aggregate on coarse aggregate contact. The VCA_{MIX} was calculated as follows:

$$VCA_{MIX} = 100 - \frac{G_{mb} \times P_{ca}}{G_{ca}} \qquad (1)$$

Where G_{mb} is the bulk specific gravity of compacted mixture, G_{ca} is the combined bulk specific gravity of the coarse aggregate fraction, which is the aggregates retain on 1.18 mm sieve, and P_{ca} is the coarse aggregate content, percent by total mass of mixture.

Draindown Test

The draindown test provides an evaluation of the draindown potential of an asphalt mixture during field production/transportation. The draindown test in this study was based on AASHTO T 305-97 using both the standard 6.3 mm wire cloth and the 2.36 mm wire cloth.

A loose sample of asphalt mixture to be tested was placed in a wire basket which was positioned on a paper plate or other suitable container of known mass. The sample, basket, and plate or container was then placed in a forced draft oven for one hour at a pre-selected temperature. At the end of one hour, the basket containing the sample was removed from the oven along with the plate or container and the mass of the plate or container determined. The difference in mass of the plate or container before and after the test was defined as the amount of draindown. The acceptable amount of draindown measured for 4.75 SMA mixtures was set as 0.3% according to AASHTO MP8-01. The draindown test limit was set as 0.3% even though the 2.36 mm wire cloth was employed for the draindown test. Refinement of the specification limit for this draindown test by using the 2.36 mm sieve was not included in this study, further work will be needed to determine the appropriate limit.

TEST RESULTS AND ANALYSIS

Mix Design

Mix design results are summarized in Table 7 for the eight mix design combinations. Results are provided for optimum binder content, VMA, VFA, VCA_{MIX} and VCA_{DRC}, % G_{mm} @ N_{ini}, effective binder content, dust to effective binder ratio, and film thickness.

Table 7. Mix Design Results

Agg. Type	Dust content, %	VTM	Total AC, %	VCA_{MIX}, %	VCA_{DRC}, %	VMA, %	VFA, %	% G_{mm} @ N_{ini}	Eff. AC, %	Dust to Eff. AC Ratio	Film Thickness, micron
GRN	9	4	6.5	36.3	44.20	18.0	77.8	85.1	6.3	1.43	8.89
	9	6	5.8	36.3	44.20	18.1	66.8	83.6	5.6	1.61	7.84
	12	4	6.0	35.4	44.20	16.8	76.2	85.7	5.8	2.07	7.18
	12	6	5.3	35.8	44.20	17.3	65.2	83.7	5.1	2.35	6.26
LMS	9	4	5.7	33.6	40.97	14.6	72.7	85.3	5.0	1.80	6.96
	9	6	4.7	33.3	40.97	14.2	57.8	84.9	4.0	2.25	5.51
	12	4	5.4	33.3	40.97	14.0	71.5	85.0	4.7	2.55	5.75
	12	6	4.6	33.3	40.97	14.1	57.5	83.2	3.9	3.08	4.73

Initial observation of Table 7 shows that all mixes met the criteria for stone-on-stone contact (VCA_{MIX} less than VCA_{DRC}). None of the four limestone mixes met the VMA requirements for an SMA (17 percent minimum).

Optimum binder contents shown in Table 7 ranged from a low of 4.7 percent to a high of 6.5 percent (Figure 5). On average the granite mixes had higher optimum binder content (average of 5.9 percent) than the limestone mixes (average of 5.1 percent).

As the percent passing the 0.075 mm sieve ($P_{0.075}$) increased, optimum asphalt content decreased for mixes using both aggregate types. For granite mixes, increasing the $P_{0.075}$ by 3 percent from 9 to 12 percent generally reduced optimum asphalt content by 0.5 percent; however, for limestone mixes, increasing the $P_{0.075}$ by 3 percent, from 9 to 12 percent, decreased optimum asphalt content by 0.2 percent.

As expected, $P_{0.075}$ had the greatest effect on film thickness. The film thickness was calculated based on effective asphalt volume divided by aggregate surface area, and in this study mineral filler was counted as aggregate to calculate surface area. The 9 and 12 percent $P_{0.075}$ mixes had average film thickness of 7.30 and 5.98 microns, respectively. This data suggests that an increase of 3 percent of $P_{0.075}$ resulted in an average decrease in film thickness of about 1.3 microns or 20 percent.

If the mineral filler is not counted as aggregate in calculating the surface area, the film thickness will significantly increase. The 9 and 12 percent $P_{0.075}$ mixes will have the same calculated aggregate surface area, and have average film thickness of 12.18 and 11.32 microns, respectively. This data again suggests that an increase of mineral filler content resulted in lower film thickness because of the decrease of the effective asphalt content.

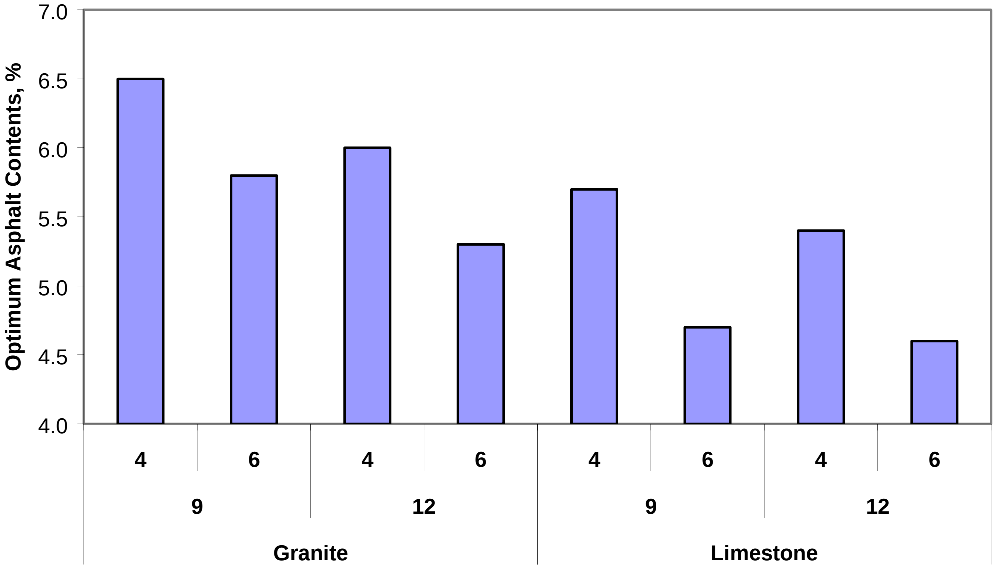

Figure 5. Range in Optimum Asphalt Contents

Also as expected, the mixes designed at 4.0 percent air voids had higher average optimum asphalt contents (5.9 percent) than the mixes designed at 6.0 percent air voids (5.1 percent). The 2.0 percent range in design air voids resulted in about 0.8 percent difference in optimum asphalt content.

VMA values for the individual mixes ranged from a high of 18.1 percent to a low of 14.0 percent (Figure 6). As expected, VMA at optimum asphalt content was affected by the aggregate type and $P_{0.075}$. Design air voids did not appear to significantly affect the overall average VMA values. This is also as expected, since SMA has stone on stone contact, resulting in little densification, the extra asphalt for 4 percent design air voids only serve to reduce the air voids. On average, the granite mixes had higher VMA (average 17.5 percent) than the limestone mixes (average 14.3 percent). Also expected, when the $P_{0.075}$ increased, the average VMA of granite mixes decreased (from18.1 to 17.1 percent), the average VMA of limestone slightly decreased (from 14.4 to 14.1 percent).

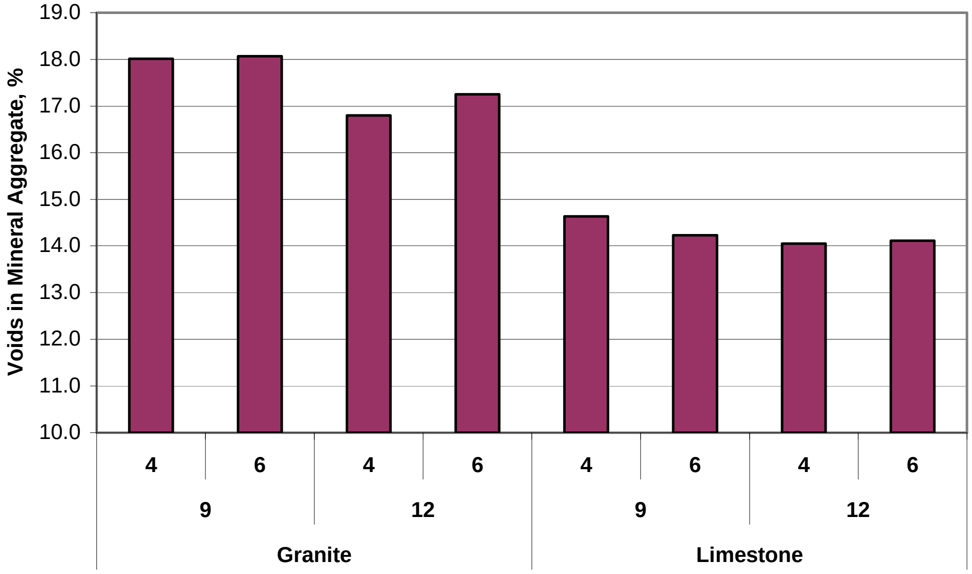

Figure 6. Range in Voids in Mineral Aggregate Values

VCA_{DRC} values were 44.2 percent for the granite and 41.0 percent for the limestone aggregates. VCA_{MIX} values ranged from a low of 33.3 percent to a high of 36.3 percent (Figure 7). All VCA_{MIX} values were smaller than the VCA_{DRC} values, which indicates all mix designs had coarse aggregate on coarse aggregate contact. A sample picture of 4.75 mm SMA vertical cross section is shown in Figure 8. The coarse aggregate on coarse aggregate structure can be observed from Figure 8.

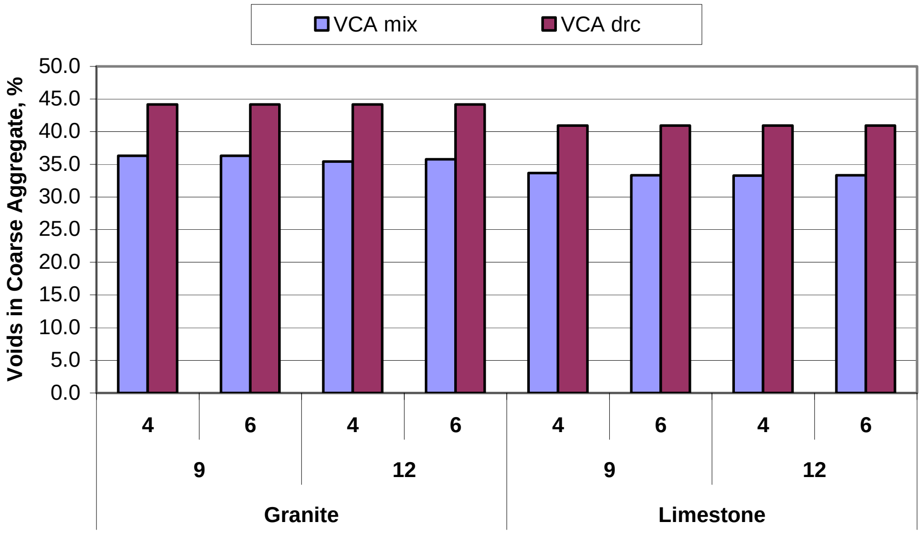

Figure 7. Range in Voids in Coarse Aggregate Values

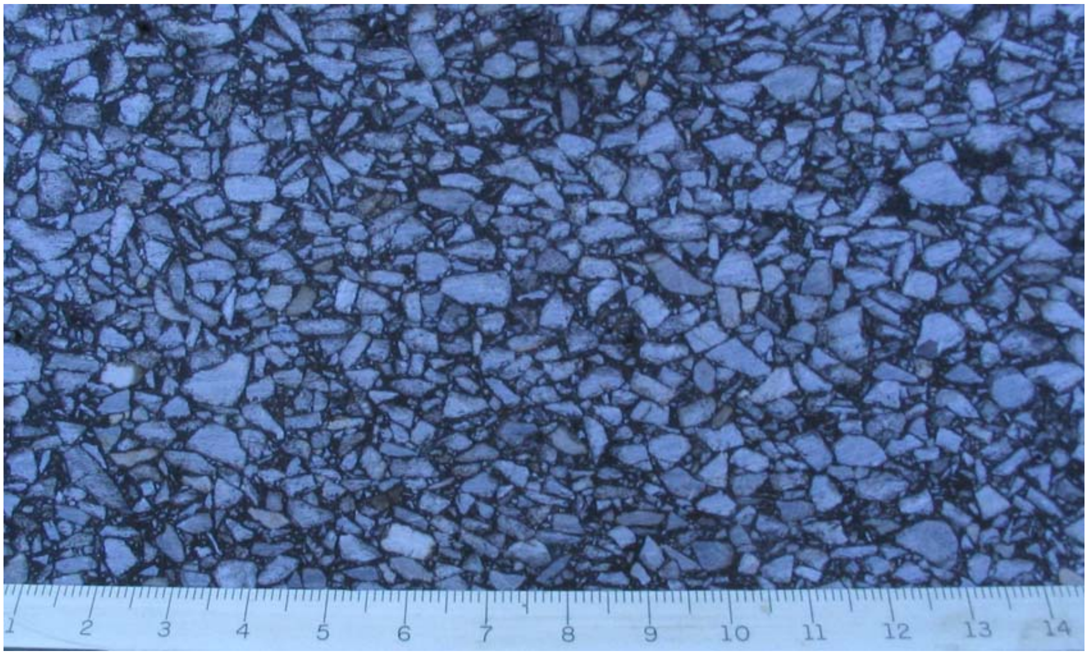

Figure 8. Vertical Cross Section of 4.75 mm SMA (Limestone @ 5.7% AC)

Rut Testing

Table 8 provides the Asphalt Pavement Analyzer (APA) rut depth data for the eight mixes evaluated in this study. Figure 9 illustrates all the rut data.

Table 8. Results of Asphalt Pavement Analyzer Testing

Agg. Type	Dust Content, %	Air Voids, %	Total Binder Content, %	VMA, %	VCA Ratio	Average Rut Depth, mm
Granite	9	4	6.5	18.0	0.821	12.69
		6	5.8	18.1	0.822	7.11
	12	4	6.0	16.8	0.801	10.45
		6	5.3	17.3	0.809	10.63
Limestone	9	4	5.7	14.6	0.821	17.18
		6	4.7	14.2	0.814	11.49
	12	4	5.4	14.0	0.812	15.15
		6	4.6	14.1	0.813	6.25

All the rutting results shown in Table 8 and Figure 9 are relatively high compared to the conventional NMAS SMA (In Georgia DOT specification, the maximum APA rut depth recommended for SMA is 5mm based on 100 psi hose pressure and 100 lb load). This may be mainly explained by the fact that non-modified asphalt was used in this study. Another possibility for the high rut depth would be the small NMAS in combination with 115mm sample height and the hose diameter within the APA testing. Since only thin layers will be expected to be used with 4.75 mm SMA mixes, rutting would not be expected to be a major issue. All rutting results are only used for relative comparisons and factor analysis.

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, dust content, and design air voids) and any interactions between the main factors on rut depths. Results of the ANOVA are presented in Table 9.

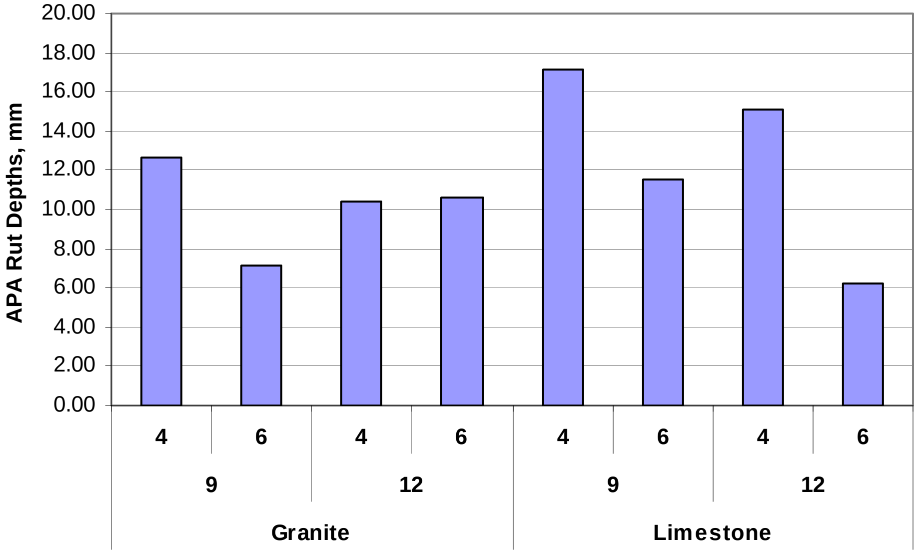

Figure 9. Range in APA Rut Depth Values

Table 9. Results of Analysis of Variance for Rut Depth

Source	DF	Seq SS	Adj SS	Adj MS	F Statistic	P-Value	Significant *?
Aggregate	1	20.167	29.84	29.84	24.05	0.000	Yes
Dust Content	1	7.258	12.685	12.685	10.22	0.006	Yes
Air Voids (VTM)	1	134.803	141.106	141.106	113.73	0.000	Yes
Agg*Dust	1	25.187	25.831	25.831	20.82	0.000	Yes
Agg*VTM	1	32.504	29.927	29.927	24.12	0.000	Yes
Dust*VTM	1	3.336	2.28	2.28	1.84	0.195	No
Agg*Dust*VTM	1	28.366	28.366	28.366	22.86	0.000	Yes
Error	15	18.611	18.611	1.241			
Total	22	270.232					

*Level of significance is 95%.

From Table 9, all main factors significantly affected the APA rut depth results. The rut depth results depended on aggregate type. Granite had an average rut depth of 10.2 mm while the limestone had the average rut depth of 12.5 mm. This may because the granite had more surface texture and angularity than the limestone. The fine aggregate angularity of the granite was 49 whereas fine aggregate angularity of the limestone was 46.

With the increase of dust content from 9 percent to 12 percent, the average rut depth decreased from 12.1 mm to 10.6 mm. This was because under the same compactive effort, the higher dust content generally corresponded to lower binder contents and a stiffer asphalt mortar.

The average rut depth also decreased with the increase in design air voids. Mixes designed at 4 percent air voids had an average rut depth of 13.9 mm while the mixes designed at 6 percent air voids had an average rut depth of 8.9 mm. This was because under the same compactive effort, the higher design air voids resulted in lower binder contents and a stiffer asphalt mortar. For 4.75 mm SMA mixture, the design air voids have the potential to be higher, the higher air voids tend to have less rutting.

The interaction between aggregate type and dust content was also shown to be significant. Figure 10 shows that rut depths were similar with the increase of dust content for granite, however, the rut depth decreased with the increase of dust content for limestone. This may be a result of the granite material developing a stronger aggregate skeleton due to increased angularity. Therefore, the effect of dust content was minimal.

The interaction between aggregate type and design air void content was also shown significant. Figure 11 shows that there was a greater difference between average rut depths at 4 and 6 percent design air voids for the limestone mixes than for the granite mixes.

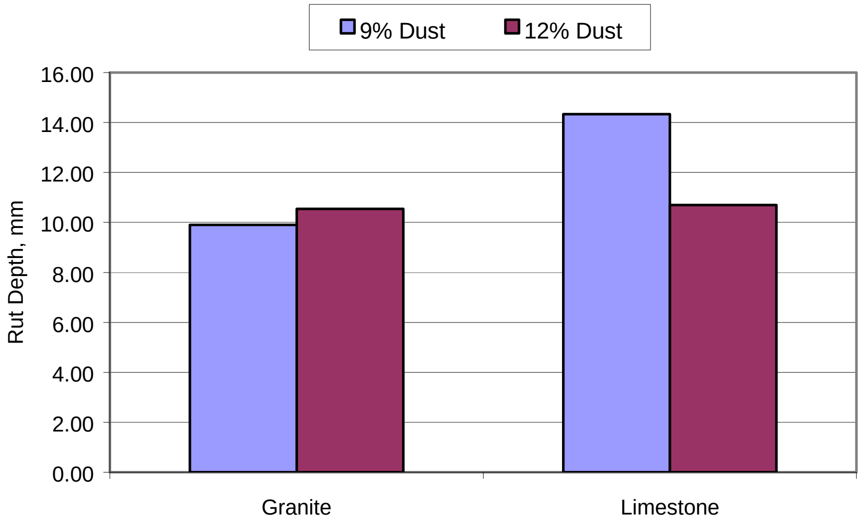

Figure 10. Interaction between Aggregate Type and Dust Content

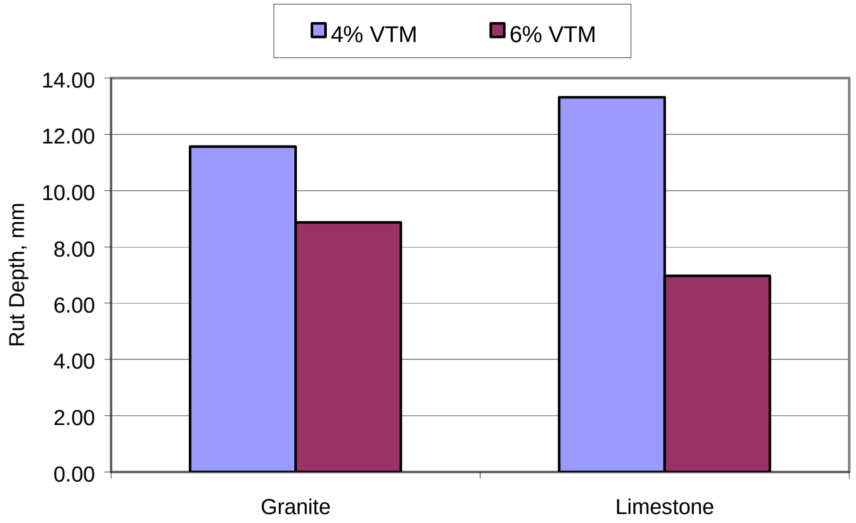

Figure 11. Interaction between Aggregate Type and Design Air Voids Content

Comparisons of Draindown Baskets

Draindown tests were conducted using two baskets having different sieve cloth sizes: 6.3 mm and 2.36 mm. For both the granite and limestone aggregates at 9 percent $P_{0.075}$, draindown tests were conducted at the optimum binder content determined at 4 percent design air voids, tests were also conducted at the optimum plus up to 3 percent asphalt content to consider any field variability. The goal of this testing was to determine whether the smaller sized wire cloth would help prevent aggregate particles from falling through the basket. Results of this testing are shown in Table 10.

Table 10. Results of Draindown Testing

Aggregate	Dust Content, %	Optimum P_b, %	Percent Draindown, %							
			Opt. P_b, %		Opt.+1%		Opt.+2		Opt.+3%	
			2.36 mm[1]	6.3 mm	2.36 mm	6.3 mm	2.36 mm	6.3 mm	2.36 mm	6.3 mm
Granite	9	6.5	0.00	0.07	0.02	0.31	NT [2]	NT	NT	NT
Limestone	9	5.7	0.00	0.00	NT	NT	0.00	0.23	1.79	2.21

1. Mesh size of basket used in draindown test.
2. NT – Not Tested.

All of the draindown tests at optimum asphalt content showed essentially no draindown. This supports the idea presented previously that the surface area and relatively high dust contents will help prevent draindown for a 4.75 mm NMAS SMA mix. Based upon the mix design data presented previously in Table 7, the granite mix had a higher optimum binder content (6.5 percent) than the limestone mix (5.7 percent). The granite mix was combined with asphalt binder at a binder content of optimum plus one percent and draindown tests conducted using both baskets. The results indicated that the test conducted with the 2.36 mm wire cloth provided a lower draindown result (0.02 percent) than the test conducted with the 6.3 mm wire cloth (0.31 percent). The test conducted with the 6.3 mm wire cloth failed the requirement of 0.3 percent draindown maximum.

Because of the relatively low optimum binder content for the limestone mix, it was prepared at optimum plus 2 percent. Results of this testing indicated that neither test failed the requirement of maximum 0.3 percent draindown. However, again the results using the 2.36 mm wire cloth were lower in magnitude (0.00 percent compared to 0.23 percent draindown). Therefore, an additional test was conducted at optimum binder content plus 3 percent. Both mixes failed the maximum requirement of 0.3 percent at this binder content. Once again, the results with the 2.36 mm wire cloth basket were lower than for the standard basket (1.79 percent compared to 2.21 percent draindown).

Based upon the results of this draindown testing, it is obvious that the draindown using the 2.36 mm wire cloth basket were lower than the results utilizing the 6.3 mm wire cloth basket. There are two possible explanations for this occurrence. First, because of the larger openings within the 6.3 mm wire cloth, aggregate particles were able to fall through the openings of the basket and were counted as draindown. The experiences of the authors have noted this to occur in previous draindown tests using larger NMAS mixes. The second possibility has to do with the increased surface area for the 2.36 mm wire cloth basket. Having a smaller opening size, along with a basket of the same dimensions, indicates that there was more surface area covered by the wire mesh. Asphalt binder draining from the mix during the test may have stuck to the wire mesh and, therefore, not drained onto the container used under the basket. If a sufficient amount of binder stuck to the wire mesh, it would be anticipated that the test results with the 2.36 mm wire mesh basket would have produced lower draindown values.

A sample picture of the draindown testing results comparing the two baskets with the two different mesh sizes is shown in Figure 12. During testing of the different mixes, it was noted that aggregate particles did indeed fall through the wire mesh onto the container when using the standard mesh basket. From Figure 12, one can observe that the left plate (6.3 mm basket) had much higher draindown amount than the right plate (2.36 mm basket). A significant part of remains in the left plate were aggregate particles. Therefore, it was believed that aggregate particles falling through the larger mesh accounted for the increase in draindown with the 6.3 mm mesh, and was concluded to have predominantly caused the differences in draindown values between baskets having the two wire mesh sizes.

Figure 12. Sample Draindown Test Results (Granite @ 7.5% AC)

CONCLUSIONS AND RECOMMENDATIONS

The objective of this research study was to further refine the design of 4.75 mm NMAS SMA. Specifically, the fraction passing the 0.075 mm sieve and the draindown basket were evaluated. Based upon the test results and analyses from this limited study, the following are concluded:

1. Based on the draindown test results, durability consideration, and relative comparison of APA testing results, SMA mixes having a 4.75 mm NMAS can sometimes be successfully designed having gradations with aggregate fractions passing the 0.075 mm sieve less than 12 percent. Gradations with aggregate fractions passing the 0.075 mm sieve of 9 percent can be utilized as long as all other requirements are met.

2. APA rutting results of 4.75 mm SMA in this study were relatively high for all the mixtures tested. This is mainly because the non-modified asphalt was used and high ratio of sample height and NMAS was used for APA testing. Based on the APA test results, 4.75 mm SMA with non-modified asphalt is not recommended for high volume traffic roads.

3. Aggregate shape, angularity and texture played an important role in achieving the required design volumetric criteria required for 4.75 mm NMAS SMA mixes. Within this study, the SMA mixes comprised of a granite aggregate passed all volumetric criteria, while SMA mixes comprised of a limestone aggregate failed VMA criteria.

4. Draindown tests conducted using a wire mesh basket with 2.36 mm openings produced test results with less draindown than tests conducted with a wire mesh basket having 6.3 mm openings. It was concluded that the difference in draindown results between the two basket types was related to the amount of aggregate that could fall through the different mesh size openings.

Based upon the conclusions of this study, it is recommended to change the gradation criteria on the 0.075 mm sieve to between 9 and 15 percent from 12 to 15 percent. It is also recommended to utilize a draindown basket having a 2.36 mm wire mesh size for 4.75 mm NMAS SMA instead of the currently standard basket size of 6.3 mm. The specification limit of 0.3 percent for draindown test when using 2.36 mm basket appears reasonable but needs further refinements.

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