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ABSTRACT

Thin-lift hot mix asphalt (HMA) layers are utilized in almost every maintenance and re-habilitation application. These mix types require smaller maximum particle sizes than most conventional HMA surface layers. Although the primary functions of thin-lift HMA are to level the pavement surface, smooth the surface, and/or slow the deterioration of the existing pavement, these mixes may also provide some structural improvement, depending on the layer thickness placed.

The use of manufactured aggregate screenings (fine aggregate stockpiles) as the sole aggregate portion of an HMA mixture was evaluated in this study. Mixes of this nature have the potential for use as thin-lift HMA layers. Two different sources of aggregate screenings, granite and limestone, were utilized to design mixtures at varying design air void contents and then tested for rut susceptibility. The use of a neat versus modified asphalt binder was also evaluated, as well as evaluating potential advantages of cellulose fiber additives. Mixtures using 100 percent manufactured screenings were most often shown to be acceptable with regards to rutting resistance. No work was performed in this study to look at thermal cracking or durability.

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INTRODUCTION

In 1987, the U.S. Congress authorized the Strategic Highway Research Program (SHRP). This research program was a $150 million effort to improve transportation facilities. The hot mix asphalt (HMA) portion of the SHRP research was aimed at the properties of asphalt binders and paving mixtures. The study of aggregate properties (including gradations) was intentionally excluded from the HMA program. However, SHRP researchers had to recommend a set of aggregate gradation specifications based on past experience without the benefit of additional experimental data.

In order to recommend aggregate specifications, SHRP formed an Aggregate Expert Task Group (ETG) (1). This ETG was charged with recommending aggregate properties and gradations for use in HMA. Specifications for gradations resulting from the ETG included definitions for nominal maximum aggregate size, maximum aggregate size, maximum density line, gradation control limits, and a restricted zone. Additionally, a recommendation was made by the ETG that HMA mixes designed for high traffic volume roadways have gradations passing below the restricted zone (i.e., coarse-graded).

Based upon the recommendations of the ETG, many states required gradations passing below the restricted zone for most HMA mixes. The net result of these requirements was that most of the Superpave mixes that have been designed within the U.S. when this report was prepared have been coarse-graded (gradation passing below restricted zone).

In order to blend gradations that would be considered coarse-graded, it is typical that coarse aggregate stockpiles be added at high percentages of the blend. Therefore, the percentage of fine aggregate stockpiles being used in Superpave mixes is generally low. The increased use of these coarse-graded Superpave mixes, plus the increased use of stone matrix asphalt which also utilizes a high percentage of coarse aggregate, has led to large volumes of fine aggregate stockpiles accumulating at quarries. Therefore there is a need to evaluate new methods of utilizing these fine aggregate stockpiles in the HMA industry.

One possible use for the fine aggregate stockpiles (or sometimes called screenings) is for thin-lift HMA applications. Thin-lift HMA layers have been used for most maintenance and rehabilitation applications (2). Thin-lift HMA layers have been placed at thicknesses ranging from approximately 6 mm to 50 mm (2). Typically, thin-lift HMA layers have been used for one or more of the following reasons (2): extend pavement life, improve ride quality, correct surface defects (leveling), improve safety characteristics, enhance appearance, and reduced road-tire noise. Probable applications for an HMA with a high percentage of screenings would be to extend pavement life, improve ride quality, correct surface defects, reduce road-tire noise and enhance appearance. Another potential area for utilization of these types of mixes would be for low volume roadways. Depending on the layer thickness, these screening mixes may also improve the structural properties of a pavement structure.

Due to the large amounts of processed aggregate screenings piling up at quarries and HMA facilities, there was a need to increase the utilization of this product. Because of this need, the possibility of using screenings as the sole aggregate fraction was evaluated in this study.

OBJECTIVES

The main objective of this study was to determine if rut-resistant HMA mixtures could be attained with the aggregate portion of the mixture consisting solely of manufactured aggregate screenings. Secondary objectives were to determine what effect both a modified asphalt binder and a fiber additive might have on rutting performance.

TEST PLAN

To accomplish the project objectives, two fine aggregate stockpiles (screenings), two grades of asphalt binder, and a fiber additive were selected to be used throughout this study. The two aggregate sources selected were both common manufactured aggregates: granite and limestone. The two asphalt binder grades chosen were also commonly used: PG 64-22 and PG 76-22 (SBS modified). Likewise, the fiber additive (cellulose) chosen was common to the asphalt industry. The material variables were combined to produce eight test mixtures (two aggregate sources * 2 binders * with/without fibers). Each of these mixtures was designed at three different air void contents (4, 5, and 6 percent) and then tested in the Asphalt Pavement Analyzer. Because of the relative fineness of screening stockpiles, there was a concern that the designed mixes could have higher optimum binder contents. Therefore, rutting potential was the distress selected for evaluation within this study. Figure 1 shows a summary of the research test plan.

Materials

Screenings Sources

The two manufactured aggregate screenings utilized in this study were a granite and limestone. These two aggregate types are commonly used for asphalt mixtures. Properties of these two materials are presented in Table 1. Gradations for both of the screenings are illustrated in Figure 2. The granite screenings met an AASHTO No. 10 standard grading. This material is relatively cubical and has a rough surface texture with a fine aggregate angularity (FAA) value of 49.3. The limestone screenings also met an AASHTO No. 10 grading and was also considered to be angular with an FAA value of 45.8. Table 1 also shows that the limestone was more absorptive (1.8 percent for limestone compared to 0.2% for granite) than the granite. Figure 2 shows that the granite screenings were much finer than the limestone screenings. For example, the granite screenings had 52% passing the 0.6 mm size while the limestone screenings had 30% passing.

Asphalt Binder Grades

Because of the relative fineness of the screening stockpiles, mixtures in the study were expected to have higher than normal optimum binder contents. Therefore, it was decided to evaluate the effect of both a neat and modified asphalt binder. The two binder grades selected for the study are commonly used in many locations throughout the United States due to their high temperature performance characteristics. The PG64-22 binder is often used for low to medium design traffic levels, while the PG76-22 is typically used for high design traffic levels.

Fiber Additive

A cellulose fiber was used to determine if the addition of a fiber additive would improve rutting-resistance of the HMA mixtures. It is expected that a mineral fiber would provide similar results. These types of additives are typically used with Stone Matrix Asphalt and Open-Graded Friction Course mixtures. The fiber helps to stiffen the asphalt binder/mineral filler mortar. Cellulose fiber was added at 0.3% of the total mixture weight.

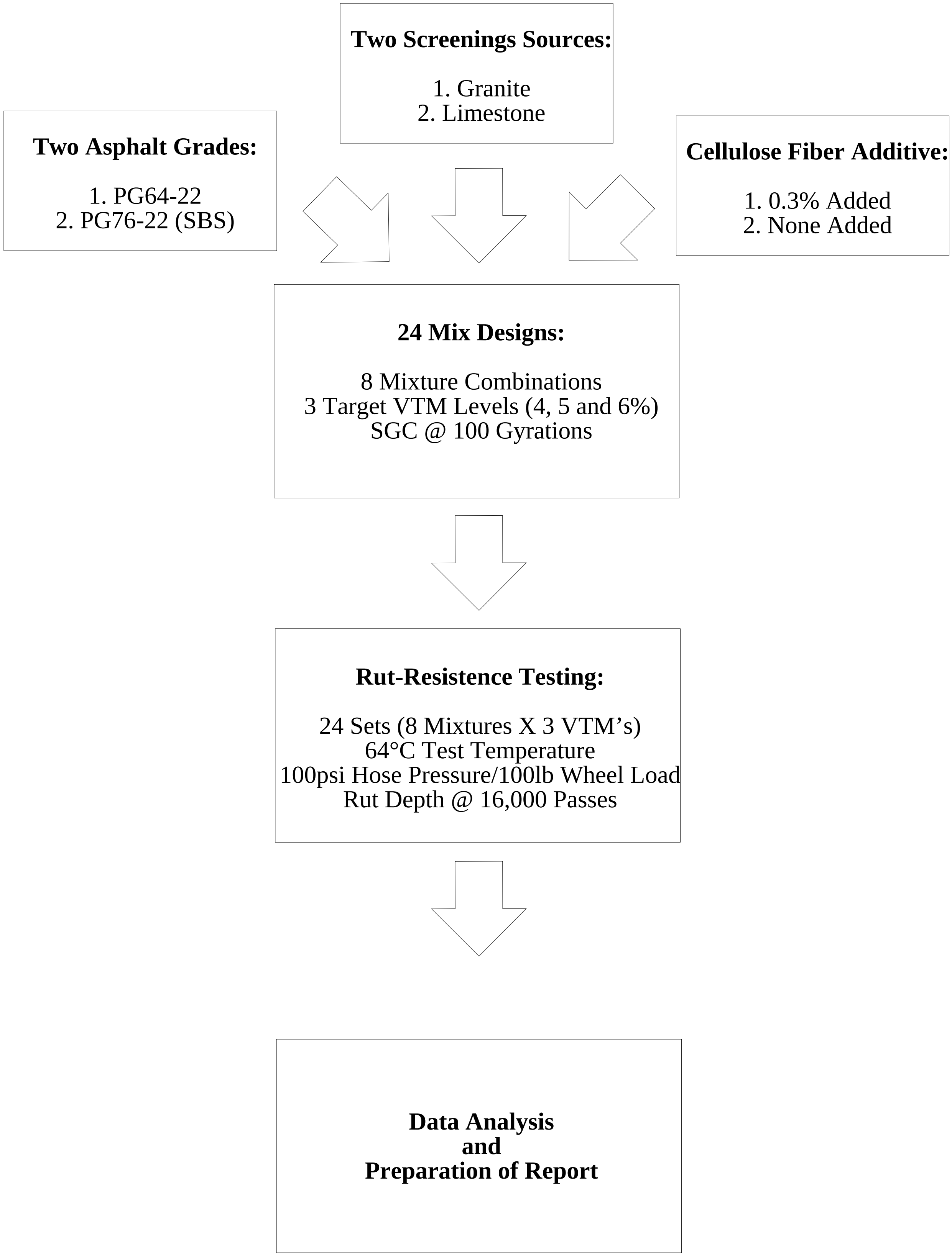

Figure 1. Flow Chart of Research Test Plan

Table 1. Gradations and Properties of Screenings

Sieve Size (U.S. Standard)	**Sieve Size (Metric)**	**Granite (% Passing)**	**Limestone (% Passing)**
3/8 inch	9.50 mm	100	100
No. 4	4.75 mm	99	92
No. 8	2.36 mm	82	68
No. 16	1.18 mm	66	45
No. 30	0.600 mm	52	30
No. 50	0.300 mm	38	21
No. 100	0.150 mm	24	16
No. 200	0.075 mm	14.4	12.0
Aggregate Specific Gravities		**Granite**	**Limestone**
Apparent Specific Gravity (G_{sa})		2.726	2.746
Effective Specific Gravity (G_{se})		2.720	2.730
Bulk Specific Gravity (G_{sb})		2.711	2.616
Absorption (%)		0.2	1.8

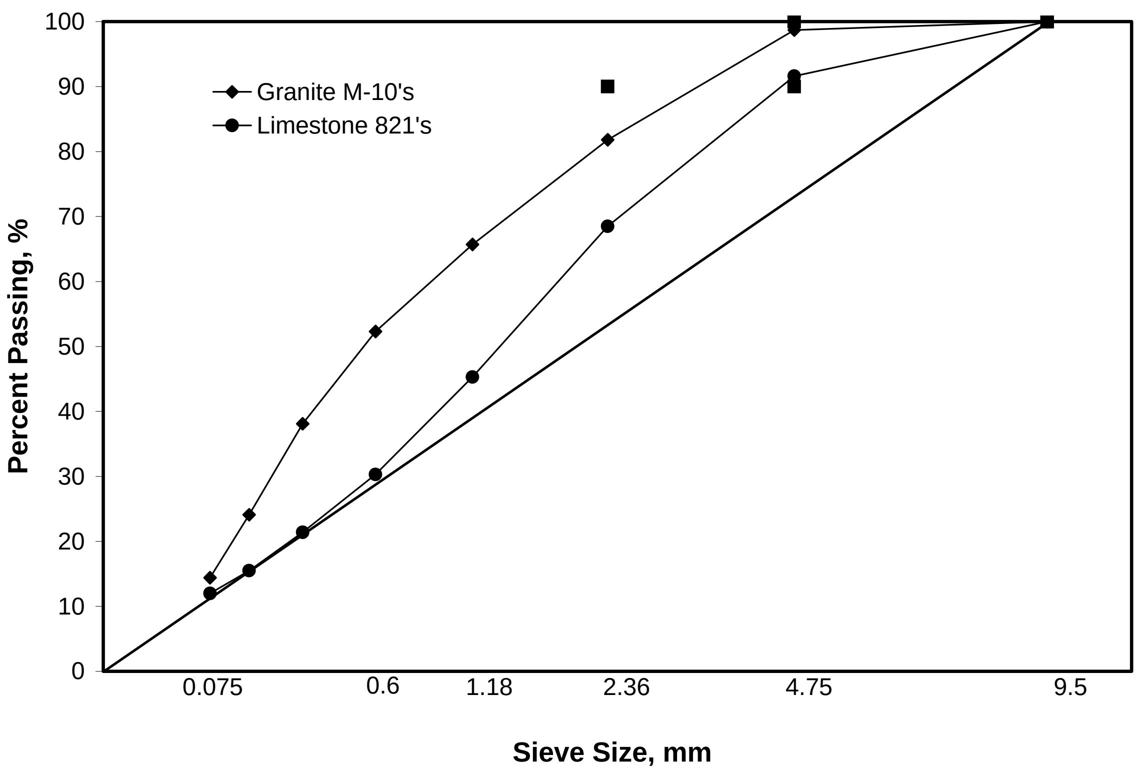

Figure 2. Screenings Gradation

Mix Designs

Because it was expected that optimum binder contents would be higher than typical, conventional mixes, it was decided to evaluate different design void levels in an effort to control optimum binder contents. Design air void contents of 4, 5, and 6 percent were targeted. Also, at the time this study was performed most mixtures were being designed according to Superpave standards, hence, the Superpave gyratory compactor was selected as the laboratory compaction device. For each of the eight mixture combinations, binder contents that corresponded to the three design air void contents were determined.

For each mixture combination, enough screenings material was split out to provide for eight 4,600 gram and two 2,000 gram batches of aggregate. The gradation of these batches represented the gradation of the original stockpile. Since three different air void levels were targeted it was decided to prepare the eight 4,600 gram gyratory samples at 1.0 percent binder content increments (duplicated at each of the asphalt contents). By doing this, it was possible to bracket all three air void levels. The two 2,000 gram samples were prepared for maximum specific gravity testing (AASHTO T209). All samples, including the maximum specific gravity samples, were mixed and short-term aged (AASHTO PP2) for two hours in a forced-draft oven set to compaction temperature. The compaction temperature for the PG 64-22 was determined by evaluating the relationship between temperature and viscosity. Compaction temperature was selected as the temperature that yielded a viscosity of 0.28 Pas. This testing yielded a compaction temperature of 149°C. A compaction temperature of 163°C was utilized for the PG 76-22 as recommended by the supplier.

Once the two hour short-term aging had been completed, the gyratory samples were removed from the oven and loaded into the gyratory molds for compaction. The maximum specific gravity samples were removed and allowed to cool to room temperature for testing according to AASHTO T-209 (theoretical maximum specific gravity, G_{mm}). The compaction level for the mixes was selected to be 100 gyrations. This level of compaction was based on the 1.0 - 3.0 million design ESALs level (AASHTO TP4-96). All samples were compacted at this compactive effort and then extruded from the mold and allowed to cool over-night at room temperature before being further tested.

The gyratory compacted samples were tested according to AASHTO T-166 to determine bulk specific gravity. Also the two maximum specific gravity samples were tested and used to determine an average effective specific gravity value. This effective specific gravity value was then utilized to calculate maximum specific gravity values for each binder content utilized in the design. With both the bulk specific gravity of the compacted specimen and the maximum specific gravity of the mixture at each binder content, the air void content could be calculated for each compacted specimen. By plotting the air void content versus binder content, the respective binder contents corresponding to the three different air void targets could be determined. These binder percentages were then utilized to compact additional specimens for rut testing. Therefore, a total of twenty-four (8 mixtures x 3 air void levels = 24) mixes were designed to determine optimum asphalt content.

Rut-Resistance Testing

Once each of the eight mixtures was optimized at 4.0, 5.0 and 6.0 percent air voids, samples were prepared for rut-resistance testing. Table 2 shows the overall number of samples needed for this phase of the study. To do this, it was decided that six 4600 gram gyratory samples would be mixed for each of the eight mixtures, short term aged, and compacted in the same manner as the mix design samples. Once it was determined that all six samples had air void contents within ±0.5 percent of their target (4.0, 5.0 or 6.0 percent), they were cut to a height of 75mm. This height was required for the standard rut test that was utilized (Asphalt Pavement Analyzer). Only one face of the specimens was cut and this face was not tested. The cut samples were then allowed to pre-condition at the test temperature of 64°C for 12-18 hours.

Table 2. Rut Testing Sample Preparation Plan

Screenings Source	Asphalt Grade	Fiber Additive	Rut Test Specimens
Granite	PG64-22	None Added	6 @ 4.0% VTM
			6 @ 5.0% VTM
			6 @ 6.0% VTM
		0.3% Cellulose	6 @ 4.0% VTM
			6 @ 5.0% VTM
			6 @ 6.0% VTM
	PG76-22 SBS	None Added	6 @ 4.0% VTM
			6 @ 5.0% VTM
			6 @ 6.0% VTM
		0.3% Cellulose	6 @ 4.0% VTM
			6 @ 5.0% VTM
			6 @ 6.0% VTM
Limestone	PG64-22	None Added	6 @ 4.0% VTM
			6 @ 5.0% VTM
			6 @ 6.0% VTM
		0.3% Cellulose	6 @ 4.0% VTM
			6 @ 5.0% VTM
			6 @ 6.0% VTM
	PG76-22 SBS	None Added	6 @ 4.0% VTM
			6 @ 5.0% VTM
			6 @ 6.0% VTM
		0.3% Cellulose	6 @ 4.0% VTM
			6 @ 5.0% VTM
			6 @ 6.0% VTM

Once conditioned for the minimum time, samples were loaded into the test molds and placed in the APA test chamber. The samples were loaded with a 1 inch diameter linear hose inflated to 100psi with a steel wheel applying a 100lb load to the hose. The steel wheel made 16,000 passes (8,000 cycles) across the test samples to complete the testing. Measurements were taken before testing began and after the completion of the testing to determine how much the samples "rutted" under this simulation.

TEST RESULTS AND ANALYSIS

Data Presentation (Coding System)

In order to delineate the different mixtures used in the project a coding system was developed. The coding system used for tabular and graphical presentations is provided below:

GRN-64-F

Where,

GRN = Granite Screenings LMS = Limestone Screenings
64 = PG64-22 Asphalt 76 = PG76-22 SBS Asphalt
F = Fiber Added NF = No Fiber Added

Mix Design Results

Mix design results for the granite and limestone screening materials are presented in Tables 3 and 4, respectively. Results are presented in the tables for optimum binder content, effective binder content, voids in mineral aggregate (VMA), voids filled with asphalt, effective binder volume, and the percent maximum density at the initial number of gyrations (%G_{mm}@$N_{initial}$). Complete information on the designs is presented in Appendix A.

Table 3. Mix Design Summary for Granite Screenings Mixtures

Mix ID	Target VTM	Binder Content (%)	Effective Asphalt (%)	VMA (%)	VFA (%)	Eff. Binder Volume (%)	% G_{mm} @ $N_{initial}$
GRN-64-NF	4.0	7.75	7.63	21.0	81.9	17.0	89.1
	5.0	7.30	7.18	21.0	77.1	16.0	88.1
	6.0	6.75	6.63	21.8	71.4	15.8	86.8
GRN-64-F	4.0	8.50	8.37	22.6	82.8	18.6	88.6
	5.0	8.05	7.92	22.9	76.8	17.9	87.5
	6.0	7.70	7.57	22.6	74.0	16.6	86.6
GRN-76-NF	4.0	7.70	7.43	21.1	79.4	17.1	89.1
	5.0	7.20	7.18	21.0	76.9	16.0	87.9
	6.0	7.00	6.84	21.2	72.2	15.2	86.8
GRN-76-F	4.0	8.60	8.35	22.5	82.9	18.5	89.6
	5.0	8.15	8.05	22.3	79.0	17.3	88.5
	6.0	7.70	7.44	22.5	73.1	16.5	87.4

Table 4. Mix Design Summary for Limestone Screenings Mixtures

Mix ID	Target VTM	Asphalt Content (%)	Effective Asphalt (%)	VMA (%)	VFA (%)	Eff. Binder Volume (%)	% G_{mm} @ $N_{initial}$
LMS-64-NF	4.0	5.15	3.55	12.2	68.5	8.2	84.7
	5.0	4.75	3.15	12.1	61.2	7.1	83.7
	6.0	4.40	2.79	12.9	50.4	6.9	82.3
LMS-64-F	4.0	5.50	3.95	13.4	68.9	9.4	84.9
	5.0	5.25	3.70	13.7	62.3	8.7	84.0
	6.0	4.85	3.29	13.7	55.4	7.7	83.2
LMS-76-NF	4.0	5.00	3.41	12.1	66.2	8.1	84.6
	5.0	4.70	3.11	12.3	58.9	7.3	83.7
	6.0	4.45	2.86	13.1	50.4	7.1	82.9
LMS-76-F	4.0	5.80	4.23	14.0	70.9	10.0	84.9
	5.0	5.45	3.87	14.2	63.0	9.2	83.1
	6.0	5.15	3.57	14.2	57.7	8.2	82.0

Initial analysis of the mix design data entailed conducting an analysis of variance (general linear model) on optimum binder content, VMA, and $\%G_{mm}@N_{inital}$ responses (three separate analyses). Factors included in each of these analyses were screenings material, inclusion of cellulose fiber, design air void content, and binder type. Because the responses are volumetric properties, there was only one response per factor-level combination. Therefore, there was no true error term to determine a F-statistic.

Because of the lack of true error, the data was analyzed by creating a residual error. This was accomplished by determining the mean squares error for each factor and all interactions. High-order interactions with very low mean squares (and, hence low impact on the response) can be combined to create a residual error that can be used to calculate a F-statistic. For the purposes of this study, residual errors were limited to only three- and four-way interactions. It should be pointed out that caution must be used when analyzing F-statistics calculated with residual errors. The use of residual error can sometimes magnify the impact of some factors/interactions even though they are not highly significant.

Table 5 presents the mean square results of each main factor and all interactions for the optimum binder content analysis. This table shows that the screenings material had the largest effect on optimum binder content, followed by the existence of fiber and design air void content, respectively. Table 5 also shows that all of the three- and four-way interactions had mean squares that were very low compared to the main factors. Therefore, the sum of squares for these three- and four-way interactions were combined to develop a residual error.

Table 5. Mean Squares for Optimum Binder Content Analysis

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Screenings Material (Scrng)	1	42.268	42.268
Existence of Fiber (Fiber)	1	3.118	3.118
Design Void Content (Voids)	2	2.404	1.202
Binder Type (Binder)	1	0.030	0.030
Scrng*Fiber	1	0.128	0.128
Scrng*Voids	2	0.063	0.031
Scrng*Binder	1	0.018	0.018
Fiber*Voids	2	0.003	0.001
Fiber*Binder	1	0.076	0.076
Voids*Binder	2	0.003	0.001
Scrng*Fiber*Voids	2	0.003	0.001
Scrng*Fiber*Binder	1	0.023	0.023
Scrng*Voids*Binder	2	0.003	0.001
Fiber*Voids*Binder	2	0.012	0.006
Scrng*Fiber*Voids*Binder	2	0.002	0.001

Table 6 presents the results of the analysis of variance (ANOVA) to determine the significance of the main factors and two-way interactions using the residual error. Based on Table 6, the screenings material, existence of fiber, and design air void level were all significant. None of the two-way interactions were deemed significant because of the low mean squares values compared to the relatively larger mean squares for screenings material, existence of fiber, and design air void level.

Table 6. Results of ANOVA for Optimum Binder Content Analysis

Source of Variation	Mean Squares	F-statistic	F-critical	P-value	Significant at 0.05%
Screenings Material (Scrng)	42.268	8928.90	5.12	0.000	Yes
Existence of Fiber (Fiber)	3.118	658.58	5.12	0.000	Yes
Design Void Content (Voids)	1.202	253.96	4.26	0.000	Yes
Binder Type (Binder)	0.030	6.36	5.12	0.033	No[1]
Scrng*Fiber	0.128	26.96	5.12	0.001	No[1]
Scrng*Voids	0.031	6.62	4.26	0.017	No[1]
Scrng*Binder	0.018	3.72	5.12	0.086	No
Fiber*Voids	0.001	0.29	4.26	0.758	No
Fiber*Binder	0.076	16.04	5.12	0.003	No[1]
Voids*Binder	0.001	0.29	4.26	0.758	No
Residual error	0.005	---	---	---	---

[1] - Although the P-value indicates significance, the small mean squares imply practical insignificance.

Figure 3 illustrates the effect of screenings material on optimum binder content. The granite materials yielded a significantly higher optimum binder content than did the limestone materials. The average optimum binder content for the granite mixes was 7.7 percent versus an average optimum binder content of 5.0 percent for the limestone materials. The primary reason why the granite mixes had higher optimum binder contents than the limestone mixes was that the granite produced higher VMA at the design compactive effort. Figure 4 illustrates that the granite mix produced an average of 8 percent more VMA (21.9 to 13.2 percent) than did the limestone mixes. One reason for this higher VMA is that the granite material tends to be more angular and has more surface texture than the limestone. This, in turn, would require more compactive effort to obtain the same degree of aggregate packing. Also, as shown in Figure 2, the granite material was much finer than the limestone, which would also tend to lead to higher VMA values.

The existence of fiber was another factor shown significant on optimum binder content. In fact, Table 6 indicates that fiber was more significant than design air void content because the F-statistic is larger. On average, mixes containing the cellulose fibers had approximately 0.7 percent higher optimum binder content (average of 6.7 percent for mixes with fiber and 6.0 percent without). Based on these results, it appears the fibers do lead to a stiffening of the binder/dust mortar. This stiffening effect tends to resist compaction and thus create VMA. The fibers may also help resist packing of the aggregate. With an increased VMA, more binder is needed to reach a design air void content. The probable reason for the stiffening is that since cellulose fiber is highly absorptive, it tends to absorb some of the asphalt binder and becomes dispersed within the mortar resulting in a stiffening effect on the binder. These two factors in combination probably led to the increased stiffness. For mixes that are to be designed for applications requiring a long service life (e.g., low volume roadways without heavy or standing

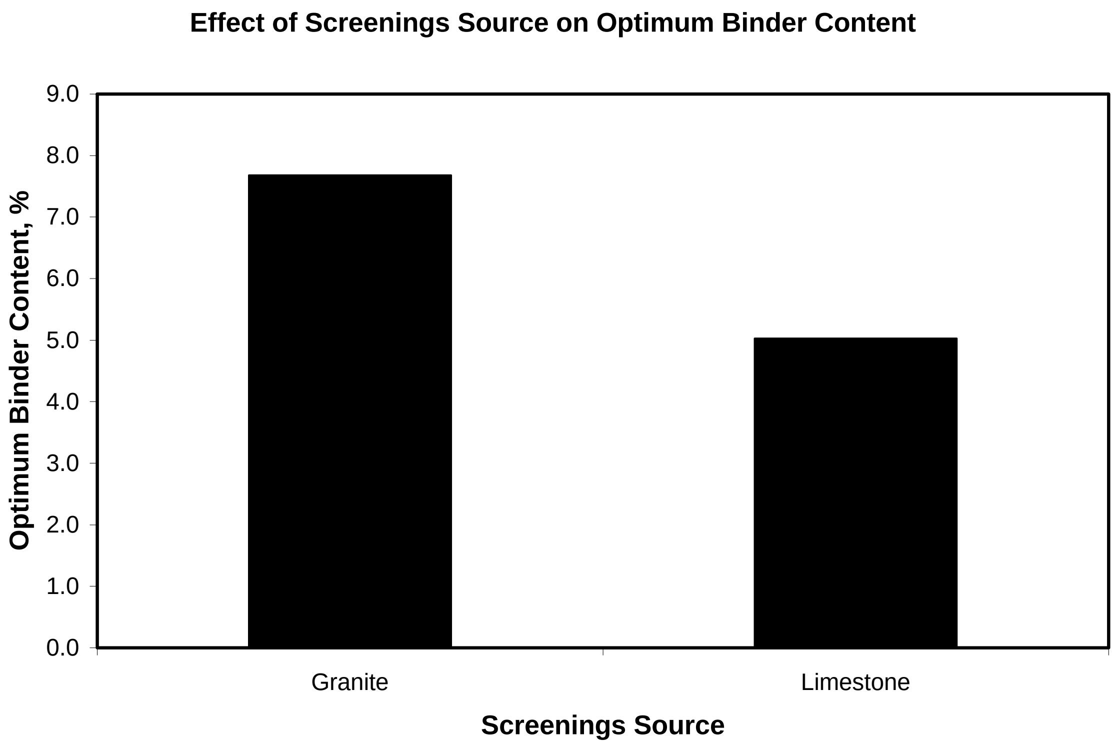

Figure 3. Effect of Screenings Source on Optimum Binder Content

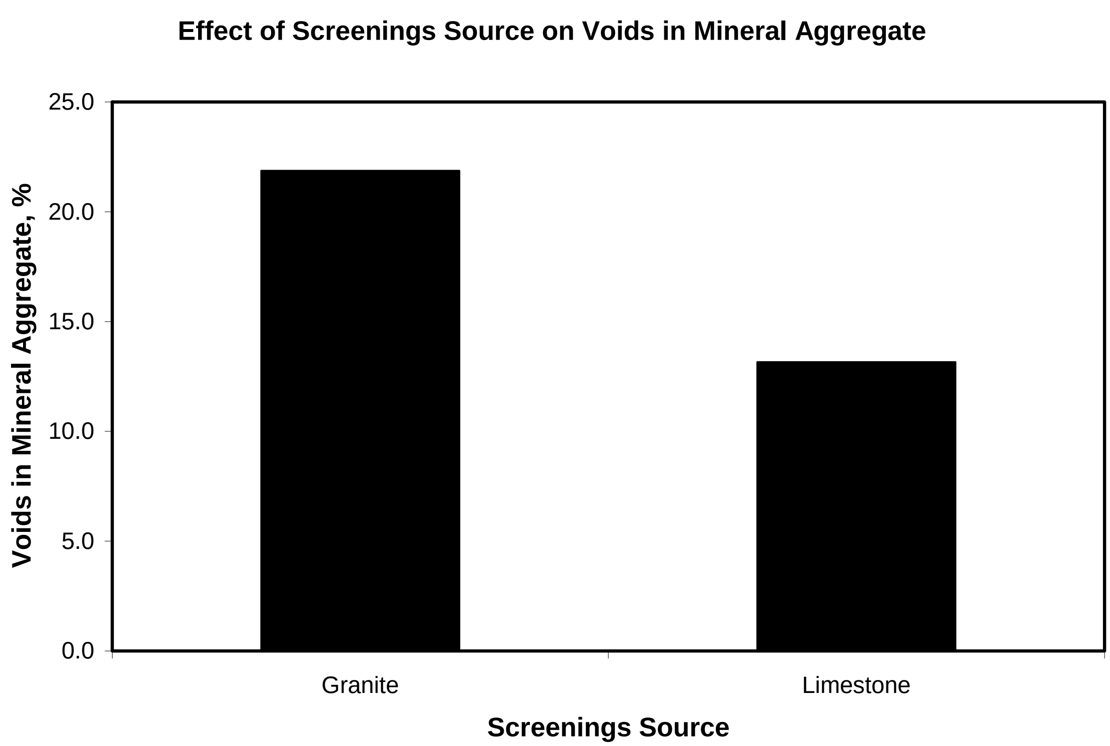

Figure 4. Effect of Screenings Source on Voids in Mineral Aggregate

traffic), the inclusion of fibers will ensure more binder within the mix. This may help with the long-term durability of the pavement layer. However, the use of fibers will increase the cost of the mix and may not be desirable in many cases. Potentially, the inclusion of fiber could decrease the workability and lead to compaction problems in the field as well. However, neither of these aspects were evaluated in this study.

The final factor found significant in Table 6 was design air void content. It was expected that this factor would be significant. For a given compactive effort and aggregate type/gradation, binder content is the method of changing air void content. Based upon the data, the mixes designed to 4 percent air voids had the highest optimum binder contents at an average of 6.8 percent. The next highest binder content was for mixes designed to 5 percent air voids (average of 6.3 percent) and the lowest optimum binder contents were for the mixes designed to 6 percent air voids (6.0 percent binder). On average, 1 percent difference in design air voids resulted in about 0.4 percent difference in optimum binder content.

Table 7 presents the mean squares for the main factors and all interactions for the VMA response. This table shows that the screenings source and existence of fiber had much larger mean squares than did any of the other factors/interactions. Because of the relatively low mean squares for the three- and four-way interactions, these interactions were used to produce a residual error.

Table 7. Mean Squares for VMA Analysis

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Screenings Material (Scrng)	1	455.882	455.882
Existence of Fiber (Fiber)	1	11.760	11.760
Design Void Content (Voids)	2	0.676	0.338
Binder Type (Binder)	1	0.015	0.015
Scrng*Fiber	1	0.002	0.002
Scrng*Voids	2	0.106	0.053
Scrng*Binder	1	0.427	0.427
Fiber*Voids	2	0.502	0.251
Fiber*Binder	1	0.042	0.042
Voids*Binder	2	0.018	0.009
Scrng*Fiber*Voids	2	0.016	0.008
Scrng*Fiber*Binder	1	0.107	0.107
Scrng*Voids*Binder	2	0.061	0.030
Fiber*Voids*Binder	2	0.081	0.040
Scrng*Fiber*Voids*Binder	2	0.101	0.050

Results of the ANOVA utilizing the residual error are presented in Table 8. This table shows that only two factors are significant: screenings material and fiber. Based upon the F-statistics, the screenings material factor was the most significant factor. Figure 4 showed that there was over 8 percent difference in VMA for the two screening materials. The probable cause in these differences was the fineness and increased angularity/surface texture of the granite material.

The effect of the fibers on optimum binder content is evident by the significance of the fiber factor in Table 8. On average, mixes containing fibers had approximately 1.4 percent higher VMA than mixes without fiber (Figure 5).

Table 8. Results of ANOVA for VMA Analysis

Source of Variation	Mean Squares	F-statistic	F-critical	P-value	Significant at 95%
Screenings Material (Scrng)	455.882	11000	5.12	0.000	Yes
Existence of Fiber (Fiber)	11.760	289.97	5.12	0.000	Yes
Design Void Content (Voids)	0.338	8.33	4.26	0.009	No[1]
Binder Type (Binder)	0.015	0.37	5.12	0.558	No
Scrng*Fiber	0.002	0.04	5.12	0.844	No
Scrng*Voids	0.053	1.30	4.26	0.318	No
Scrng*Binder	0.427	10.52	5.12	0.010	No[1]
Fiber*Voids	0.251	6.2	4.26	0.020	No[1]
Fiber*Binder	0.042	1.03	5.12	0.337	No
Voids*Binder	0.009	0.22	4.26	0.810	No
Residual error	0.041	---	---	---	---

[1] - Although the P-value indicates significance, the small mean squares imply practical insignificance.

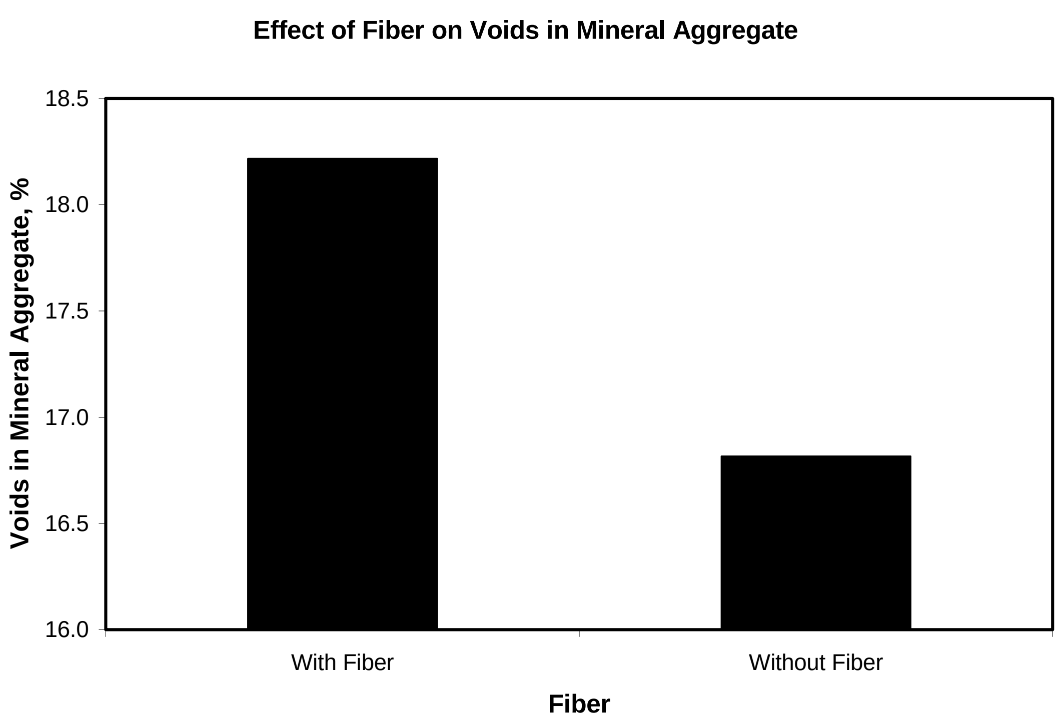

Figure 5. Effect of Fiber on Voids in Mineral Aggregate

Table 9 presents the mean squares for the main factors and all interactions for the $\%G_{mm}@N_{initial}$ analysis. Based on this table, all of the three- and four-way interactions had relatively small mean squares. Therefore, these interactions were used to provide a residual error for use in the ANOVA.

Table 9. Mean Squares for $\%G_{mm}@N_{initial}$ Analysis

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares
Screenings Material (Scrng)	1	112.667	112.667
Existence of Fiber (Fiber)	1	0.375	0.375
Design Void Content (Voids)	2	19.148	9.573
Binder Type (Binder)	1	0.042	0.042
Scrng*Fiber	1	0.202	0.202
Scrng*Voids	2	0.006	0.003
Scrng*Binder	1	0.735	0.735
Fiber*Voids	2	0.333	0.166
Fiber*Binder	1	0.327	0.327
Voids*Binder	2	0.066	0.033
Scrng*Fiber*Voids	2	0.146	0.073
Scrng*Fiber*Binder	1	0.427	0.427
Scrng*Voids*Binder	2	0.023	0.011
Fiber*Voids*Binder	2	0.066	0.033
Scrng*Fiber*Voids*Binder	2	0.036	0.018

Table 10 presents the results of the ANOVA to evaluate the significance of the main factors and one- and two-way interactions on $\%G_{mm}@N_{initial}$. This table shows that both the screenings source and design air void content were significant. Both of these were likely significant because of their effect on optimum binder content. However, it is interesting that the existence of fiber did not affect $\%G_{mm}@N_{initial}$ results even though it was shown as a significant effect on optimum binder content and VMA.

On average, the granite mixes had $\%G_{mm}@N_{initial}$ values approximately 3.5 percent higher than the limestone mixes (88.0 percent versus 83.7 percent). The increased optimum binder contents for the granite mixes (Figure 3) likely aided in the early compaction of the mixes and thus led to the higher $\%G_{mm}@N_{initial}$ values for the granite mixes. Also, the granite screening material was finer than the limestone, and historically finer gradations yield higher $\%G_{mm}@N_{initial}$ values. As expected, mixes designed to 4 percent air voids had the highest $\%G_{mm}@N_{initial}$ values (86.9 percent). Mixes designed at 5 percent air voids had the next lowest $\%G_{mm}@N_{initial}$ values with an average of 85.8 percent and the mixes designed at 6 percent air voids had the lowest $\%G_{mm}@N_{initial}$ values (84.8 percent).

Table 10. Results of ANOVA for %G_{mm}@$N_{initial}$ Analysis

Source of Variation	Mean Squares	F-statistic	F-critical	P-value	Significant at 95%
Screenings Material (Scrng)	112.667	1455.50	5.12	0.000	Yes
Existence of Fiber (Fiber)	0.375	4.84	5.12	0.055	No
Design Void Content (Voids)	9.573	123.67	4.26	0.000	Yes
Binder Type (Binder)	0.042	0.54	5.12	0.482	No
Scrng*Fiber	0.202	2.61	5.12	0.141	No
Scrng*Voids	0.003	0.04	4.26	0.963	No
Scrng*Binder	0.735	9.50	5.12	0.013	No[1]
Fiber*Voids	0.166	2.15	4.26	0.173	No
Fiber*Binder	0.327	4.22	5.12	0.070	No
Voids*Binder	0.033	0.43	4.26	0.666	No
Residual error	0.077	---	---	---	---

[1] - Although the P-value indicates significance, the small mean squares imply practical insignificance.

Results of Asphalt Pavement Analyzer Rut Testing

Results of rut testing conducted on the granite and limestone mixes are presented in Tables 11 and 12 and illustrated in Figures 6 and 7, respectively. Prior to presenting analysis of the rut depth data, a discussion of critical rut depths is warranted. Critical rut depth infers that historical data has suggested that rut depths above a given value may result in excessive rutting in the field. Probably the most referenced critical rut depth in the literature is the one used by the Georgia Department of Transportation (GDOT). Georgia has long used a critical rut depth of 5 mm (3). However, the test temperature utilized in Georgia is different than was used in this study. Georgia has historically used 50°C, while testing in this project was conducted at 64°C. Therefore, a more realistic critical rut depth was needed.

Zhang et.al. (4), recently compared APA results to more fundamental tests (confined repeated load (CRL) test and repeated shear at constant height (RSCH)). Based upon the relationships developed between the APA and RSCH, the APA and CRL, and critical values of the RSCH and CRL test methods published in the literature, a range of critical rut depths in the APA was formulated. This range was verified using a temperature-effect model (3) that converted the GDOT critical rut depth of 5-mm at 50°C to the test temperature of 64°C used in this study. A critical rut depth of 8.2 mm was identified based upon the comparisons by Zhang, et. al. This value was used as the critical rut depth for this study.

Table 11. Laboratory Rutting Test Results for Granite Screenings Mixtures

ID Code	Target VTM	Asphalt Content (%)	Rut Depth Measurement (mm)
GRN-64-NF	4.0	7.75	8.77
	5.0	7.30	5.45
	6.0	6.75	5.53
GRN-64-F	4.0	8.50	10.72
	5.0	8.05	6.41
	6.0	7.70	5.34
GRN-76-NF	4.0	7.70	3.69
	5.0	7.20	2.52
	6.0	7.00	2.82
GRN-76-F	4.0	8.60	4.34
	5.0	8.15	1.85
	6.0	7.70	2.18

Table 12. Laboratory Rutting Test Results for Limestone Screenings

Mixture Identification ID Code	Target VTM	Asphalt Content (%)	Rut Depth Measurement (mm)
LMS-64-NF	4.0	5.15	4.00
	5.0	4.75	3.22
	6.0	4.40	3.65
LMS-64-F	4.0	5.50	3.33
	5.0	5.25	2.63
	6.0	4.85	3.28
LMS-76-NF	4.0	5.00	2.36
	5.0	4.70	1.38
	6.0	4.45	1.39
LMS-76-F	4.0	5.80	2.35
	5.0	5.45	1.40
	6.0	5.15	1.52

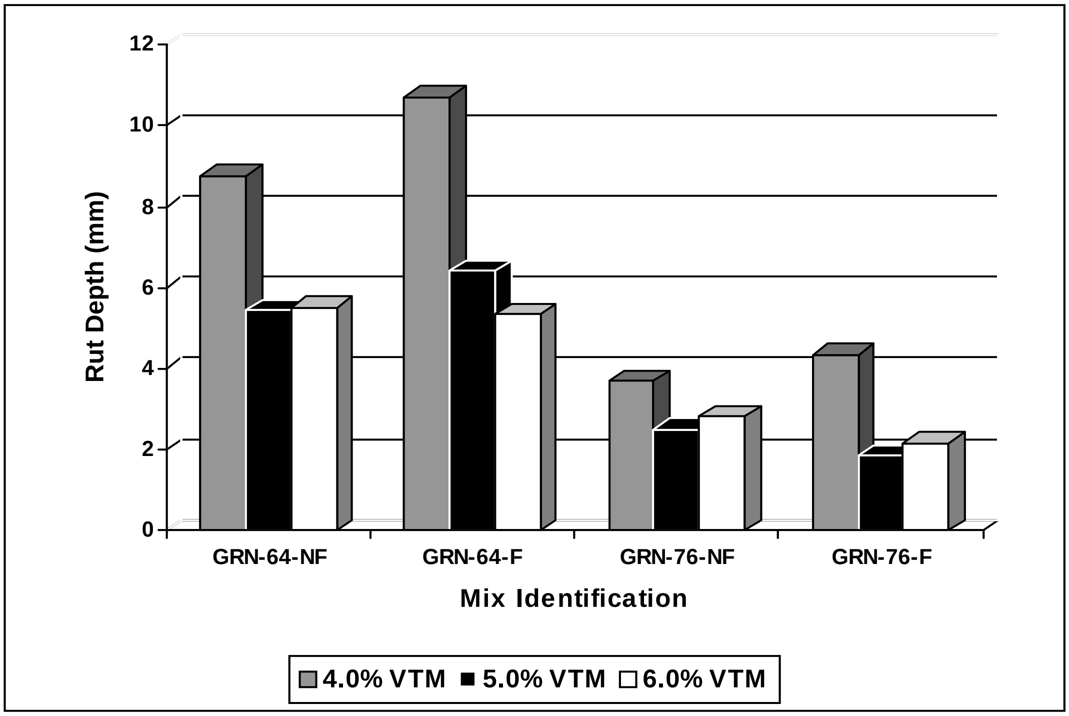

Figure 6. Plot of Laboratory Rutting Results for Granite Screenings Mixtures

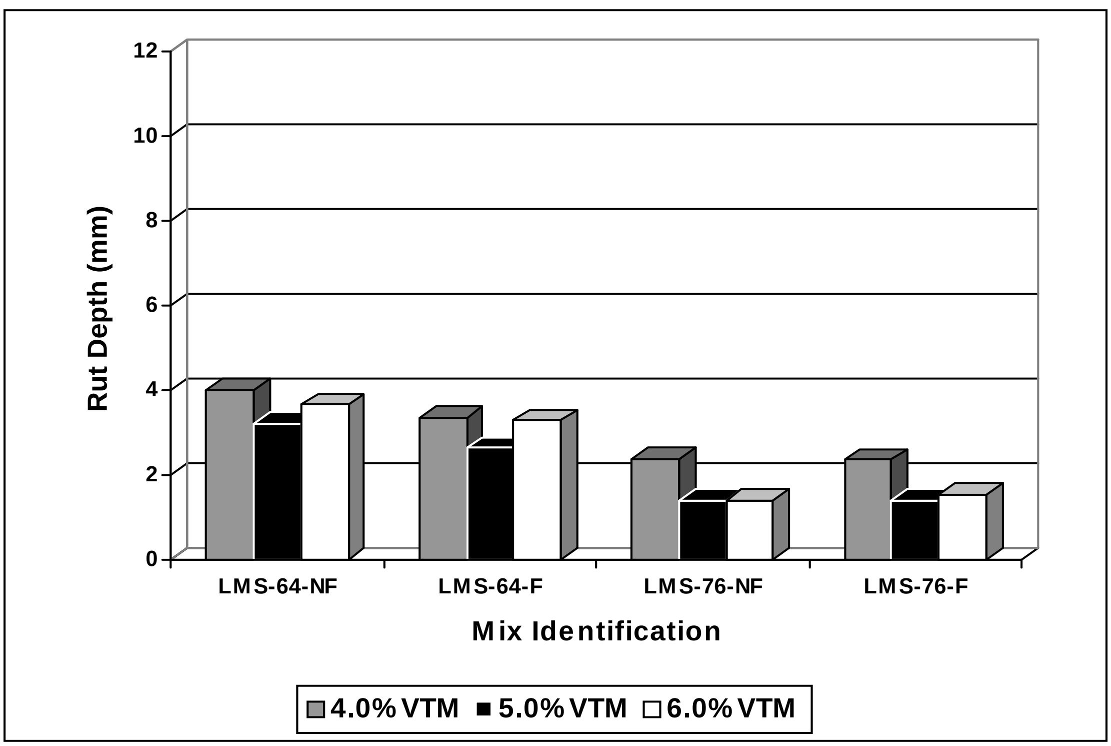

Figure 7. Plot of Laboratory Rutting Results for Limestone Screenings Mixtures

The rut depth data in Tables 11 and 12 suggest that only two factor-level combinations (mixes) exceeded the maximum rut depth criteria of 8.2 mm: GRN-64-NF-4.0 design voids and GRN-64-F-4.0 design voids. There are three characteristics of these two mixes that are similar. First, both mixes utilized the granite screenings. Next, both mixes utilized the PG 64-22 binder and, finally, both mixes were designed at 4 percent air voids. Based on the discussion of volumetric properties presented earlier, the combination of the angular, fine-graded granite aggregate and 4 percent design air voids led to high VMA values and, thus, high optimum binder contents. This is the likely reason for the high rut depths for these two mixes. It should be noted that when both of these combinations were designed at 5.0 percent air voids, the rut depths were well below the critical value of 8.2 mm (5.45 and 6.41 mm, respectively).

Analysis of the rut depth data consisted of conducting an ANOVA. For this analysis, three replicate observations were included for each factor-level combination. Within the Asphalt Pavement Analyzer (APA), six cylindrical samples (three sets of two) were tested per mix. Each set of two samples were averaged to produce a single depth observation. Because there were three replicate observations, a measure of experimental error was available for calculating the F-statistics during the ANOVA analysis.

Table 13 presents the results of the ANOVA conducted on the results of APA rut testing. Based on the results of the ANOVA shown in Table 13, three of the four main factors were significant (screenings material, design void content, and binder type) as well as a number of two- and three-way interactions. Based upon the F-statistics, the binder type was the most significant main factor followed by the screenings material and design air void content, respectively.

Table 13. Results of ANOVA on Rut Depth Data

Source of Variation	Degrees of Freedom	Mean Squares	F-statistic	F-critical	P-value	Significant at 95%
Screenings Material (Scrng)	1	107.8	196.15	4.06	0.000	Yes
Existence of Fiber (Fiber)	1	0.029	0.05	4.06	0.820	No
Design Void Content (Voids)	2	28.629	52.09	3.21	0.000	Yes
Binder Type (Binder)	1	148.035	269.37	4.06	0.000	Yes
Scrng*Fiber	1	0.544	0.99	4.06	0.325	No
Scrng*Voids	2	7.711	14.03	3.21	0.000	Yes
Scrng*Binder	1	25.040	45.56	4.06	0.000	Yes
Fiber*Voids	2	1.882	3.42	3.21	0.041	Yes
Fiber*Binder	1	2.040	3.71	4.06	0.060	No
Voids*Binder	2	4.680	8.52	3.21	0.001	Yes
Scrng*Fiber*Voids	2	0.499	0.91	3.21	0.410	No
Scrng*Fiber*Binder	1	3.371	6.13	4.06	0.017	Yes
Scrng*Voids*Binder	2	3.700	6.73	3.21	0.003	Yes
Fiber*Voids*Binder	2	0.167	0.30	3.21	0.740	No
Scrng*Fiber*Voids*Binder	2	0.299	0.54	3.21	0.584	No
Error	48	0.550	---	---	---	---

Based upon Table 13, binder type had the most significant effect on rut depths. On average, mixes containing the PG 76-22 binder had about 3 mm lower rut depths than did the mixes containing the PG 64-22 binder (5.3 mm versus 2.4 mm). This was as expected. The PG 76-22 binder is significantly stiffer at a given temperature than the PG 64-22 and, thus, helps resist rutting. These results may indicate that the addition of a polymer modified binder to a screenings material would allow the mix to be placed in areas containing heavy, or standing traffic.

The next most significant effect on rut depths was the screenings material. This was also as expected. Recall that mixes containing the granite material had significantly higher optimum binder contents than did the mixes with the limestone screening (average difference of 2.7 percent binder). The increased binder contents for the granite mixes likely caused the higher rut depths.

The final main factor that was identified as being significant was the design air void content. Mixes designed to 4 percent air voids had the highest average rut depths at 5.1 mm. Interestingly, however, there was no difference in rut depths between the mixes designed at 5 and 6 percent air voids (averages of 3.2 and 3.2 mm, respectively) even though there was an average difference in optimum binder content of 0.3 percent.

West (5) has shown that there is a significant effect of sample air void content on APA rut depths. As air void contents increase, rut depths increase. However, for this study increases in air void contents also meant decreases in optimum binder content because all samples were compacted with the same compactive effort (100 gyrations). These two mechanisms (binder content and air voids) work against each other in rutting. At 4 percent air voids, the high optimum binder contents led to the high rut depths. From 4 to 5 percent design air voids, the reduction in optimum binder content (0.4 percent on average) was more significant than the increase in air voids and thus led to the lower rut depths for mixes designed at 5 percent air voids. From 5 to 6 percent design air voids, there were no differences in rut depth. This means that the effect of increasing air voids and decreasing binder content cancelled each other.

Possibly the most interesting results shown in Table 13 was that the existence of fiber was not shown significant even though mixes containing fiber had significantly higher optimum binder contents (average of 0.7 percent higher). This would indicate that for a given screenings type and gradation, the inclusion of fiber would allow for an increase in binder content without the loss of stability.

One of the two-way interactions shown significant in Table 13 was the interaction between screenings material and design air voids. Figure 8 illustrates this interaction on rut depths. Based on this figure, there was a much greater difference in rut depths going from 4 to 5 percent design air voids for mixes containing the granite screenings than for the mixes containing the limestone screenings. This figure also shows that rut depths basically are identical going from 5 to 6 percent design air voids for both aggregate types. Figure 8 suggests that the granite mixes designed below 5 percent air voids were more sensitive to binder content than the limestone mixes. This is most likely due to the very large VMA values obtained for the granite mixes.

Another interaction that was shown significant on rut depths by the ANOVA was the interaction between screenings material and binder type (Figure 9). The significance of the interaction was caused by the differences in rut depth reduction due to binder type for the two screening sources. Figure 9 shows that there was greater reduction in rut depth going from a PG 64-22 to a PG 76-22 for the granite mixes (almost 60 percent reduction) than for the limestone mixes (approximately 45 percent reduction).

The next interaction that was shown significant on rut depths was the interaction between the existence of fiber and design air void level. Figure 10 illustrates this interaction. This figure shows that at the 4 percent design air void level, the mixes containing fiber had slightly higher rut depths than mixes not containing fiber (0.6 mm difference). At the 5 and 6 percent design air void levels, mixes without fiber had slightly higher rut depths than mixes with fiber. Practically, there was no difference in rut depths between mixes with and without fiber at the 5 and 6 percent design air void levels.

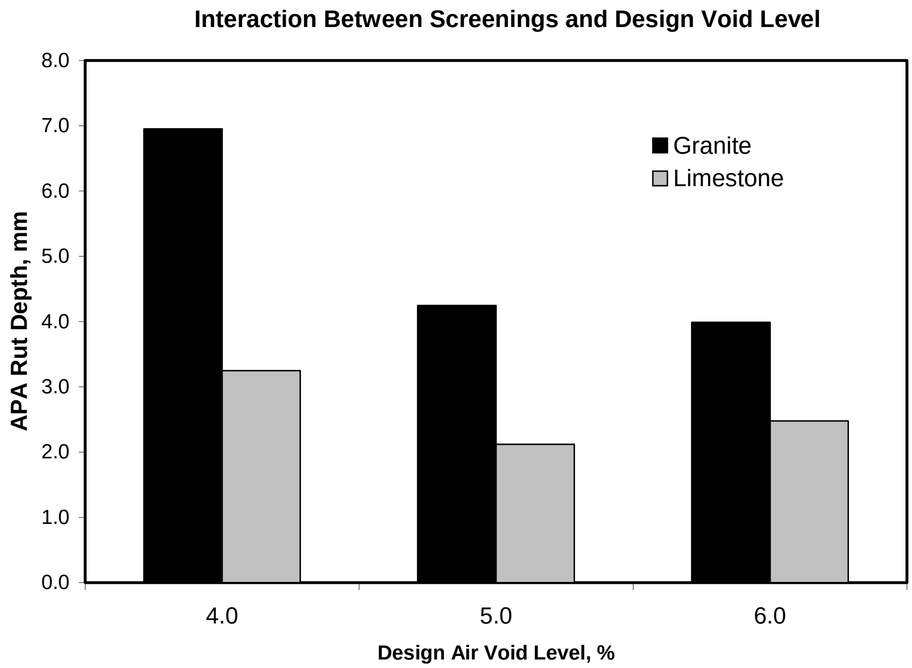

Figure 8. Interaction Between Screenings Material and Design Air Void Level on Rut Depths

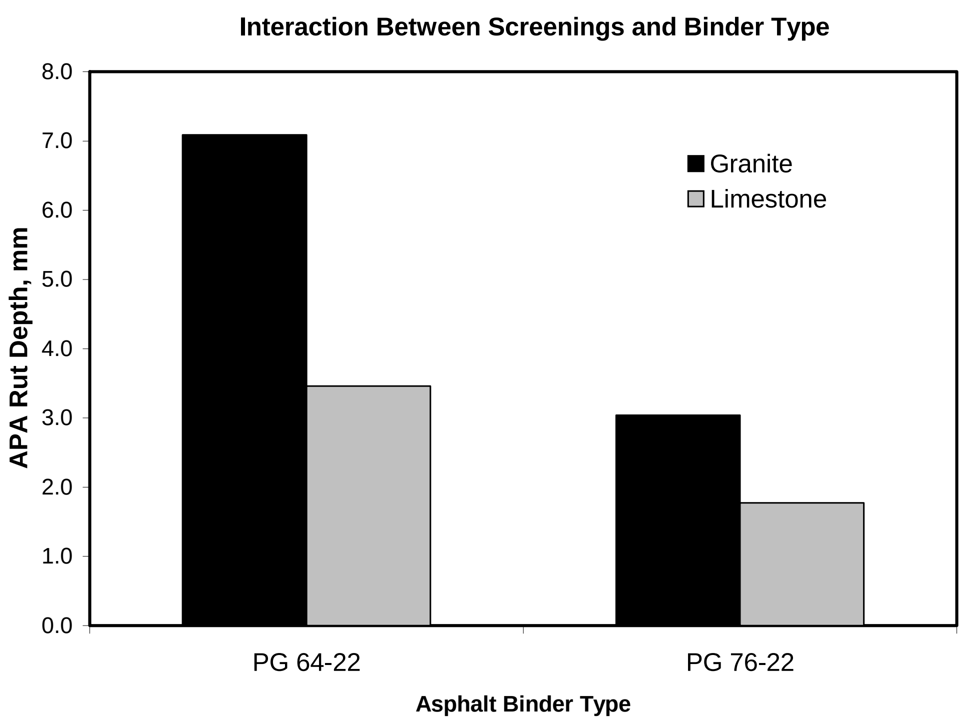

Figure 9. Interaction Between Screenings Material and Binder Type on Rut Depths

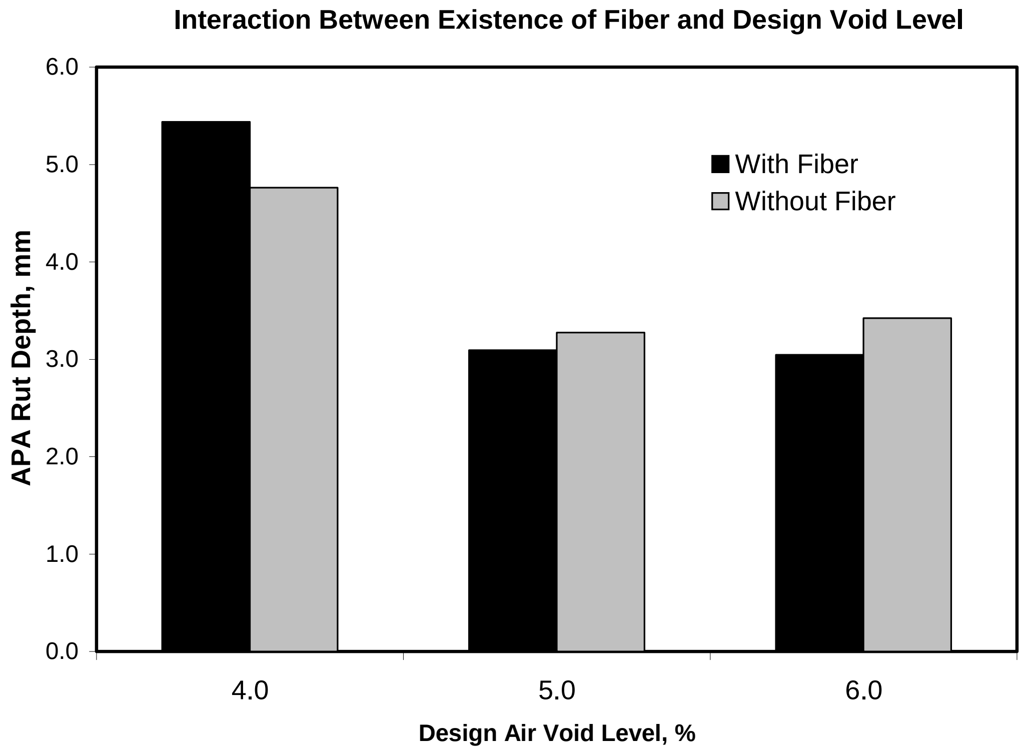

Figure 10. Interaction Between Fiber and Design Void Level on Rut Depths

The final two-way interaction that was shown significant for the rut depth data was the interaction between binder type and design air void content (Figure 11). Based on the data, there was a greater reduction in rut depths going from 4 to 5 percent design air voids for mixes containing the PG 64-22 than for mixes containing the PG 76-22. For both binder types, rut depths were similar at both the 5 and 6 percent design air void levels.

Selection of Design Criteria For Screening Mixes

Recently, recommended criteria for the design of 4.75 mm nominal maximum aggregate size (NMAS) Superpave mixes have been developed (6, 7). These specifications have applicability to the results of this study because most fine aggregate stockpiles to be used as the sole aggregate fraction for HMA would be considered as having a 4.75 mm NMAS. Appendix B presents the draft mix design standard for 4.75 mm NMAS Superpave mixes (6). Results from mix designs conducted during this study were compared to the recommendations for 4.75 mm NMAS Superpave mixes to determine if these screening mixes would fit within the 4.75 mm NMAS mix design system.

The first criterion compared was the gradation requirements. Figure 12 illustrates the gradations for the two aggregate materials used in this study compared to the gradation limits recommended by Cooley et al. (6). Based on this figure, the limestone material would meet the recommended requirements, but the Granite material would not. The granite material was finer than the gradation requirements.

Another recommended criteria for 4.75 mm NMAS Superpave mixes was to design mixes to 4.0 percent air voids with a minimum VMA of 16%. Both draft specifications (6, 7) also recommend a maximum VMA of 18 percent for certain traffic applications (N_{des} of 75, 100, and 125). Following the recommended draft specification, none of the mixes designed in this study would meet the VMA criteria. All of the limestone mixes failed to meet the minimum VMA criteria of

Figure 11. Interaction Between Type and Design Air Void Content on Rut Depth

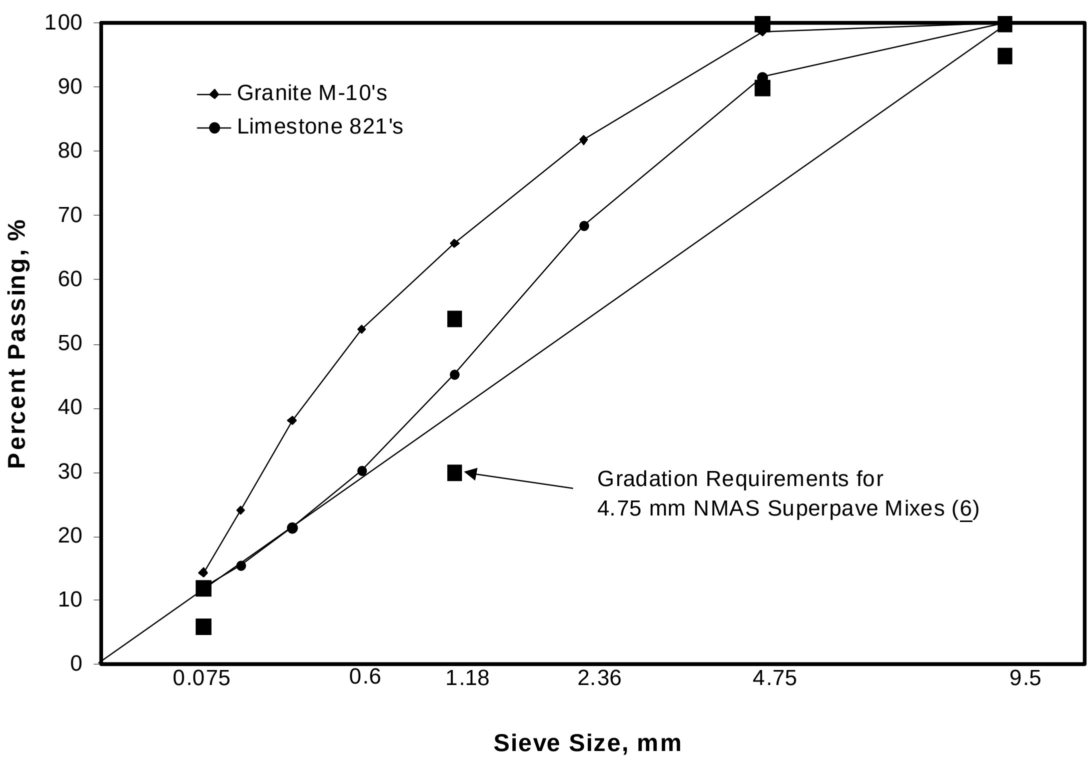

Figure 12. Comparison of Gradations

16 percent and all of the granite mixes had VMA values in excess of 18 percent. Therefore, the 4.75 mm draft standards are not applicable to all mixes comprised of a single fine aggregate stockpile as the sole aggregate fraction. Mixes to be comprised of a screening stockpile that has a gradation falling within the gradation band for 4.75 mm NMAS mixes should be designed utilizing the criteria recommended (6, 7). However, if the chosen stockpile does not have a gradation falling within the control limits, additional guidance may be needed for the design of these screening mixes.

Because of relatively high binder contents obtained for some granite mixes, a range of design air voids is likely warranted in the design of screening mixes. By increasing the design air void content for a given mixture, the optimum binder content is reduced and, thus, the mix's resistance to rutting improves. From a balancing of rut resistance and durability aspect, the lowest design air void content would be desired as long as the mix was rut resistant.

In an effort to identify other volumetric criteria to help ensure rut resistance, VMA, effective volume of binder, and voids filled with asphalt (VFA) were compared versus rut depths. Figures 13 through 15 illustrate these relationships. Data in these figures only represent mixes containing the PG 64-22 binder because all of the mixes containing the PG 76-22 were very rut resistant (rut depths less than 4.5 mm) and inclusion of the PG 76-22 mixes may skew the analyses.

Figure 13 presents the relationship between APA rut depths and VMA. From the figure, it is obvious that two data sets are shown. There is a cluster of data at a VMA range of 12 to 14 percent and another cluster of data at VMA values of 21 to 23 percent. These two data sets represent the two screenings used in this study: granite and limestone. The coefficient of determination (R^2) for this relationship is not good at 0.54. Recall that previously in this report, a critical rut depth was presented as 8.2 mm under the APA testing conditions used during this study. Based on this critical rut depth (depicted on Figure 13 as a horizontal line), a maximum VMA value of 21 percent would be required to ensure rut resistance. However, if a maximum of

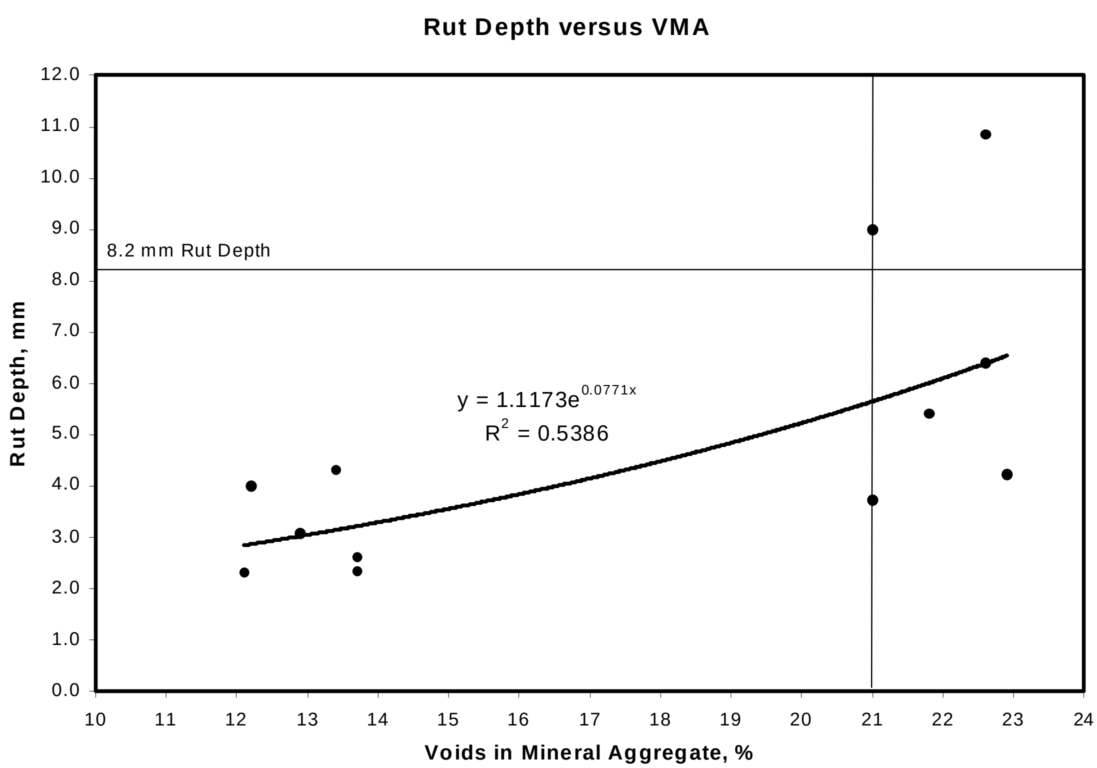

Figure 13. Relationship Between APA Rut Depths and VMA

21 percent were specified four mixes that would be considered good performers would be excluded. Therefore, VMA alone may not be a good indicator of rut resistance. Additionally, VMA is dependant on the aggregate type and therefore a single criterion may not be applicable for different aggregate types to ensure rut resistance.

The next volumetric property evaluated as a potential indicator of rutting potential was the percent effective binder volume. The effective volume of binder is the difference between VMA and design air void content. Figure 14 illustrates the relationship between rut depths and effective volume of binder. Similar to Figure 13, there appears to be two separate clusters of data. Again, these clusters represent the two aggregate types utilized in this study. The R^2 value for the relationship (0.63) shown in Figure 13 is higher than that for rut depth versus VMA (Figure 13). Based on Figure 14, it appears that a criterion for effective binder volume could be 17 percent maximum. This value would exclude the two mixes with excessive rut depths; however, one of the mixes that performed well with respect to rutting would also have been excluded. Based on these results, effective binder volume may be a good indicator of rutting potential.

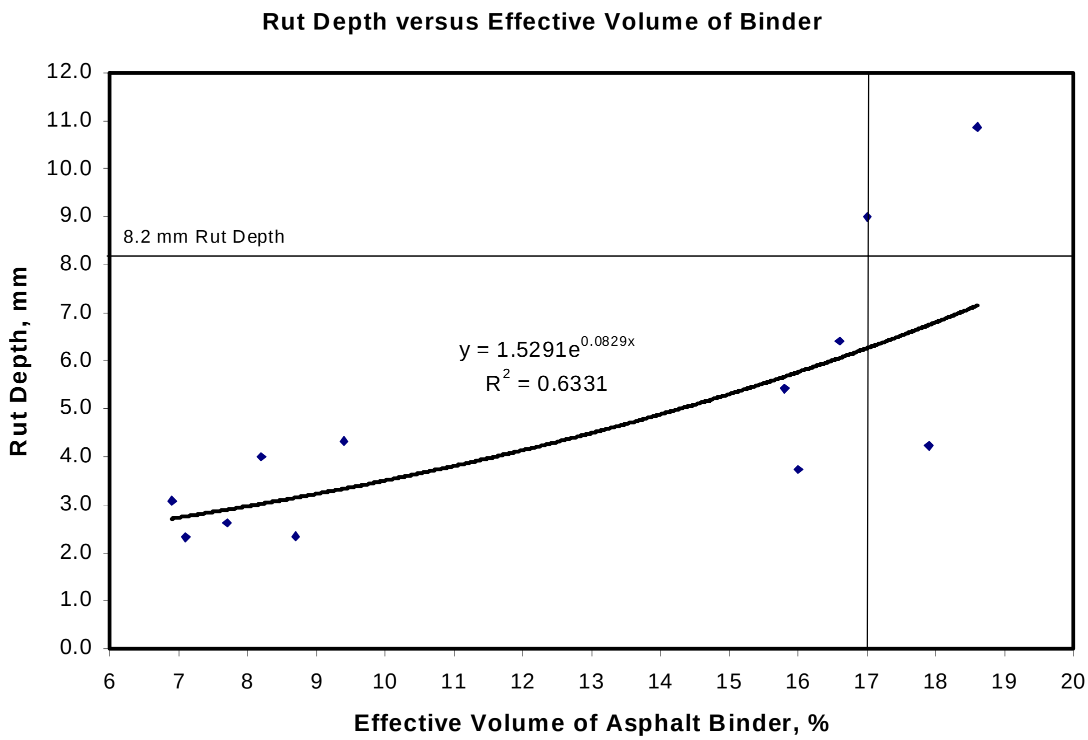

Figure 14. Relationship Between Rut Depths and Effective Binder Volume

The next volumetric property evaluated to control high rut potential mixes was voids filled with asphalt (VFA). Figure 15 illustrates the relationship between rut depths and VFA. Unlike Figures 13 and 14, the data within Figure 15 appears to be well dispersed and does not have the clusters of data. The relationship in Figure 15 has a higher R^2 (0.68) than the previous two relationships shown in Figures 13 and 14. Data in Figure 15 also suggests a defining value between the mixes that performed well and the mixes that had excessive rut depths. Based on the figure, it appears that limiting VFA to 80 percent would prevent excessive rutting. Interestingly, a maximum VFA value of 80 was also recommended for Superpave designed 4.75 mm NMAS mixes. Table 1 showed that both of the screenings materials used in this study would meet a Superpave defined

4.75 mm NMAS. Therefore, it appears that VFA can be used as a criterion for preventing high rut potential mixes during design.

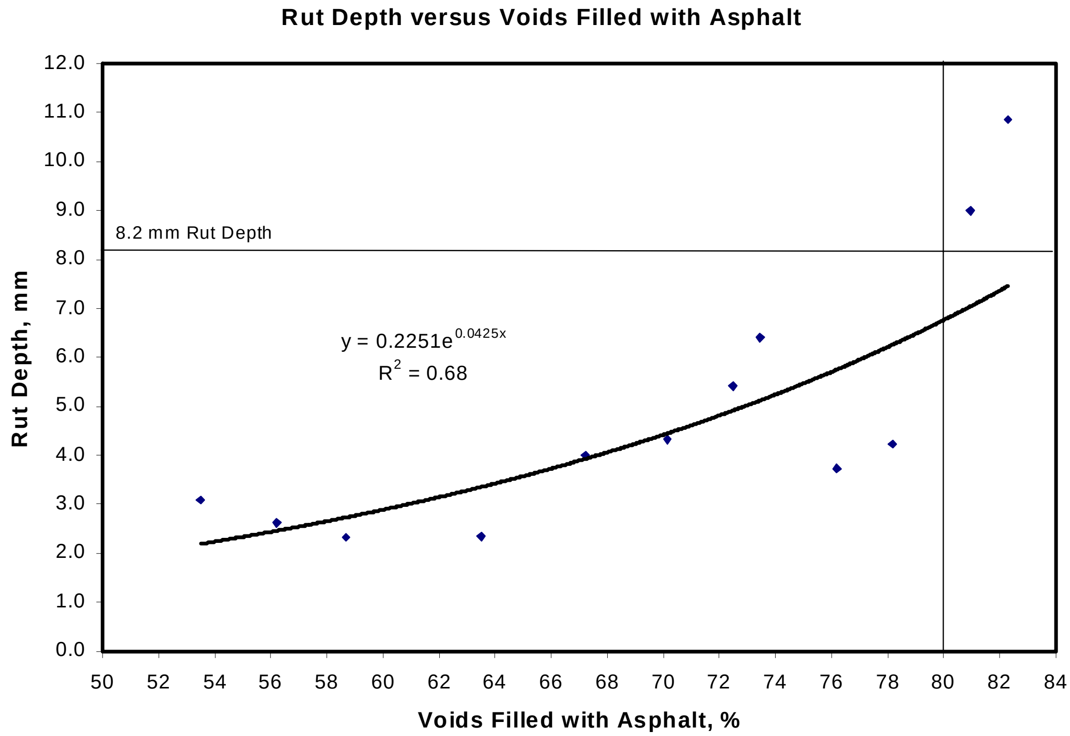

Figure 15. Relationship Between Rut Depths and VFA

No durability testing was conducted during the conduct of this study. However, the two draft standards suggested minimum specifications for durability for 4.75 mm NMAS Superpave mixes (6, 7). A minimum VMA value was recommended as 16 percent. However, this VMA value was based upon a single design air void content of 4 percent. Within this study, design air voids of 4, 5, and 6 were evaluated. Using the 4 percent design air voids and 16 percent minimum VMA (6, 7), a critical value for effective binder volume would be 12 percent (16.0-4.0=12.0). This value can be used to ensure sufficient binder is added to the mix for durability concerns. A designer would simply subtract the air void content corresponding to the selected binder content from the VMA at that same binder content. If this value were above 12 percent, the mix would be expected to perform with respect to durability. None of the limestone mixes' designed in this study would meet this criterion; however, all of the granite mixes did achieve more than 12 percent effective binder volume.

DISCUSSION

The increased use of coarse-graded HMA (Superpave or stone matrix asphalt) has led to large volumes of fine aggregate stockpiles being accumulated. Combined with the need for durable and rut-resistant HMA for use in thin-lift pavement layers, the use of screenings mixes would be beneficial for HMA providers, aggregate producers, and transportation agencies.

Based upon the results of this study, it appears that screenings mixes can be designed to be rut-resistant. However, the long-term durability was not evaluated and needs further study. It is assumed that the long term durability will be controlled by the effective binder volume and good compaction in the field, just as with conventional mixes. Results presented herein suggest that all screening stockpiles do not warrant use as a screenings mix. The limestone mixes had optimum asphalt contents below 5 percent. These mixes would not likely perform with respect to long-term durability (insufficient binder volume) and, hence, they may need to be blended with other material to increase the VMA.

As a mix designer, the best tool in the design of these screening mixes is likely design air void content. For this study, mixes were designed at 4, 5, and 6 percent air voids. If the screenings mix is intended for a low volume roadway, where long-term durability is most important, mixes should be designed at 4 percent air voids. Designing at 4 percent air voids will provide the highest optimum binder content of the design air voids evaluated in this study. Another method to increase the binder content would be to add fibers; however, this will also significantly increase cost. Results from this study showed a significant increase in binder content (0.7 percent on average) with the inclusion of cellulose fibers. Intuitively, an increase in the long-term durability of pavements would be expected for mixes containing cellulose fibers when compared to mixes designed without the fiber because of the increased binder content. Another factor that may affect the use of cellulose fibers in this mix type is the cost-benefit. The cost of the cellulose fibers and higher binder content would increase overall mix costs. Until the benefit of using the fibers is quantified, it is unclear whether the inclusion of cellulose fibers is justified.

It should be pointed out that the increased binder contents obtained from the fibers only reflects the use of cellulose fibers. No other fiber types were included. Therefore, the inclusion of mineral, polyester, polypropylene, etc. is unclear.

When a designed mix is intended for a roadway that will contain either heavy or slow/standing traffic, design air void contents above 4 percent may be required. By increasing the design void level, optimum binder content is reduced and, thus, a given mixture would be more resistant to rutting. A maximum VFA criterion of 80 percent can be used to help identify mixes with a high potential for rutting (Figure 15). As with any mix designed for heavy and/or slow/standing traffic, some type of torture test is needed to verify the designed mix.

There are a number of potential applications for a screenings mix. First, this type of mix can be used as a thin-lift maintenance mix. If the screenings mix is intended for this application, the underlying pavement should be structurally sound. Typically, a screenings mix would be placed 19 to 25 mm thick. Therefore, it should not be placed to significantly increase the structural integrity of a pavement structure.

Another possible application for this mix type would be low volume traffic areas such as residential streets and parking lots. Results of this study indicated that these mixes can be designed to resist the standing loads of passenger vehicles. The increased binder contents also should make these mixes durable. However, this mix type probably should not be used on truck delivery lanes unless the PG grade is bumped. Otherwise, the relative small aggregate size and high binder contents may lead to rutting and or shoving in these lanes.

A final possible application for this mix type is as a leveling course to correct surface defects. Generally, small aggregate size mixes are used for this application. Depending on the roadway for the intended use, an appropriate design binder content could be chosen.

CONCLUSIONS AND RECOMMENDATIONS

The use of manufactured aggregate screenings as the sole aggregate portion of an HMA was evaluated in this study. Mixes of this nature have the potential for use in a number of thin-lift pavement layer applications. Factors included in this research were aggregate screenings type, binder type, fiber, and design air void content. The following conclusions were obtained from this research:

- Mixes having screenings as the sole aggregate portion can be successfully designed in the laboratory for some screenings but may be difficult for others.

- Screenings type, the existence of cellulose fiber, and design air void content significantly affected optimum binder content. Of these three factors, screenings type had the largest impact on optimum binder content followed by the existence of cellulose fiber and design air void content, respectively.

- Screenings type and the existence of cellulose fiber significantly affected voids in mineral aggregate. Screenings material had a larger impact.

- Screenings material and design air void content significantly affected % G_{mm} @ $N_{initial}$ results. Again, the screenings material had the largest impact.

- Screenings material, design air void content, and binder type significantly affected laboratory rut depths. Of these three, binder type had the largest impact followed by screening material and design air void content, respectively. Mixes containing a PG 76-22 binder had significantly lower rut depths than mixes containing a PG 64-22. Mixes designed at 4 percent air voids had significantly higher rut depths than mixes designed at 5 or 6 percent air voids.

Based upon the conclusions of the study, the following recommendations are provided:

- Mixes utilizing a screenings stockpile as the sole aggregate portion and having a gradation that meets the requirement for 4.75 mm Superpave mixes should be designed in accordance with the recommended Superpave mix design system.

- Mixes utilizing a screenings stockpile as the sole aggregate portion but with gradations not meeting the requirements for 4.75 mm Superpave mixes should be designed using the following criteria.

Property	Criteria
Design Air Void Content, %	4 to 6
Effective Volume of Binder, %	12 min.
Voids filled with Asphalt, %	67-80

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Appendix A
Mix Design Data

National Center for Asphalt Technology
Screenings Evaluation
Mix Design Summary

Mixture ID: Screenings
Aggregate: Labstock Granite M-10's
Asphalt: PG 64-22
Date: 7/9/99
Filler Type: None
Fiber Additive: None

Compaction Device: Troxler SGC
Compaction Level: 100 gyrations
Binder Gravity (Gb): 1.028

Apparent Gravity Solids (Gsa): 2.726
Effective Gravity Solids (Gse): 2.720
Bulk Gravity Solids (Gsb): 2.711

Percent Minus 0.075mm Sieve: 14.4
Number of Gyrations @ Ninitial: 8
Number of Gyrations @ Ndesign: 100

Sample ID	Asphalt Content (%)	Dry Weight (grams)	Height @ Nintial (mm)	Height @ Ndesign (mm)	Bulk Gravity (g/cm^3)	Rice Gravity (g/cm^3)	Correction Factor	%Gmm at Nini (%)	Effective Asphalt (%)	VTM (%)	VMA (%)	VFA (%)	Dust Asphalt	Film Thickness (microns)	Densification Slope
6.0-1	6.0	4905.1	131.3	121.4	2.274	2.476	0.995	84.9	5.88	8.1	21.2	61.5	2.45	5.00	6.31
6.0-2	6.0	4877.4	130.5	121.0	2.272	2.476	0.996	85.1	5.88	8.2	21.2	61.3	2.45	5.00	6.09
Avg								85.0	5.9	8.2	21.2	61.4	2.45	5.00	6.20
7.0-1	7.0	4925.2	128.9	119.3	2.321	2.439	0.993	88.1	6.88	4.8	20.4	76.3	2.09	5.91	6.46
7.0-2	7.0	4869.9	129.0	119.4	2.297	2.439	0.995	87.2	6.88	5.8	21.2	72.5	2.09	5.91	6.39
Avg								87.6	6.9	5.3	20.8	74.4	2.09	5.91	6.43
8.0-1	8.0	4988.2	129.8	120.2	2.330	2.404	0.992	89.8	7.88	3.1	20.9	85.4	1.83	6.85	6.54
8.0-2	8.0	4990.4	131.0	121.2	2.310	2.404	0.991	88.9	7.88	3.9	21.6	82.0	1.83	6.85	6.55
Avg								89.3	7.9	3.5	21.3	83.7	1.83	6.85	6.55
9.0-1	9.0	5019.1	128.8	121.0	2.324	2.369	0.990	92.2	8.89	1.9	22.0	91.3	1.62	7.80	5.42
9.0-2	9.0	5025.5	128.9	121.4	2.328	2.369	0.994	92.5	8.89	1.7	21.9	92.1	1.62	7.80	5.21
Avg								92.4	8.9	1.8	21.9	91.7	1.62	7.80	5.31

National Center for Asphalt Technology
Screenings Evaluation
Mix Design Summary

Mixture ID:	Screenings	**Date:**	5/26/99
Aggregate:	Labstock Granite M-10's	**Filler Type:**	None
Asphalt:	PG 64-22	**Fiber Additive:**	Cellulose

Compaction Device:	Troxler SGC	Apparent Gravity Solids (Gsa):	2.726	Percent Minus 0.075mm Sieve:	14.4
Compaction Level:	100 gyrations	Effective Gravity Solids (Gse):	2.721	Number of Gyrations @ Ninitial:	8
Binder Gravity (Gb):	1.028	Bulk Gravity Solids (Gsb):	2.711	Number of Gyrations @ Ndesign:	100

Sample ID	Asphalt Content (%)	Dry Weight (grams)	Height @ Nintial (mm)	Height @ Ndesign (mm)	Bulk Gravity (g/cm^3)	Rice Gravity (g/cm^3)	Correction Factor	%Gmm at Nini (%)	Effective Asphalt (%)	VTM (%)	VMA (%)	VFA (%)	Dust Asphalt	%Gmm @ Ninitial (%)	Densification Slope
7.0-1	7.0	4908.4	132.4	122.3	2.245	2.440	0.988	85.0	6.87	8.0	23.0	65.3	2.10	85.0	6.4
7.0-2	7.0	4931.4	133.4	123.3	2.228	2.440	0.984	84.4	6.87	8.7	23.6	63.2	2.10	84.4	6.3
Avg								84.7		8.3	23.3	64.2	2.10	84.7	6.4
8.0-1	8.0	4950.9	131.6	121.4	2.282	2.404	0.989	87.6	7.87	5.1	22.6	77.5	1.83	87.6	6.7
8.0-2	8.0	5000.1	132.1	121.9	2.282	2.404	0.983	87.6	7.87	5.1	22.6	77.5	1.83	87.6	6.7
Avg								87.6		5.1	22.6	77.5	1.83	87.6	6.7
9.0-1	9.0	5062.3	132.8	123.1	2.297	2.370	0.987	89.8	8.87	3.1	22.9	86.6	1.62	89.8	6.5
9.0-2	9.0	5031.8	133.2	123.0	2.294	2.370	0.991	89.4	8.87	3.2	23.0	86.1	1.62	89.4	6.8
Avg								89.6		3.1	22.9	86.3	1.62	89.6	6.6

National Center for Asphalt Technology
Screenings Evaluation
Mix Design Summary

Mixture ID: Screenings
Aggregate: Labstock Granite M-10's
Asphalt: PG 76-22

Date: 5/26/99
Filler Type: None
Fiber Additive: None

Compaction Device: Troxler SGC
Compaction Level: 100 gyrations
Binder Gravity (Gb): 1.028

Apparent Gravity Solids (Gsa): 2.726
Effective Gravity Solids (Gse): 2.732
Bulk Gravity Solids (Gsb): 2.711

Percent Minus 0.075mm Sieve: 14.4
Number of Gyrations @ Ninitial: 8
Number of Gyrations @ Ndesign: 100

Sample ID	Asphalt Content (%)	Dry Weight (grams)	Height @ Nintial (mm)	Height @ Ndesign (mm)	Bulk Gravity (g/cm^3)	Rice Gravity (g/cm^3)	Correction Factor	%Gmm at Nini (%)	Effective Asphalt (%)	VTM (%)	VMA (%)	VFA (%)	Dust Asphalt	%Gmm @ Ninitial (%)	Densification Slope
6.0-1	6.0	4880.8	131.3	121.3	2.270	2.485	0.997	84.4	5.73	8.6	21.3	59.4	2.51	84.4	6.3
6.0-2	6.0	4877.8	130.7	120.7	2.277	2.485	0.996	84.6	5.73	8.4	21.0	60.3	2.51	84.6	6.4
Avg								84.5		8.5	21.2	59.8	2.51	84.5	6.4
7.0-1	7.0	4942.1	130.2	120.5	2.316	2.448	0.998	87.6	6.73	5.4	20.6	73.8	2.14	87.6	6.4
7.0-2	7.0	4939.2	130.2	120.4	2.316	2.448	0.998	87.5	6.73	5.4	20.6	73.8	2.14	87.5	6.5
Avg								87.5		5.4	20.6	73.8	2.14	87.5	6.5
8.0-1	8.0	4959.1	129.3	119.9	2.335	2.412	0.998	89.8	7.73	3.2	20.8	84.6	1.86	89.8	6.4
8.0-2	8.0	4986.8	130.5	121.0	2.323	2.412	0.996	89.3	7.73	3.7	21.2	82.5	1.86	89.3	6.4
Avg								89.5		3.4	21.0	83.6	1.86	89.5	6.4
9.0-1	9.0	5026.1	129.2	121.8	2.317	2.377	0.992	91.9	8.73	2.5	22.2	88.6	1.65	91.9	5.1
9.0-2	9.0	5012.6	128.4	121.8	2.324	2.377	0.998	92.7	8.73	2.2	22.0	89.8	1.65	92.7	4.6
Avg								92.3		2.4	22.1	89.2	1.65	92.3	4.8

National Center for Asphalt Technology
Screenings Evaluation
Mix Design Summary

Mixture ID: Trial SMA
Aggregate: Labstock Granite M-10's
Asphalt: PG 76-22
Date: 5/26/99
Filler Type: None
Fiber Additive: Cellulose

Compaction Device: Troxler SGC
Compaction Level: 100 gyrations
Binder Gravity (Gb): 1.028
Apparent Gravity Solids (Gsa): 2.726
Effective Gravity Solids (Gse): 2.731
Bulk Gravity Solids (Gsb): 2.711
Percent Minus 0.075mm Sieve: 14.4
Number of Gyrations @ Ninitial: 8
Number of Gyrations @ Ndesign: 100

Sample ID	Asphalt Content (%)	Dry Weight (grams)	Height @ Nintial (mm)	Height @ Ndesign (mm)	Bulk Gravity (g/cm^3)	Rice Gravity (g/cm^3)	Correction Factor	%Gmm at Nini (%)	Effective Asphalt (%)	VTM (%)	VMA (%)	VFA (%)	Dust Asphalt	%Gmm @ Ninitial (%)	Densification Slope
7.0-1	7.0	4969.2	132.6	122.6	2.275	2.447	0.992	86.0	6.74	7.0	22.0	68.0	2.14	86.0	6.4
7.0-2	7.0	4957.7	133.7	123.6	2.254	2.447	0.993	85.1	6.74	7.9	22.7	65.2	2.14	85.1	6.3
Avg								85.6		7.5	22.3	66.6	2.14	85.5	6.4
8.0-1	8.0	5004.0			2.272	2.411			7.74	5.8	22.9	74.8	1.86		
8.0-2	8.0	4979.7	132.1	122.4	2.291	2.411	0.995	88.0	7.74	5.0	22.3	77.6	1.86	88.0	6.4
Avg								88.0		5.4	22.6	76.2	1.86	88.0	6.4
9.0-1	9.0	5059.1	132.1	123.2	2.312	2.377	0.995	90.7	8.75	2.7	22.4	87.9	1.65	90.7	6.0
9.0-2	9.0	5048.2	132.3	123.8	2.300	2.377	0.997	90.6	8.75	3.2	22.8	85.9	1.65	90.6	5.7
Avg								90.6		3.0	22.6	86.9	1.65	90.6	5.8

National Center for Asphalt Technology
Screenings Evaluation
Mix Design Summary

Mixture ID: Screenings
Aggregate: Labstock Limestone 821's
Asphalt: PG 64-22

Date: 5/26/99
Filler Type: None
Fiber Additive: None

Compaction Device: Troxler SGC	Apparent Gravity Solids (Gsa): 2.746	Percent Minus 0.075mm Sieve:	12.0
Compaction Level: 100 gyrations	Effective Gravity Solids (Gse): 2.733	Number of Gyrations @ Ninitial:	8
Binder Gravity (Gb): 1.028	Bulk Gravity Solids (Gsb): 2.616	Number of Gyrations @ Ndesign:	100

Sample ID	Asphalt Content (%)	Dry Weight (grams)	Height @ Nintial (mm)	Height @ Ndesign (mm)	Bulk Gravity (g/cm^3)	Rice Gravity (g/cm^3)	Correction Factor	%Gmm at Nini (%)	Effective Asphalt (%)	VTM (%)	VMA (%)	VFA (%)	Dust Asphalt	%Gmm @ Ninitial (%)	Densification Slope
4.0-1	4.0	4801.2	128.6	113.9	2.350	2.563	0.985	81.2	2.38	8.3	13.8	39.6	5.03	81.2	9.6
4.0-2	4.0	4775.6	128.2	113.8	2.360	2.563	0.994	81.7	2.38	7.9	13.4	40.9	5.03	81.7	9.4
Avg								81.5		8.1	13.6	40.2	5.03	81.5	9.5
5.0-1	5.0	4820.6	126.1	110.8	2.405	2.524	0.977	83.7	3.40	4.7	12.7	62.8	3.53	83.7	10.5
5.0-2	5.0	4802.9	126.3	110.8	2.412	2.524	0.983	83.8	3.40	4.4	12.4	64.2	3.53	83.8	10.7
Avg								83.8		4.6	12.5	63.5	3.53	83.8	10.6
5.15-1	5.15	4828.7	128.0	112.5	2.433	2.518	1.002	84.9	3.55	3.4	11.8	71.4	3.38	84.9	10.7
5.15-2	4.00	4854.2	128.9	113.3	2.434	2.563	1.004	83.5	2.38	5.0	10.7	52.9	5.03	83.5	10.5
Avg								84.2		4.2	11.2	62.1	4.20	84.2	10.6

National Center for Asphalt Technology
Screenings Evaluation
Mix Design Summary

Mixture ID:	Screenings		**Date:**	5/26/99
Aggregate:	Labstock Limestone 821's		**Filler Type:**	None
Asphalt:	PG 64-22		**Fiber Additive:**	Cellulose

Compaction Device:	Troxler SGC	Apparent Gravity Solids (Gsa):	2.746	Percent Minus 0.075mm Sieve:	12.0
Compaction Level:	100 gyrations	Effective Gravity Solids (Gse):	2.730	Number of Gyrations @ Ninitial:	8
Binder Gravity (Gb):	1.028	Bulk Gravity Solids (Gsb):	2.616	Number of Gyrations @ Ndesign:	100

Sample ID	Asphalt Content (%)	Dry Weight (grams)	Height @ Nintial (mm)	Height @ Ndesign (mm)	Bulk Gravity (g/cm^3)	Rice Gravity (g/cm^3)	Correction Factor	%Gmm at Nini (%)	Effective Asphalt (%)	VTM (%)	VMA (%)	VFA (%)	Dust Asphalt	%Gmm @ Ninitial (%)	Densification Slope
4.0-1	4.0	4805.6	131.9	117.0	2.325	2.560	1.000	80.6	2.42	9.2	14.7	37.5	4.95	80.6	9.4
4.0-2	4.0	4799.2	131.2	116.4	2.330	2.560	0.999	80.7	2.42	9.0	14.5	38.0	4.95	80.7	9.4
Avg								80.7		9.1	14.6	37.7	4.95	80.7	9.4
5.0-1	5.0	4850.2	131.3	116.0	2.371	2.521	1.002	83.1	3.44	6.0	13.9	57.2	3.49	83.1	10.0
5.0-2	5.0	4857.1	129.5	114.8	2.394	2.521	1.000	84.2	3.44	5.0	13.1	61.4	3.49	84.2	9.8
Avg								83.6		5.5	13.5	59.3	3.49	83.6	9.9
6.0-1	6.0	4910.8	130.1	115.0	2.418	2.483	1.001	86.1	4.46	2.6	13.1	80.0	2.69	86.1	10.3
6.0-2	6.0	4904.5	130.1	114.9	2.418	2.483	1.001	86.0	4.46	2.6	13.1	80.0	2.69	86.0	10.4
Avg								86.0		2.6	13.1	80.0	2.69	86.0	10.3

National Center for Asphalt Technology
Screenings Evaluation
Mix Design Summary

Mixture ID: Screenings
Aggregate: Labstock Limestone 821's
Asphalt: PG 76-22
Date: 5/26/99
Filler Type: None
Fiber Additive: None

Compaction Device: Troxler SGC
Compaction Level: 100 gyrations
Binder Gravity (Gb): 1.028
Apparent Gravity Solids (Gsa): 2.746
Effective Gravity Solids (Gse): 2.732
Bulk Gravity Solids (Gsb): 2.616
Percent Minus 0.075mm Sieve: 12.0
Number of Gyrations @ Ninitial: 8
Number of Gyrations @ Ndesign: 100

Sample ID	Asphalt Content (%)	Dry Weight (grams)	Height @ Nintial (mm)	Height @ Ndesign (mm)	Bulk Gravity (g/cm^3)	Rice Gravity (g/cm^3)	Correction Factor	%Gmm at Nini (%)	Effective Asphalt (%)	VTM (%)	VMA (%)	VFA (%)	Dust Asphalt	%Gmm @ Ninitial (%)	Densification Slope
4.0-1	4.0	4807.8	130.8	115.9	2.358	2.562	1.005	81.6	2.40	8.0	13.5	40.9	5.00	81.6	9.6
4.0-2	4.0	4805.7	131.1	116.3	2.355	2.562	1.007	81.5	2.40	8.1	13.6	40.5	5.00	81.5	9.5
Avg								81.5		8.0	13.5	40.7	5.00	81.5	9.5
5.0-1	5.0	4848.7	128.5	113.5	2.424	2.523	1.003	84.9	3.41	3.9	12.0	67.2	3.51	84.9	10.2
5.0-2	5.0	4845.1	128.8	113.9	2.421	2.523	1.006	84.9	3.41	4.0	12.1	66.5	3.51	84.9	10.1
Avg								84.9		4.0	12.0	66.9	3.51	84.9	10.2
6.0-1	6.0	4909	127.4	114.3	2.439	2.485	1.004	88.1	4.43	1.9	12.4	85.0	2.71	88.1	9.2
6.0-2	6.0	4886.7	128.0	114.0	2.433	2.485	1.003	87.2	4.43	2.1	12.6	83.4	2.71	87.2	9.8
Avg								87.6		2.0	12.5	84.2	2.71	87.6	9.5

National Center for Asphalt Technology
Screenings Evaluation
Mix Design Summary

Mixture ID:	Trial SMA	**Date:**	5/26/99
Aggregate:	Labstock Limestone 821's	**Filler Type:**	None
Asphalt:	PG 76-22	**Fiber Additive:**	Cellulose

Compaction Device:	Troxler SGC	Apparent Gravity Solids (Gsa):	2.746	Percent Minus 0.075mm Sieve:	12.0
Compaction Level:	100 gyrations	Effective Gravity Solids (Gse):	2.732	Number of Gyrations @ Ninitial:	8
Binder Gravity (Gb):	1.028	Bulk Gravity Solids (Gsb):	2.616	Number of Gyrations @ Ndesign:	100

Sample ID	Asphalt Content (%)	Dry Weight (grams)	Height @ Nintial (mm)	Height @ Ndesign (mm)	Bulk Gravity (g/cm^3)	Rice Gravity (g/cm^3)	Correction Factor	%Gmm at Nini (%)	Effective Asphalt (%)	VTM (%)	VMA (%)	VFA (%)	Dust Asphalt	%Gmm @ Ninitial (%)	Densification Slope
4.0-1	4.0	4793.2	133.0	118.1	2.308	2.562	1.005	80.0	2.40	9.9	15.3	35.2	5.00	80.0	9.2
4.0-2	4.0	4797.3	132.2	117.2	2.324	2.562	1.003	80.4	2.40	9.3	14.7	36.9	5.00	80.4	9.4
Avg								80.2		9.6	15.0	36.0	5.00	80.2	9.3
5.0-1	5.0	4841.5	132.2	116.6	2.364	2.523	1.006	82.6	3.41	6.3	14.2	55.5	3.51	82.6	10.1
5.0-2	5.0	4849.8	132.5	116.8	2.358	2.523	1.004	82.4	3.41	6.5	14.4	54.5	3.51	82.4	10.1
Avg								82.5		6.4	14.3	55.0	3.51	82.5	10.1
6.0-1	6.0	4896.5	130.7	115.6	2.405	2.485	1.003	85.6	4.43	3.2	13.6	76.3	2.71	85.6	10.2
6.0-2	6.0	4902.5	132.0	116.2	2.395	2.485	1.003	84.8	4.43	3.6	13.9	74.0	2.71	84.8	10.5
Avg								85.2		3.4	13.8	75.2	2.71	85.2	10.4

Appendix B
Draft Standard Specification for Designing 4.75 mm Superpave Mixes (From Reference 6)

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 B-1: Binder Selection on the Basis of Traffic Speed and Traffic Level

Design ESAL's[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 grrade 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-XX and increasing the design ESALs by one level (eg., 10 to <30 million increased to 30 million).

Table B-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 B-3: Superpave Aggregate Consensus Property Requirements

Design ESALs[1]	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 6-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 B-4: Superpave HMA Design Requirements

Design ESALs[1]	Required Relative Density (Percent of Theoretical Maximum Specific Gravity)			Voids in the Mineral Aggregate (VMA) (Percent), minimum	Voids Filled With Asphalt (VFA) Range (Percent)	Dust-to-Binder Ratio Range
	$N_{initial}$	N_{design}	N_{max}	16.0	75-80	
<0.3	≤91.5					
0.3 to <3	≤90.5					
3 to <10						
10 to <30						
≥30	≤89.0	96.0	≤98.0	16.0-18.0	75-78	09-2.2

(1) Design ESALs are the anticipated project 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 7-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.