NCAT Report 02-02

COARSE VERSUS FINE-GRADED SUPERPAVE MIXTURES: COMPARATIVE EVALUATION OF RESISTANCE TO RUTTING

By

Prithvi S. Kandhal
L. Allen Cooley, Jr.

February 2002

National Center for Asphalt Technology
NCAT
AUBURN UNIVERSITY
277 Technology Parkway • Auburn, AL 36830

COARSE VERSUS FINE-GRADED SUPERPAVE MIXTURES: COMPARATIVE EVALUATION OF RESISTANCE TO RUTTING

By

Prithvi S. Kandhal
Associate Director
National Center for Asphalt Technology
Auburn University, Alabama

L. Allen Cooley, Jr.
Civil Engineer
National Center for Asphalt Technology
Auburn University, Alabama

NCAT Report 02-02

February 2002

DISCLAIMER

ABSTRACT

Both coarse and fine-graded hot mix asphalt mixtures can be designed within the gradation control points recommended within the Superpave mix design system. However, some states have begun to specify only coarse-graded mixtures (below the restricted zone) and other states are specifying only fine-graded mixtures (above the restricted zone). This study was conducted to compare coarse-graded Superpave mixtures with fine-graded Superpave mixtures in terms of resistance to rutting so as to determine whether restrictions on gradations (either coarse- or fine-graded mixtures) are justified.

Fourteen mixtures comprising two nominal maximum aggregate sizes: 9.5 and 19.0 mm; two coarse aggregates: granite and crushed gravel; and four fine aggregates: sandstone, limestone, granite, and diabase, were tested. Resistance to rutting of both coarse- and fine-graded mixtures was evaluated using three test methods: Asphalt Pavement Analyzer, Superpave shear tester, and repeated load confined creep test.

Statistical analyses of the test data obtained by the three performance tests indicate no significant difference between the rutting resistance of coarse- and fine-graded Superpave mixtures. It has been recommended that mix designs should not be limited to designing mixes on the coarse or fine side of the restricted zone.

KEY WORDS: Superpave, asphalt mixtures, HMA, coarse-graded, fine-graded, gradation, rut resistance, permanent deformation, creep test, APA, SST

COARSE VERSUS FINE-GRADED SUPERPAVE MIXTURES: COMPARATIVE EVALUATION OF RESISTANCE TO RUTTING

Prithvi S. Kandhal and L. Allen Cooley, Jr.

INTRODUCTION

The aggregate gradation used in Superpave hot mix asphalt (HMA) mix design is required to be within control points at 0.075 mm (No. 200), 2.36 mm (No. 8), and nominal maximum aggregate size. Both coarse- and fine-graded mixtures can be designed within these control points. A majority of states accept both coarse- and fine-graded Superpave mixtures if the Superpave volumetric properties such as voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA) are met. However, some states have begun to specify only fine-graded Superpave mixtures whereas others specify only coarse-graded Superpave mixtures. The states which specify coarse-graded mixtures (defined generally as those mixtures with gradation below the restricted zone) believe the coarse gradation provides a “strong aggregate structure.” This belief is not essentially based on any significant mix strength test data. After some coarse-graded Superpave mixtures exhibited premature and excessive rutting (more than the fine-graded mixtures) on WesTrack and exhibited excessive in-situ permeability in many other states, some states have started to specify only fine-graded mixtures (defined generally as those mixtures with gradation above the restricted zone).

Obviously, the question arises as to which specification is justified. Based on the recommendations from the just-completed NCHRP Project 9-14, “Investigation of the Restricted Zone in the Superpave Aggregate Gradation Specification,” the restricted zone is expected to be deleted entirely from Superpave (*1*). Ironically, that would require a new definition for coarse- and fine-graded mixtures in case some states continue to specify one over the other.

OBJECTIVE

This study was conducted to compare coarse-graded Superpave mixtures with fine-graded Superpave mixtures in terms of resistance to rutting so as to determine whether restrictions on gradation type (either coarse- or fine-graded mixtures) are justified.

MATERIALS AND MIXTURES USED

The following materials and mixtures were used in this study. These were selected from a large variety of materials and mixtures used in NCHRP Project 9-14 in which comparisons could be made between coarse and fine gradations utilizing similar materials.

Coarse Aggregates

Two coarse aggregates, crushed granite and crushed gravel, were used for this study. Selection criteria for these two coarse aggregates was that they should come from different mineralogical types and have different particle shapes and textures. Properties of these two coarse aggregates are provided in Table 1.

Fine Aggregates

Four fine aggregates of different mineralogical compositions, particle shape and surface texture were used in this study. Table 2 gives the properties including the fine aggregate angularity (FAA) of the four fine aggregates.

Table 1. Coarse Aggregate Properties

Test	Procedure	Crushed Gravel	Granite
Flat or Elongated 2:1	ASTM D4791	20	57
Flat or Elongated 3:1	ASTM D4791	2	11
Flat or Elongated 5:1	ASTM D4791	0	1
Flat and Elongated 2:1	ASTM D4791	40.1	64.3
Flat and Elongated 5:1	ASTM D4791	0	1.0
Uncompacted Voids (Method A)	AASHTO TP56	41.7	47.0
Apparent Specific Gravity	AASHTO T84	2.642	2.724
Bulk Specific Gravity	AASHTO T85	2.591	2.675
Water Absorption, %	AASHTO T85	0.7	0.6
Los Angeles Abrasion, % loss	AASHTO	28	41
Coarse Aggregate Angularity % 1 FF, % 2 FF	ASTM D5821	100/92	100/100

Table 2. Fine Aggregates Selected for Study

Mineralogical Type	FAA Value	Bulk Sp. Gr.	% Absorption	Comments
Sandstone	49.7	2.731	0.8	Mined, cone crusher, from Alabama
Limestone	46.9	2.661	1.0	Mined, impact crusher, from Alabama
Granite	48.9	2.711	0.4	Mined, cone crusher, from Minnesota, used on MnRoad
Diabase	50.1	2.909	0.8	Mined, impact crusher, from Virginia

Asphalt Binder

The asphalt binder selected for this study was a Superpave performance-based PG 64-22 which is one of the most commonly used grades in the United States. Properties of this asphalt binder are provided elsewhere (*1*).

Mixtures

Eight 9.5 mm nominal maximum aggregate size (NMAS) mixtures were designed using a combination of granite or crushed gravel coarse aggregate and three fine aggregates: limestone, sandstone, and diabase (traprock). Sandstone fine aggregate was used with both granite and crushed gravel coarse aggregate. Two gradations, coarse gradation below the restricted zone (BRZ) and fine gradation above the restricted zone (ARZ), were used for each coarse/fine aggregate combination. These gradations for 9.5 mm mixes are given in Table 3 and are illustrated in Figure 1.

Both gradations follow the same trend from the 12.5 mm sieve down to the 4.75 mm sieve. From the 4.75 mm sieve, the BRZ (below restricted zone) gradation passes below the restricted zone and above the lower control points. The ARZ (above restricted zone) gradation passes above the restricted zone and below the upper control points. Obviously, both gradations do not violate the

Superpave restricted zone. Both gradations then meet at the 0.15 mm sieve and follow the same trend down to the 0.075 mm sieve. A common material passing 0.075 mm sieve (No. 200) sieve (P200) was used in all HMA mixtures to eliminate P200 as a variable. Different P200 materials stiffen the asphalt binder and HMA mixtures to a different degree and, therefore, affect the mix performance test results. A limestone filler (Rigden voids=33.5 %) was utilized as the P200.

TABLE 3 9.5 mm Nominal Maximum Size Gradations

Sieve, mm	BRZ[a]	ARZ[b]
12.5	100	100
9.5	95	95
4.75	60	60
2.36	42	50
1.18	28	42
0.60	18	32
0.30	14	22
0.15	10	10
0.075	5	5

[a] BRZ - Below the Restricted Zone
[b] ARZ - Above the Restricted Zone

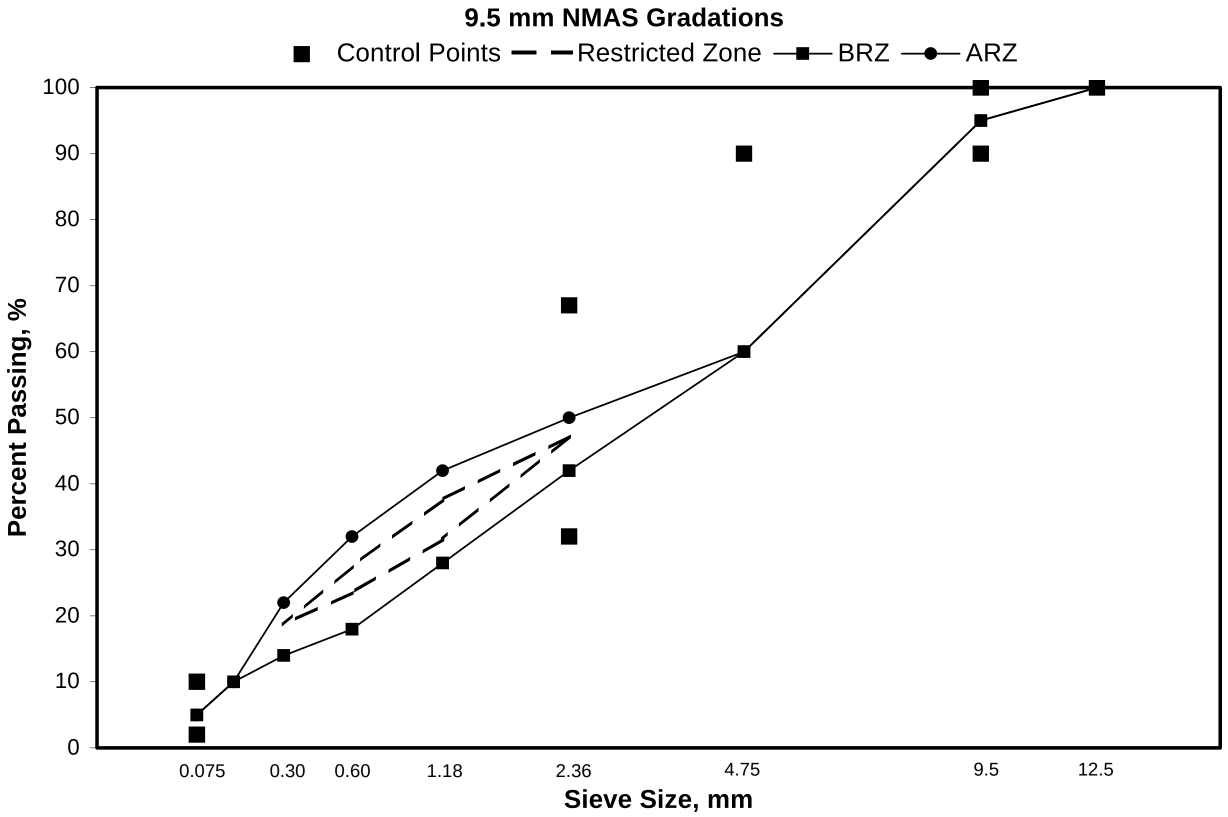

Figure 1. 9.5 mm NMAS Gradations

All eight 9.5-mm NMAS mixtures including BRZ and ARZ gradations were designed with Superpave volumetric mix design method. The initial, design, and maximum number of gyrations used were 8, 100, and 160, respectively which represent a design traffic level (20 year) of 3-30 million ESALs. Compaction was carried out to N_{design} to determine optimum asphalt content (4 percent voids). Once optimum was found, two replicates were compacted to 160 gyrations. Table 4 gives a summary of mix design data such as optimum asphalt content, voids in total mix (VTM), VMA, VFA, $\%G_{mm}@N_{ini}$, and $\%G_{mm}@N_{max}$ for the eight mixtures.

Three 19.0 mm NMAS mixtures were designed using a combination of granite or crushed gravel coarse aggregate and three fine aggregates: granite, sandstone, and diabase. Again, two gradations, BRZ and ARZ were used for each coarse/fine aggregate combination, and are illustrated in Figure 2.

A summary of Superpave volumetric mix design data for the six mixtures is given in Table 5. Two compactive efforts (N_{design}=75 and 100 gyrations) were used with the 19.0 mm NMAS mixes as shown in the table.

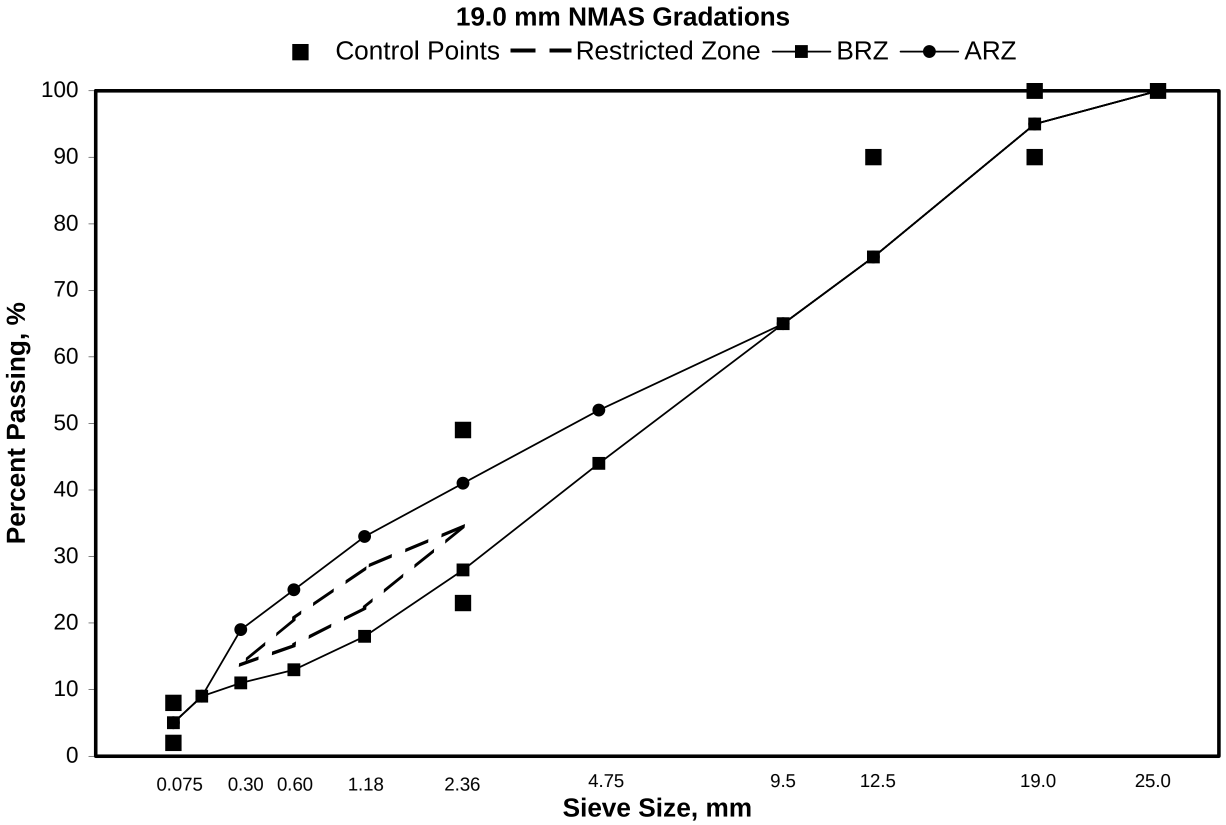

Figure 2. 19.0 mm NMAS Gradations

Table 4. Summary of Mix Designs and Performance Data for 9.5 mm NMAS (N_{design}=100)

Coarse Agg.	Fine Agg.	Grad-ation	Opt. Asphalt Content, %	Volumetric Properties at Optimum Asphalt Content					APA Rut Depth, mm	RSCH Strain, %	RLCC Strain, %
				VTM, %	VMA, %	VFA, %	% G_{mm} @ N_{ini}	% G_{mm} @ N_{max}			
Granite	Limestone (FAA=46.5)	BRZ	5.3	4.0	14.1[a]	71.6	85.4	97.7	4.82	1.105	3.19
Granite	Limestone (FAA=46.5)	ARZ	5.3	4.0	14.2[a]	71.8	87.8	97.6	4.55	1.126	1.40
Granite	Sandstone (FAA=49.7)	BRZ	6.0	4.0	16.9	76.3[a]	85.8	97.9	7.84	1.309	8.79
Granite	Sandstone (FAA=49.7)	ARZ	6.1	4.0	16.8	76.2[a]	88.7	97.8	7.28	1.301	5.57
Crushed Gravel	Sandstone (FAA=49.7)	BRZ	5.6	4.0	15.8	74.7	87.0	97.6	8.77	1.295	12.08
Crushed Gravel	Sandstone (FAA=49.7)	ARZ	5.7	4.0	16.2	75.3[a]	89.0	97.8	7.83	1.251	11.97
Crushed Gravel	Diabase (FAA=50.1)	BRZ	6.0	4.0	16.7	76.0[a]	88.4	97.5	7.10	2.087	6.36
Crushed Gravel	Diabase (FAA=50.1)	ARZ	5.5	4.0	15.7	74.5	87.8	97.6	5.37	1.942	2.62

[a] Does not meet Superpave requirements

Table 5. Summary of Mix Designs and Performance Data for 19.0 mm NMAS (N_{design}=75 and 100)

Coarse Aggregate	Fine Aggregate	N_{design} Gyrations	Gradation	AC, %	Volumetric Properties at Optimum Asphalt Content				APA Rut Depth, mm
					VMA, %	VFA, %	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}	
Crushed Gravel	Granite (FAA=48.9)	75	ARZ	4.6	13.7	70.8	90.1	97.5	9.22
Crushed Gravel	Granite (FAA=48.9)	75	BRZ	5.0	14.0	71.4	88.3	97.5	7.88
Crushed Gravel	Sandstone (FAA=49.7)	75	ARZ	4.8	14.4	72.2	89.1	97.5	8.75
Crushed Gravel	Sandstone (FAA=49.7)	75	BRZ	5.0	15.1	73.5	87.3	97.6	8.19
Granite	Diabase (FAA=50.1)	100	ARZ	4.6	14.3	72.0	88.5	97.5	5.88
Granite	Diabase (FAA=50.1)	100	BRZ	4.7	15.1	73.5	87.6	97.4	7.63

TEST PROCEDURES

The performance of 14 mixes (7 BRZ and 7 ARZ gradations) with various coarse/fine aggregate combinations meeting Superpave volumetric requirements were evaluated for rutting potential on the basis of performance-related mechanical tests. This was accomplished by two different types of tests: empirical and fundamental. For the empirical test, the Asphalt Pavement Analyzer (APA) was used. The Superpave shear tester (SST) and the repeated load confined creep (RLCC) test were utilized as fundamental tests. It was not expected that all three rutting or permanent deformation tests (one empirical and two fundamental) would provide exactly similar results. If they did, one mix validation test would be sufficient. However, all three tests might not be equally sensitive to changes in the gradations being examined.

Asphalt Pavement Analyzer (APA)

The Asphalt Pavement Analyzer (APA) is an automated, new generation of Georgia Load Wheel Tester (GLWT). The APA features controllable wheel load and contact pressure, adjustable temperature inside the test chamber, and the capability to test the samples either while they are dry or submerged in water. The APA test was conducted dry to 8,000 cycles and rut depths were measured continuously. APA testing was conducted on three pairs of gyratory compacted specimens of 75 mm height. Testing with the APA was conducted at 64°C. The air void content of the different mixtures was 6.0 ± 0.5 percent. The mixture was aged 2 hours at the compaction temperature prior to compacting. Hose pressure and wheel load were 690 kPa and 445 N (100 psi and 100 lb), respectively.

Superpave Shear Tester - SST (AASHTO TP7-94)

The Superpave shear tester (SST) simulates, among other things, the comparatively high shear stresses that exist near the pavement surface at the edge of vehicle tires; stresses that lead to the lateral and vertical deformations associated with permanent deformation in surface layers. The Repeated Shear at Constant Height Test, or RSCH, (AASHTO TP7, Procedure F) was selected to assess the permanent deformation response characteristics of the mixtures. This test operates by applying repeated shear load pulses to an asphalt mixture specimen. As the specimen is being sheared, the constant height prevents specimen dilation, thereby promoting the accumulation of permanent shear strain.

All specimens for SST testing were fabricated at 3.0 ± 0.5 percent air voids and tested at 50°C. This test temperature was selected because it is representative of the effective temperature for permanent deformation (T_{eff}(PD)) as used in SST protocol for the Southeast and is believed to be critical for inducing rutting in HMA pavements. Prior to compaction, the mixture was aged for 4 hours at 135°C in accordance with the test method.

Repeated Load Confined Creep Test (RLCC)

Repeated load confined creep test is considered to be a fundamental experimental method to characterize the rutting potential of HMA, since fundamental creep principles can be applied to deformation of viscoelastic mixes. A Material Testing System (MTS) was used to conduct this test. A deviator stress along with a confining stress was repetitively applied on a HMA sample for 1 hour, with 0.1 second load duration and 0.9 second rest period. After the one hour test the load was removed and the rebound measured for 15 minutes. The strain observed at the end of this rebound period was reported as the permanent strain. Permanent strain indicates the rutting potential of the mix. The target air void content for mixtures tested by the RLCC test was 4.0 ± 0.5 percent. Prior to compaction, the mixture was aged for 4 hours at 135°C. The test temperature was 60°C. Test loadings consisted of an 138 kPa (20 psi) confining pressure and an

827 kPa (120 psi) normal pressure.

TEST RESULTS, STATISTICAL ANALYSIS, AND DISCUSSION

Table 4 gives the performance test data for the eight 9.5 mm NMAS mixtures. Results for the APA are presented as the manually measured rut depth after 8,000 cycles. For the repeated shear at constant height (RSCH) test, results are presented as the total (plastic) strain after 5,000 cycles, expressed as a percentage. Results for the repeated load confined creep (RLCC) test are presented as the permanent strain measured after 3,600 load repetitions (applied in one hour) and a 15 minute rebound time, again expressed as a percentage. Table 5 gives APA data for six 19.0 mm mixtures, RSCH and RLCC were not conducted during the 19.0 mm NMAS work. As shown in Figure 3, there was a relatively strong relationship between the three tests. Recall that initially the three were included because it was unclear whether any of the three tests would be sensitive enough to the changes in gradation. In other work, Zhang et al. (*2*) showed that the three tests did provide similar results and therefore only the APA was used with the 19.0 mm mixes.

Figure 4 illustrates the results of APA testing in the form of a bar chart. Results are shown for all 14 mixtures (both 9.5 mm and 19.0 mm NMAS included). Data within Figure 4 are classified by whether the mixture has a coarse gradation (BRZ) or a fine gradation (ARZ). Solid black bars depict mixes having gradations below the restricted zone, while light bars represent mixes having gradations above the restricted zone. Rut depth data within the figure shows a wide range of magnitudes. As expected, the smallest rut depths are for the 9.5 mm-granite coarse aggregate-limestone fine aggregate combinations (about 5 mm). Table 4 shows that these two mixes failed VMA requirements. The highest rut depths were for the 19.0 mm-crushed gravel coarse aggregate-granite fine aggregate combinations (about 9 mm).

At first glance some of the rut depths appear high. Within the literature, the Georgia Department of Transportation's rut depth criteria of 5 mm after a 8,000 cycles in the APA is widely reported; however, testing in Georgia is conducted at 50°C. Recall that during this study testing was conducted at 64°C. In 1997, Shami et al. (*3*) presented a temperature-effect model to predict APA rut depths based upon testing conducted at a given test and number of cycles. This model was used to convert Georgia's critical rut depth of 5 mm at 50°C after 8,000 cycles to a critical rut depth at a test temperature of 64°C after 8,000 cycles. Results of this analysis indicated a critical rut depth at 64°C of 9.5 mm.

Conversion of the Georgia critical rut depth to 64°C indicates that all of the mixes presented in Figure 4 would meet the criteria. The mix with the closest rut depth was the 19.0 mm-crushed gravel coarse aggregate-granite fine aggregate ARZ combination. This particular mix was one of the mixes designed at 75 gyrations. Looking at the magnitudes of average rut depths, it appears that there was little difference in rut depths between the ARZ and BRZ gradations. To investigate whether there were significant differences between the two gradation types, two-sample *t*-tests were used to compare the two gradation shapes for each of the coarse aggregate-fine aggregate combinations. Results of this analysis are presented in Table 6. Of the seven coarse/fine aggregate combinations evaluated, only one showed significant differences between the gradation shapes: 9.5 mm-granite coarse aggregate-sandstone fine aggregate. However, a close inspection of the magnitudes of rut depths (7.84 mm for BRZ versus 7.28 mm for ARZ) for the two mixes suggests that there was practically no difference in rut depth between the two mixes. Therefore, based solely on the APA results it appears that gradations that pass both above and below the restricted zone can be designed to be rut resistant.

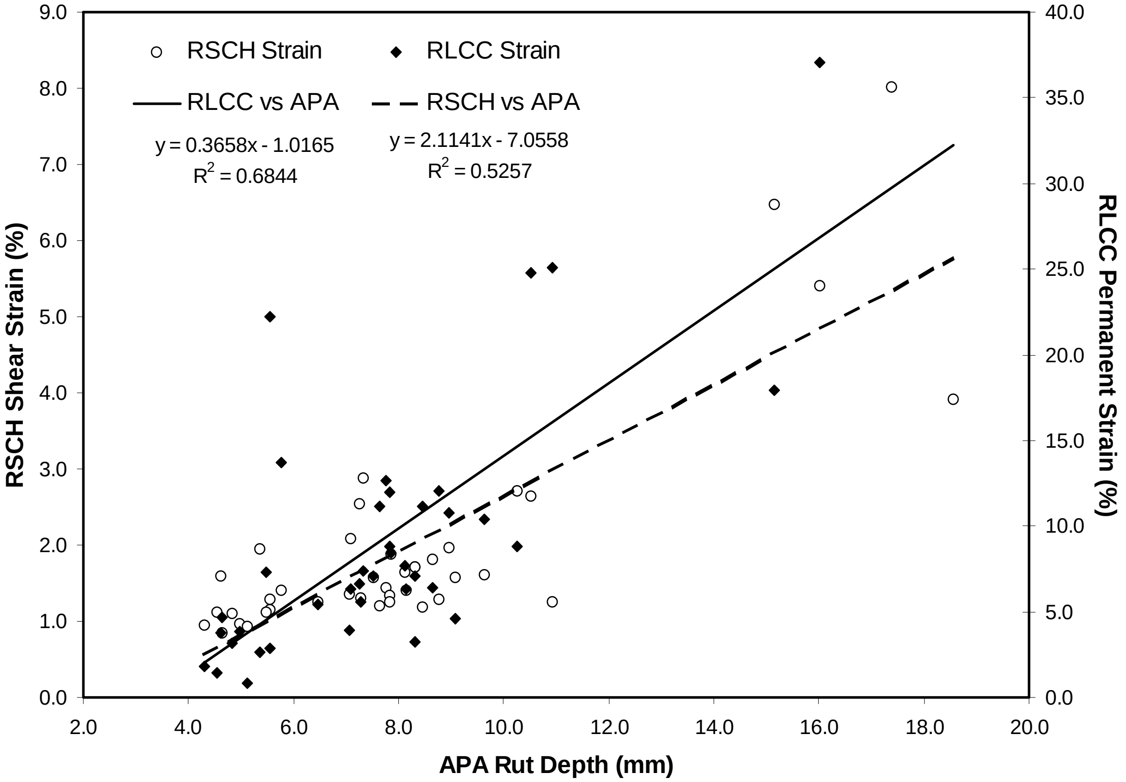

Figure 3. Relationship Between RSCH/RLCC and APA Rut Depth

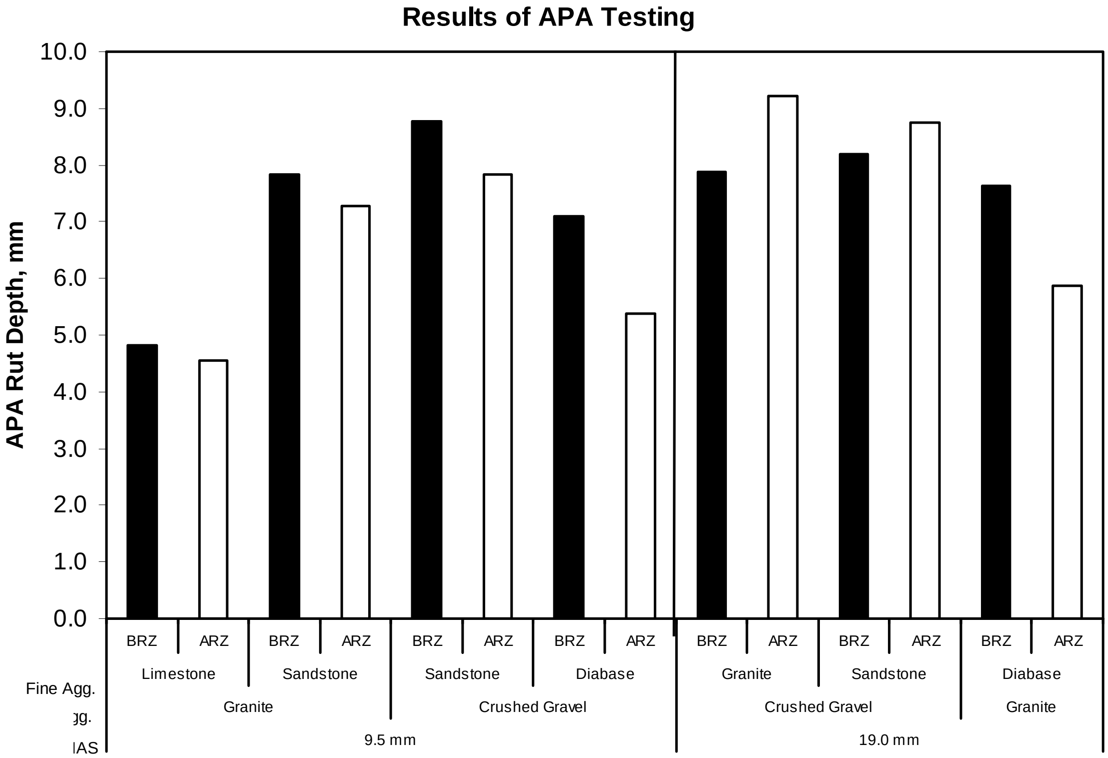

Figure 4. Results of APA Testing

Table 6. Results of T-Tests (APA Data)

Nominal Maximum Aggregate Size, mm	Coarse Aggregate	Fine Aggregate	N_{design}	t-statistic	p-value	Significantly Different?[a]
9.5	Granite	Limestone	100	0.54	0.595	No
9.5	Granite	Sandstone	100	-2.33	0.030	Yes
9.5	Crushed Gravel	Sandstone	100	-1.52	0.153	No
9.5	Crushed Gravel	Diabase	100	1.82	0.087	No
19.0	Crushed Gravel	Granite	75	1.01	0.387	No
19.0	Crushed Gravel	Sandstone	75	0.39	0.733	No
19.0	Granite	Diabase	100	-3.45	0.180	No

[a] Level of significance = 0.05

Figure 5 illustrates the RSCH results. Recall that only the 9.5 mm NMAS mixes were subjected to the RSCH testing. Therefore, only eight mixes are shown on Figure 5. Data within Figure 5 shows little differences in the magnitude of shear strain for any of the mixes. All of the shear strains were less than 2.1 percent which is considered to indicate rut resistance. Similar to the

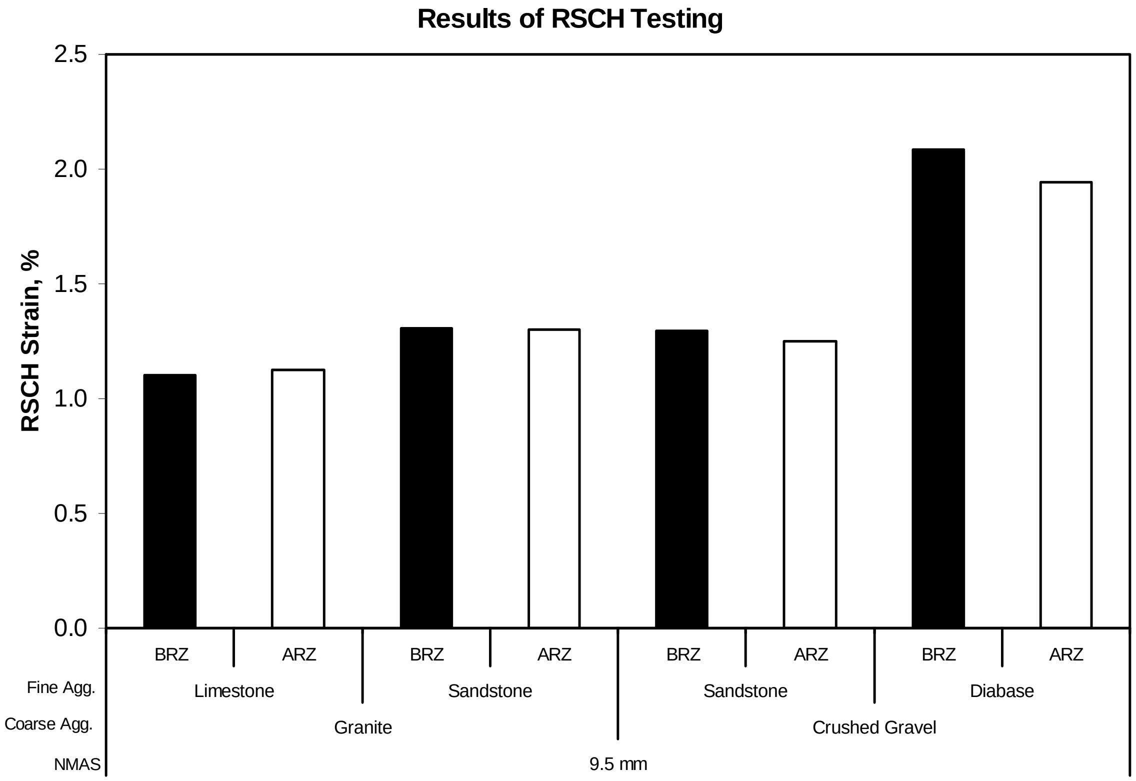

Figure 5. Results of RSCH Testing

APA analysis, a two-sample *t*-test comparison was conducted for each coarse/fine aggregate combination to evaluate whether there were significant differences in the shear strain between the ARZ and BRZ gradations (Table 7). Results of these analyses indicated no significant differences occurred between the two gradation shapes.

Table 7. Results of T-Tests (RSCH Data)

Nominal Maximum Aggregate Size	Coarse Aggregate	Fine Aggregate	N_{design}	t-statistic	p-value	Significantly Different?[a]
9.5	Granite	Limestone	100	-0.08	0.945	No
9.5	Granite	Sandstone	100	-0.03	0.976	No
9.5	Crushed Gravel	Sandstone	100	-0.17	0.874	No
9.5	Crushed Gravel	Diabase	100	-1.20	0.355	No

[a] Level of significance = 0.05

Results of RLCC tests are illustrated in Figure 6. This figure again suggests little difference in rutting potential between the ARZ and BRZ gradations. Comparisons between these two gradations were again made with the two sample *t*-test for each coarse/fine aggregate combination (Table 8). Similar to the RSCH data, no significant differences were found between the two gradation shapes.

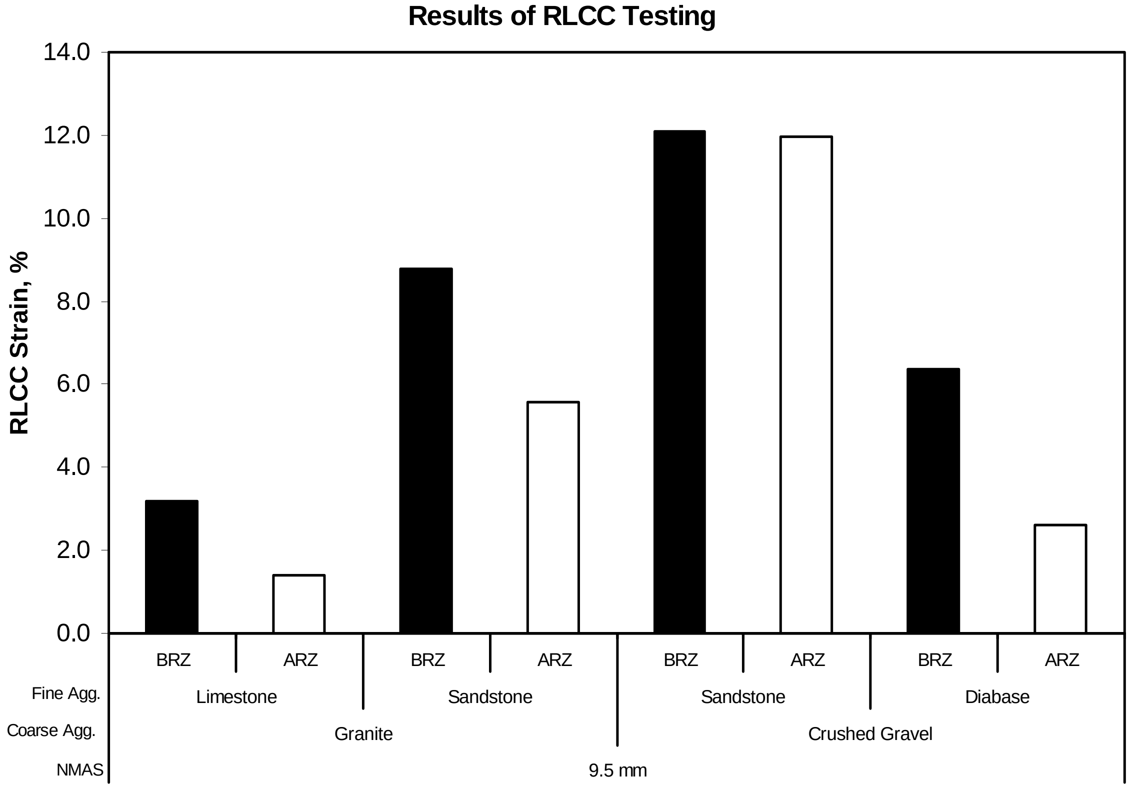

Figure 6. Results of RLCC Testing

Table 8. Results of T-Tests (RLCC Data)

Nominal Maximum Aggregate Size, mm	Coarse Aggregate	Fine Aggregate	N_{design}	t-statistic	p-value	Significantly Different?[a]
9.5	Granite	Limestone	100	-2.52	0.128	No
9.5	Granite	Sandstone	100	-2.12	0.169	No
9.5	Crushed Gravel	Sandstone	100	-0.02	0.989	No
9.5	Crushed Gravel	Diabase	100	-3.91	0.159	No

[a] Level of significance = 0.05

Results of the statistical procedures for all three performance tests indicate that the BRZ and ARZ gradations perform similarly. Disregarding the statistics and looking purely at the magnitudes of the different rutting parameters, for some NMAS/coarse aggregate/fine aggregate combinations, the BRZ gradation had lower rutting potential while for other combinations the ARZ had lower rutting potential. These observations have also been made by others (*4*, *5*, *6*, *7*, *8*, *9*).

CONCLUSIONS AND RECOMMENDATIONS

A number of state agencies are specifying HMA mixes to have gradations that pass either below the restricted zone (coarse-graded) or above the restricted zone (fine-graded). This study was conducted to compare the rutting susceptibility of Superpave mixes having coarse and fine gradations. Results of this study, using three different rutting susceptibility tests, indicate that no significant differences in rut potential occurred between the two gradation types. This was true for all three performance tests.

Based upon the results of this study, mix designers should not be limited to designing Superpave mixes on the coarse or fine side of the restricted zone. Mixes having either gradation type can perform well. Therefore, it is recommended that gradation specifications utilize both coarse- and fine-graded mixes. Regardless of the gradation type, some type of rutting torture test should be used to verify the rut resistance of the mixture.

REFERENCES

1. Kandhal, P. S., and L. A. Cooley, Jr. Investigation of the Restricted Zone in the Superpave Aggregate Gradation Specification. NCHRP Project 9-14, Draft Final Report, April 2001.
2. Zhang, J., L.A. Cooley, Jr., and P.S. Kandhal. Comparison of Fundamental and Simulative Test Methods for Evaluating Permanent Deformation of Hot Mix Asphalt. Paper prepared for presentation and publication at the 81st Annual Meeting of the Transportation Research Board, Washington, DC, 2002.
3. Shami, H.I., J.S. Lai, J.A. D'Angelo, and T.P. Harman. Development of Temperature Effect Model for Predicting Rutting of Asphalt Mixtures Using Georgia Loaded Wheel Tester. Transportation Research Record No. 1590. Transportation Research Board. Washington, DC. 1977.
4. Kandhal, P. S., and R. B. Mallick. Potential of Asphalt Pavement Analyzer (APA) to Predict Rutting of Hot Mix Asphalt. In *Proceedings, 1999 International Conference on Accelerated Pavement Testing,* Reno, NV, October 18-20, 1999.
5. Hand, A. J., and A. L. Epps. Impact of Gradation Relative to the Superpave Restricted Zone or HMA Performance. Presented at the 80th Annual Meeting of the Transportation Research Board, Washington, DC, 2001.
6. Chowdhury, A., J. C. Grau, J. W. Button, and D. N. Little. Effect of Gradation on Permanent Deformation of Superpave HMA. Presented at the 80th Annual Meeting of the Transportation Research Board, Washington, DC, 2001.
7. Anderson, R.M, and H.U. Bahia. Evaluation of Aggregate Gradations for Asphalt Mixtures Using Superpave. Transportation Research Record 1583. Transportation Research Board. Washington, DC. 1997.
8. Van de Ven, M., A. de F. Smit, R. Lorio, and R. McGennis. Validation of Some Superpave Design Parameters by Wheel Testing With the Scale Model Moblie Load Simulator. Eighth International Conference on Asphalt Pavements. Volume II Proceedings. Seattle, WA. 1997
9. El-Basyouny, M. and M.S. Mamlouk. Effect of Aggregate Gradation on the Rutting Potential of Superpave Mixes. Presented at the 78th Annual Meeting of the Transportation Research Board. Washington, DC. 1999.