



Final Report

**SOUTHEASTERN SUPERPAVE
CENTER
POOLED-FUND ACTIVITIES**

Pooled Funds SPR-3 (040) and TPF-5 (037)

ALDOT Project Number: 930-370P

By

Donald E. Watson
Lead Research Engineer
National Center for Asphalt Technology
Auburn University, Auburn Alabama

February, 2010



at AUBURN UNIVERSITY

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DISCLAIMER

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Alabama Department of Transportation or the National Center for Asphalt Technology. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENT

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ABSTRACT

Much has been learned about materials characteristics, testing procedures, new equipment, mix design, and pavement performance through the many studies conducted as a part of the Southeastern Superpave Center (SSC) pooled-fund program. Lessons learned from research conducted for agencies across the country have benefitted other agencies as well and many specification changes have been implemented based on the SSC project outcomes.

Studies conducted during this pooled-fund research program will help materials engineers for years to come understand more about the relationship between materials properties, mix design, and actual field performance. A structural analysis that considered improvements to mix design technology and HMA materials, as well as changes in traffic loading configurations was conducted. The study showed that the AASHTO layer coefficient for flexible pavements was overly conservative and recommended a new layer coefficient be used that could result in 18% reduction in HMA pavement thickness.

Advances have also been made in developing new test equipment. The National Center for Asphalt Technology (NCAT) close-proximity trailer for measuring sound pressure levels has significantly contributed to the knowledge of quieter pavements and their characteristics which will aid in mix type selection where noise levels are an issue. The field permeability device that was developed through this pooled-fund research allows technicians to determine a relative measure of permeability of in-place pavement layers without the need for coring. Moreover, the Asphalt Pavement Analyzer (APA) ruggedness testing has shown that the APA equipment can reliably rank the rutting resistance of hot mix asphalt (HMA) mixtures in an order that closely matches observed field performance over the life of the pavement.

Training opportunities through the SSC have provided technicians and engineers in several states with the appropriate skills needed to perform Superpave binder and mix design testing. Over 200 agency, contractor, and industry personnel have been certified through SSC Superpave training conducted either at NCAT facilities or at on-site locations.

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INTRODUCTION

In the mid-1990s, the Federal Highway Administration (FHWA) was instrumental in establishing five regional Superpave Centers to support states in implementing the Superpave mix design method. These regional centers were to create a partnership between agencies, academia, and regional asphalt user-producer groups in order to provide research, training, and technology transfer needed to smoothly implement Superpave technology.

The SSC has been supported by regional Department of Transportation (DOT) agencies as well as DOT agencies across the country through pooled-fund projects SPR-3 (040) and TPF-5(037). Alabama Department of Transportation (ALDOT) was the lead state providing administrative oversight for the pooled-funds. A total of 20 states contributed more than \$2.6 million to the combined pooled-fund projects since SSC inception. The funds have been largely used to provide training, verify ruggedness of equipment, check equipment calibrations, provide materials research, and aid in keeping agency personnel abreast of changes in asphalt technology.

OBJECTIVES

The SSC initial effort was concentrated on assisting state agencies with training and implementation of Superpave asphalt binder and mixture design specifications and procedures. Other objectives included developing training programs and conducting research for agency and industry benefit. In particular, these short and long-term objectives included:

- Provide training on Strategic Highway Research Program (SHRP) binder and mixture equipment
- Perform individual agency as well as group-sponsored research
- Perform/verify mix designs and binder test results for state agencies
- Perform troubleshooting for Superpave binder and mixture problems
- Perform forensic analysis of roadways with premature failures
- Provide leadership on a regional and national level for Superpave technology

SSC ACTIVITIES

Provide Training

Superpave mix design and Superpave binder training courses are typically offered at NCAT facilities annually. Most of the attendees for these courses are from regional states, but there have also been international participants attend these courses. Hands-on training is provided for technicians to become familiar with operation of the laboratory equipment and analysis of the test results.

This training has also been conducted on-site at sponsoring agency's facilities. On-site training and certification has been provided for Georgia Department of Transportation (GDOT) personnel since Superpave was implemented in that state in 1997. The training has extended to contractor and consultant technicians as well. A total of 160 technicians/engineers have been certified to perform Superpave mix designs for Georgia. Superpave mix design courses were also held at three regional offices in Louisiana. For this occasion, the NCAT mobile laboratory

was deployed on site to demonstrate test procedures and allow for hands-on operation of the laboratory testing equipment. In 2008 a course was held for Utah Department of Transportation (UDOT) in which 11 technicians received training toward certification for Superpave Mix Design.

Similarly, asphalt binder training has been provided at NCAT facilities in Auburn, AL and at on-site facilities when requested. Three technicians from Mississippi and seven from Alabama have been certified to perform Superpave binder testing. Training for GDOT personnel has been conducted both at NCAT and at the GDOT central laboratory in Forest Park, GA. There have been a total of 41 technicians between GDOT and industry personnel certified to perform binder testing for Georgia. Other participants from the industry and foreign countries such as Pakistan and Korea have attended the asphalt binder training course.

Another NCAT course well attended was the Asphalt Technology Course. This course is conducted twice a year and provides a general overview of the HMA process from design, production, and construction to maintenance and pavement management.

Conduct Research for Asphalt Materials and Mixtures

Evaluate Precision of Fine Aggregate Angularity Test

A task group under the auspices of the Southeastern Asphalt User/Producer Group (SEAUPG) completed a Round Robin inter-laboratory study of the American Association of State Highway and Transportation Officials (AASHTO) T304-96 test method for uncompacted void content of fine aggregate measurements by means of the National Aggregate Association (NAA) flow test apparatus. The purpose of this Round Robin study was to determine precision statements regarding accuracy and repeatability of the test procedure with a variety of aggregate materials. Participants were NCAT, Louisiana Transportation Research Council, 7 State DOTs, and 7 private laboratories, which included material supplier's laboratories.

Standard-graded sand was the only material used in the original Round Robin testing, which resulted in the current statement in both AASHTO T 304 and ASTM C- 1252. In this Round Robin study, four types of aggregate were distributed and tested among the 16 participating laboratories. The aggregate samples represented materials with both high and low fine aggregate angularity (FAA). The material types considered in the SSC analysis were:

- Natural Sand (A, B)
- Granite (C, D)
- Limestone (E, F)
- Standard-Graded Sand (G)

A total number of 672 samples were tested. Two replicate samples were tested for each material in accordance with AASHTO Test Method T-84, Specific Gravity and Absorption of Fine Aggregates, and AASHTO Test Method T-304, Uncompacted Void Content of Fine Aggregate. Two determinations for each test method were made and averaged.

Table 1 shows the single-operator and Multi-laboratory statistics in terms of standard deviation (1s) and coefficient of variation (1s%) for uncompacted voids for the 3 test methods described in the procedure (I). Method A utilizes a standard graded sample with masses for four sieve fractions specified in the procedure; Method B tests individual size fractions (consisting of No. 8 to No. 16, No. 16 to No. 30, and No. 30 to No. 50) and combines the results; and Method

C uses an as-received grading with the exception that material larger than the No. 4 sieve is removed. Table 2 shows the maximum range (d2s and d2s%) of two properly conducted test results by the same operator or different laboratories on similar samples. The d2s and d2s% values represent the range of results that would be equaled or exceeded only 5 percent of the time and are commonly used as the appropriate index of precision (2). The parameters 1s and d2s appear higher (around 4 times) than those stated in AASHTO Test Method T304-96 on material G (graded sand) which are 0.13 and 0.93 respectively. Moreover, Table 1 shows that methods A and B had similar precision. Method B had the best precision for single operator. Method C was less accurate for both single operator and multi-laboratory when compared to methods A and B.

Table 1: Single-Operator and Multi-laboratory Precision: Voids

	1s			1s%		
	Method A	Method B	Method C	Method A	Method B	Method C
Single-Operator	0.57	0.42	0.81	1.15	0.83	1.91
Multi-laboratory	0.75	0.76	1.15	1.51	1.49	2.70

Table 2: Maximum Acceptable Range: Voids

	d2s			d2s%		
	Method A	Method B	Method C	Method A	Method B	Method C
Single-Operator¹	1.61	1.19	2.29	3.25	2.35	5.40
Multi-laboratory²	2.12	2.15	3.25	4.27	4.21	7.64

¹Maximum acceptable range of two properly conducted test results by the same operator on similar samples, in terms of standard deviation and coefficient of variation.

²Maximum acceptable range of two properly conducted test results by different Laboratories on similar samples, in terms of standard deviation and coefficient of variation.

This analysis for voids showed that for all three methods the single-operator one-sigma limit (1s) was higher than 0.13 which was the value stated in the AASHTO Test Method T 304-96 on material G (graded sand). Similarly, for multi-laboratory analysis, the one-sigma limit (1s) for all three methods was about 5 times higher than the value of 0.33 stated in the AASHTO Test Method T 304-96 on material G (graded sand).

Tables 3 and 4 provide similar information for single-operator and multi-laboratory determination of sample mass.

Table 3: Single-Operator and Multi-laboratory Precision: Mass

	1s			1s%		
	Method A	Method B	Method C	Method A	Method B	Method C
Single-Operator	0.75	0.54	1.27	0.53	0.40	0.80
Multi-laboratory	1.43	1.66	3.69	0.81	1.17	2.09

Table 4: Maximum Acceptable Range: Mass

	d2s			d2s%		
	Method A	Method B	Method C	Method A	Method B	Method C
Single-Operator	2.12	1.53	3.59	1.50	1.13	2.26
Multi-laboratory	4.04	4.70	10.44	2.29	3.31	5.91

In summary, the results of the SEAUPG Round Robin testing for unconfined voids revealed the following:

- Test Method C has more variability compared to the other two Methods. Due to this high variability Method C should not be used in FAA determination.
- The one-sigma limit (1s) for single operator and multi-laboratory precision was found to be respectively 5 and 3 times higher than as indicated in the AASHTO T 304-96 test procedure precision statement on material G.
- Test Method A and Test Method B yielded similar results for precision.
- Based on Table 2, Method A - results of two properly conducted tests by two different laboratories on similar samples may differ as much as 2.12 (d2s). Similar conclusions can be obtained for Method B.
- The analysis for mass (Table 4) showed that when Method A is used, the results of two properly conducted tests by two different laboratories on similar samples may differ as much as 4.04 (d2s) whereas the single-operator precision may differ as much as 2.12 (d2s) for the same method. Similar conclusions can be obtained for Method B.

Refinement and Validation of Open-Graded Friction Course Design Procedure

Thirteen states participated in a study to refine the mix design procedure for Open-Graded Friction Course (OGFC) mixtures. The results of this study are available in two reports submitted to the Transportation Research Board and published in Transportation Research Record No. 1832 and No. 1891.

One of the main objectives of this research was to incorporate Superpave technology into the mix design procedure by establishing a recommended gyratory compaction level. The study analyzed results with three aggregate types- granite, traprock, and crushed gravel, and three asphalt binders- PG 67-22, PG 76-22 modified with styrene-butadiene-styrene (SBS), and PG 76-34 with chemically modified crumb rubber. Mixtures were prepared at three gradations (coarse, medium, and fine graded) and compacted to 30, 45, and 60 gyrations with the standard Superpave gyratory compactor (SGC) using an internal angle of 1.16°. Bulk specific gravity results for SGC-compacted samples were then compared to 25 and 50-blow Marshall compaction results. Figure 1 shows bulk specific gravity ratios of gyratory compaction and 50-blow Marshall. These results indicated that 50 SGC gyrations produced similar results as the 50-blow Marshall method conventionally used in Europe.

The study also evaluated the Cantabro stone loss procedure used in European practice to measure the resistance of open-graded mixture to wear and raveling. The aging and conditioning process was performed at 64°C temperature rather than 60°C as used in Europe. The 64°C

temperature was chosen in this study because it represented typical high pavement temperatures for a large portion of the United States as recommended by SHRP research and guidelines for Superpave binders. Unaged samples were tested at 25°C. European practice specifies a maximum Cantabro stone loss of 20% for unaged specimens and a maximum of 30% loss for aged samples compacted with a Marshall hammer. The analysis of results from this study recommended a maximum stone loss of 15 percent for unaged SGC samples and determined that an aging process was not necessary (3). Additionally, the study found that binder grade, especially when polymer-modified asphalt was used, was the most important factor in improving resistance to raveling based on Cantabro wear test results.

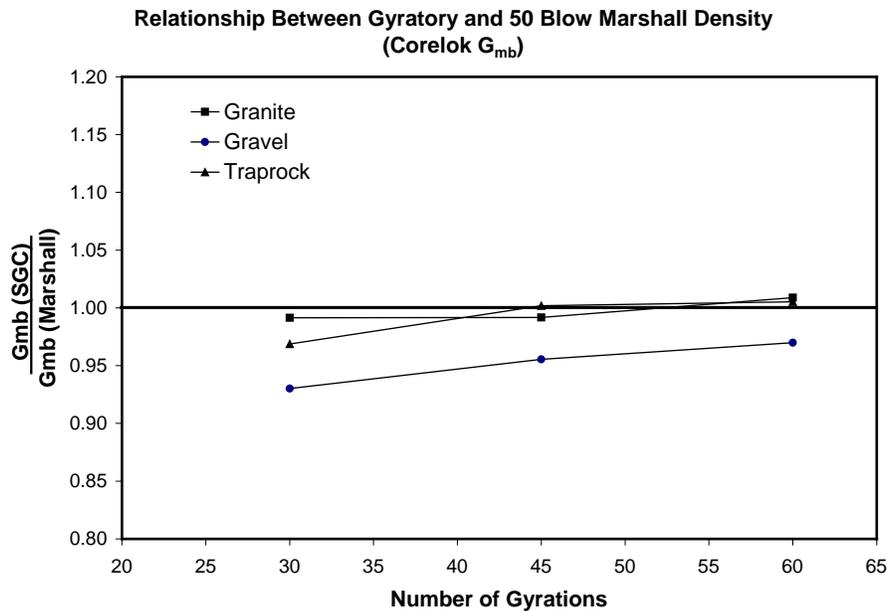


FIGURE 1 Relationship Between Bulk Specific Gravity of SGC and 50 Blow Marshall (3).

The draindown test, AASHTO T 305, was also performed to evaluate the effects of adding fiber stabilizer and using different Superpave performance grade binders. Mineral fiber was added at a dosage rate of 0.4% by total weight of mix. Draindown results were compared to those from samples without fiber stabilizer. Both PG 67-22 and PG 76-22 were used for samples with and without fiber stabilizer. As shown in Figure 2, the use of fiber stabilizer significantly improved resistance to draindown. In fact, the addition of fiber stabilizer was statistically the most significant variable in reducing binder draindown.

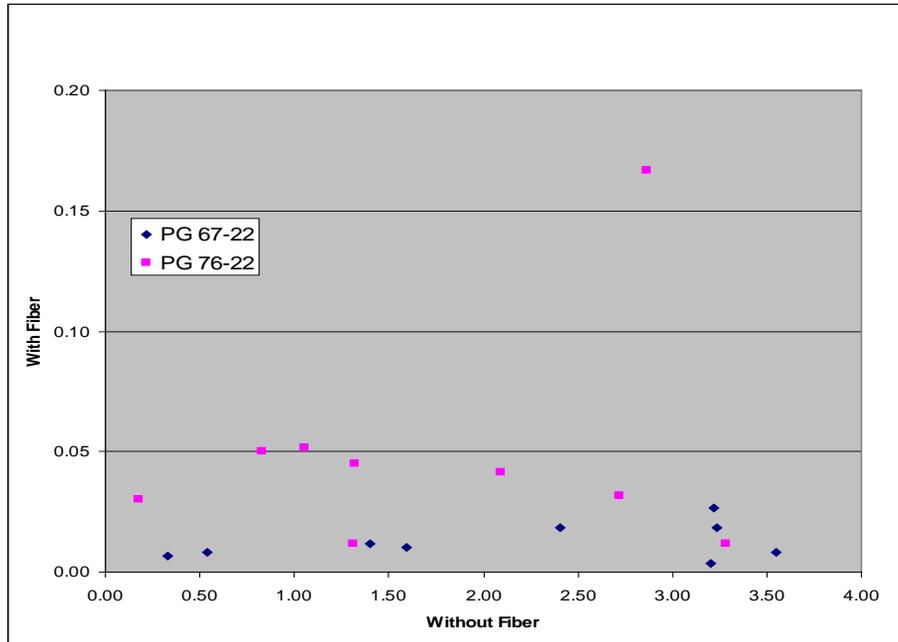


FIGURE 2 Draindown Comparison With and Without Fiber (4).

Evaluation of Warm Mix Asphalt (WMA) Technology

Several states have constructed either small test sections or full scale projects to evaluate the performance of WMA mixtures. These technologies are reported to allow achieving adequate compaction to be achieved at temperatures as low as 190°F.

Colorado Department of Transportation (CDOT) has a funded project through the SSC to evaluate three warm mix products: Aspha-min, Sasobit, and Evotherm. These processes are to be evaluated over two years and the overall construction documented by NCAT personnel. During construction, temperature readings were obtained at the mix plant and at the paving location using infrared temperature guns. Quality control and acceptance test results for mixture properties and roadway density and smoothness will be evaluated as soon as the data becomes available from FHWA which was responsible for this portion of the project.

This project also includes annual pavement evaluations which will be conducted for two years after construction to monitor pavement performance over time. The pavement evaluation will be a visual observation for rutting, cracking, and other types of pavement distress as identified in ASTM D 6433, Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys.

Development and/or Evaluation of New Test Equipment

Permeability of Superpave Mixtures: Evaluation of Field Permeameters

The objective of this study was to evaluate four field permeameters on three construction projects and select the best device based on its correlation with laboratory permeability test results, repeatability, and ease of use. Two of the permeameters were developed by commercial suppliers and two by NCAT. The research is documented in NCAT Report 99-01.

Cores were obtained from each project to determine laboratory permeability. A correlation between field and laboratory permeability is needed because of several variables with field testing that cause unknown values in the normal calculations using Darcy's Law. For example, one assumption in using Darcy's law is that the material being tested is saturated. This aspect is important since as the degree of saturation decreases, so does the measured permeability. Also, the sample dimensions are always known when performing laboratory permeability tests, whereas the sample thickness and effective area of the pavement through which the flow takes place has to be assumed or estimated (5).

Based on the analysis of the data accumulated during this study, field permeameter #3 (See Figure 3) correlated best to the laboratory permeability device, granted repeatable results, and was easy to use. This permeameter was unique from the three other devices evaluated. Permeameter #3 is characterized by a three-tiered standpipe that makes it easy to read water levels when the flow is either slow or fast through the standpipe. This aspect would allow the use of permeameter #3 in a variety of field conditions.



Device 1



Device 2



Device 3



Device 4

FIGURE 3 Field Permeameter Devices Used in the Study (5).

Determining the Effect of Tire-Pavement Interaction on Noise of HMA and Portland Cement Concrete (PCC) Pavements

Under a FHWA Cooperative agreement, prototype equipment was developed by NCAT to measure sound pressure and intensity. The NCAT close proximity (CPX) acoustic trailer, shown in Figure 4, takes noise measurements at speeds of 45 and 60 mph. Figure 5 shows the microphone configuration for sound pressure measurements. Based on successful use of the NCAT CPX trailer, Arizona Department of Transportation (ADOT) had a similar unit built under the SSC pooled fund. Testing was conducted to assure the two units produced similar results. After equipment validation, the new CPX trailer was delivered to ADOT.



FIGURE 4 NCAT CPX Trailer.

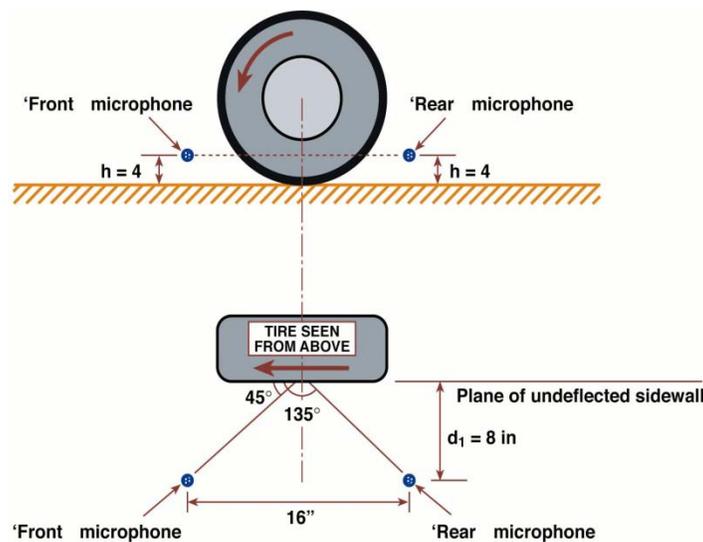


FIGURE 5 Sound Pressure Microphone Configuration.

Sound studies have been conducted for seven agencies under the SSC pooled fund using the NCAT CPX trailer with the objective of comparing noise level based on mix and pavement types. Colorado performed annual studies for four years on several pavement sections to evaluate the long-term viability of using specific pavements and mixtures for noise abatement (6). In 2003, NCAT tested 29 pavement surfaces, 14 of which were HMA and 15 PCC. In 2004, NCAT tested 13 HMA and 14 PCC sections. These sections included 13 that were tested the previous year. In 2005, 25 of the 27 sites tested in 2004 were retested. A total of 31 test sites were evaluated in 2007. These sites comprised a variety of pavement types including 18 HMA and 13 PCC sites. The HMA sections included Stone Matrix Asphalt (SMA), Superpave, Novachip and dense graded asphalt mixtures. The PCC sections included pavements longitudinally tined or grooved, finished with carpet/burlap drag surfaces, and some diamond grinded.

Table 5 shows that sound levels measured on the Colorado sections generally increased over time. This may be an indication of reduced void structure as the pavement densified under traffic. In fact, sound absorption decreases with an increase in pavement density.

TABLE 5 Sound Measurements over Time (6)

YEAR	2003	2004	2005	2007	DIFF
C01	-	96.4	99.6	99.2	-0.4
C02	96.3	99.2	99.7	101.8	2.1
C03	-	99.5	97.4	101.1	3.7
C04	96.2	98.3	97.7	98.3	0.6
C05	-	94.6	98.2	99.3	1.1
C06	-	98.7	98.3	98.9	0.6
C07	95.6	96.2	96.4	100.2	3.8
C08	-	97.1	101.1	101.6	0.5
C09	-	101.1	98.2	99.4	1.2
C10	-	97.2	99.9	99.5	-0.4
C11	98.9	101.1	99.9	100.5	0.6
C12	95.1	98.4	101.1	98.8	-2.3
C13	97.5	98.3	99.9	97.2	-2.7
C14	98.6	99.9	101.1	101.7	0.6
C15	-	98.5	98.2	98.8	0.6
C16	-	99.7	99.4	100.3	0.9
C17	-	104	97.5	99.7	2.2
C18	98	100.9	100.9	101.4	0.5
C19	-	-	8.5	98.8	0.3

The difference in measurements between 2007 data and earlier results may also be due to a change in tires since the initial testing began. One of the tire types used initially is no longer available. To overcome discrepancies in results from changes in tire design or manufacturer, there has been an effort within the industry to adopt a Standard Reference Test Tire (SRTT). Limited research by NCAT shows mean sound pressure levels with the SRTT tire are slightly different than the Uniroyal tire that was used in the past when tests were performed at 45 mph (7). Figure 6 shows a comparison between 2007 measurements of the Colorado sections with the SRTT tire and Uniroyal (UNIR) tire type used in earlier studies. The SRTT sound levels were consistently higher than the Uniroyal.

In comparing the differences between 2007 and 2005, there were several sections that decreased in sound level. It may be that seasonal differences of time and temperature also had some effect on the sound differences.

A comparison was also made of two different methods of measuring sound- sound intensity level (SIL) and sound pressure level (SPL). These tests were conducted on special quiet pavement research sections at the NCAT Test Track. Surprisingly there was a very good relationship between SPL and SIL although SPL measurements tended to be slightly higher (Figure 7).

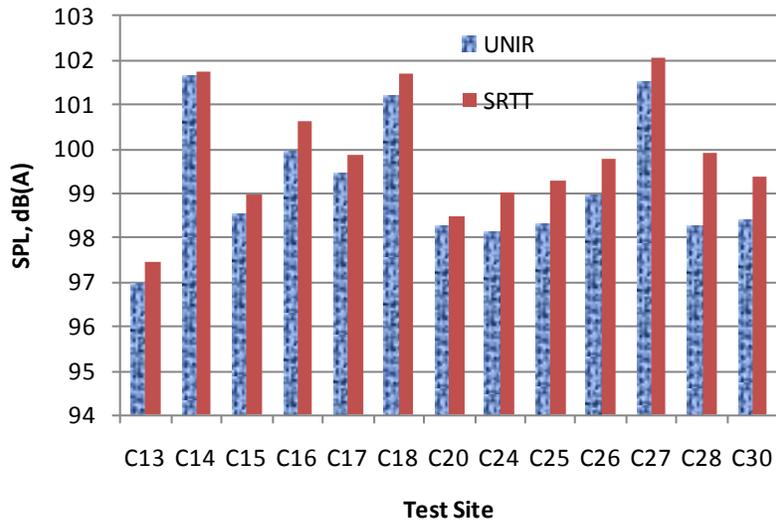


FIGURE 6 Sound Pressure Level Comparison with Different Tires (6).

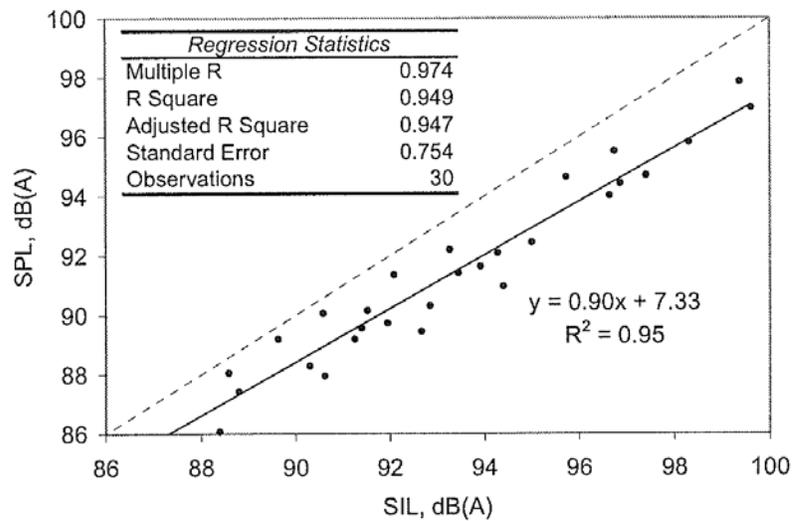


FIGURE 7 Comparison of Sound Pressure and Sound Intensity Measurements (7).

Pavement Structural Design

Recalibration of the Asphalt Layer Coefficient

ALDOT and several other agencies use the 1993 DARWin software version of the AASHTO Guide for the Design of Pavement Structures for designing flexible pavements. This design methodology is based on results from the AASHTO Road Test conducted 50 years ago. Truck and traffic configurations as well as construction materials and mix design technologies have changed considerably during that time. Therefore, there was a need to reevaluate the structural layer coefficients used in the HMA pavement design process. This was done by analyzing detailed pavement performance records of 14 structural sections at the NCAT Test Track. These sections were included in the 2003 and 2006 NCAT Test Track cycles where an accelerated loading of 10 million Equivalent Single Axle Loads (ESALs) were applied during each cycle. Details of the study are in NCAT Report 09-03 and include a sensitivity analysis of design inputs and a recalibration procedure for HMA layer coefficients (8).

As shown in Figure 8, regressed layer coefficients were consistently higher than the value of 0.44 which is currently used by most agencies for flexible pavement design. This indicates the AASHTO design guide may be overly conservative for use in designing HMA pavements. Only sections N8 placed in 2003 and N10 placed in 2006 had lower regressed layer coefficients than 0.44. A forensic analysis of these two sections revealed delamination within the structural layers as the most probable cause for the low values. Figure 8 shows an average layer coefficient of 0.54 was obtained from the 14 sections. The value had a standard deviation of 0.08 and a coefficient of determination (R^2) of 0.79.

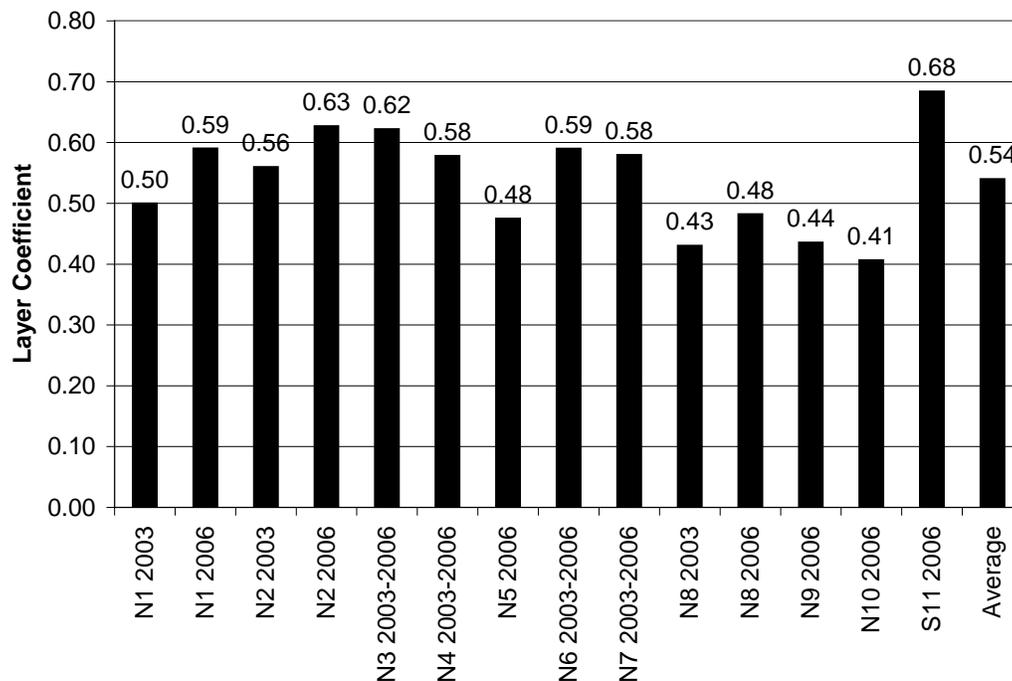


FIGURE 8 Regressed Layer Coefficients (8).

Figure 9 shows the results of an analysis to compare 0.44 and 0.54 as the layer coefficients to determine recommended depth of pavement structure for various loading conditions. The analysis shows approximately 18% reduction in HMA thickness when using the recommended layer coefficient of 0.54 as compared to the AASHTO layer coefficient of 0.44. The report notes that the study was conducted on pavement sections that had at least five inches of HMA thickness. Therefore, users are cautioned to use the conservative AASHTO coefficient of 0.44 for structures less than five inches, or set five inches as a minimum thickness for HMA pavement structures.

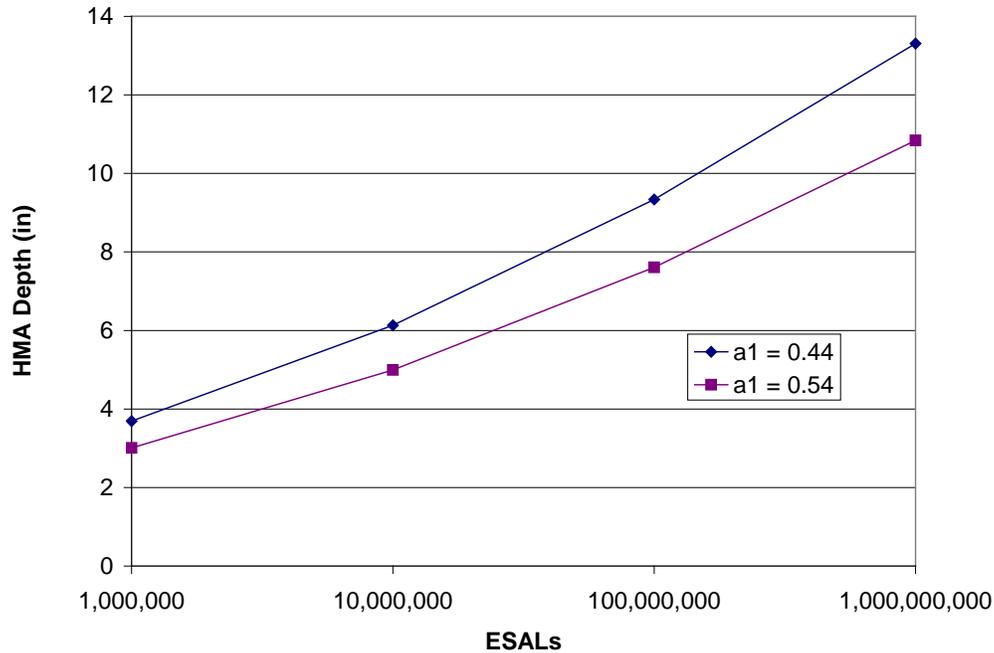


FIGURE 9 Change in Resulting HMA Thickness from $a_1 = 0.44$ to $a_1 = 0.54$ (8).

CONCLUSIONS

Much has been learned about materials characteristics, testing procedures, new equipment, mix design, and pavement performance through the many studies conducted as a part of the SSC pooled-fund projects SPR-3(040) and TPF-5(037). Training opportunities have been provided at the SSC as well as on-site enabling more than 200 technicians and engineers to become certified to perform Superpave mix design and asphalt binder testing.

The development of new equipment such as the NCAT trailer for measuring sound pressure levels has significantly improved knowledge of what is needed to produce quieter pavements and will aid in mix type selection where noise levels are an issue. The field permeameter is used by several agencies as a tool for evaluating quality and porosity of HMA construction.

The fine aggregate angularity study showed greater variability in single-operator precision and inter-laboratory precision for HMA fine aggregate materials compared to the AASHTO precision statement for the test procedure. These results may impact agency specifications for fine aggregate used in Superpave mixtures. The environmental and safety benefits of OGFC mixtures is well known, but refinement in the mix design procedure was needed to improve performance. Tests for permeability, moisture susceptibility, and stone loss

have been included in the procedure developed in this study. Warm mix asphalt projects have been placed throughout the country. It is important that these projects be monitored and long-term performance documented and compared to conventional HMA.

A significant finding through SSC research is that the use of the AASHTO flexible pavement layer coefficient results in pavement structure being about 18% thicker than necessary. It was recommended that a layer coefficient of 0.54 be used (instead of the conventional coefficient of 0.44) when pavement structures are 5 inches or more in thickness.

RECOMMENDATIONS

Research carried out through the SSC also revealed several areas that need more thorough research. Areas that need more research are:

- More research is needed for warm mix asphalt technologies to further evaluate field performance, the selection of the optimum asphalt content, the selection of binder grades for lower production temperatures, and the effect of using Reclaimed Asphalt Pavement (RAP) in warm mix technologies.
- Additional testing is needed with sound intensity measurement as this method allows use of more portable equipment. Comparisons are needed with a variety of surfaces and traffic conditions, and monitoring is needed over time to validate the possible effect of noise attenuation being reduced over time. Development of a maintenance procedure and routine for cleaning the pore structure is needed to extend drainage performance. The Cantabro wear test is currently used to validate mixture durability. A test that better simulates long-term durability is needed.
- New products and new equipment related to the HMA industry will need to be evaluated. This process can be made more efficient by using the SSC to conduct the testing and evaluation rather than each agency conducting similar work.
- Additional training to share technological advances needs to be provided. Specialized training to supply knowledgeable and certified personnel for conducting testing and inspection of HMA construction operations is needed.
- More research is needed for pavement structural design methods. As agencies transition from the AASHTO layer coefficient procedures to the Mechanistic-Empirical Pavement Design Guide (MEPDG), validation efforts will be needed. The MEPDG will need inputs of soil and aggregate resilient modulus values, dynamic modulus and volumetric properties of asphalt mixtures, and climatic conditions. These properties may be determined for each state or on a regional basis.

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