May 2022

Superpave Regional Center, Southeastern Region

Pooled Funds SPR-0002(064) - TPF-5(228)
ALDOT Project Number: 930-763P

National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

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ACKNOWLEDGMENTS

This project was sponsored by Department of Transportation (DOT) agencies across the country, with the Alabama Department of Transportation (ALDOT) being the lead state that provided administrative oversight.

1 INTRODUCTION

The Southeast Superpave Center (SESC) was established in the mid-1990s among other regional Superpave Centers to support states in implementing the Superpave mix design method. The SESC was supported through two pooled fund projects. Both pooled fund projects were supported by the Departments of Transportation (DOT) in the southeast and some across the country. The Alabama Department of Transportation (ALDOT) was the lead state providing administrative oversight for both pooled fund projects.

The first pooled fund project, SPR-3(040) (i.e., TPF-5(037)), was active from 1998 through 2010. In the first pooled fund project, the SESC helped create a partnership between agencies, academia, and the regional asphalt user-producer group to conduct research, training, and technology transfer needed to implement Superpave technology smoothly. To continue the efforts in training, implementable research, and technology transfer, the support for SESC continued through the second pooled fund, SPR-2(064) (i.e., TPF-5(228)), from 2010 through 2022.

This report documents the second pooled fund project's training, research, and technology transfer activities. Eleven states and Puerto Rico contributed more than $3.4 million to the second pooled-fund project.

2 PROJECT OBJECTIVES

Several objectives were proposed for SESC in the second pooled fund study; however, not all of them were pursued during the project as the funds were primarily used, as directed by the participating agencies, to provide training, verify the ruggedness of equipment, provide materials research, and aid in keeping agency personnel abreast of changes in asphalt technology.

- Conducted training regarding Superpave binders, mix design, and performance testing and provided training on particular topics as requested by participating agencies.
- Performed cooperative and agency-specific research sponsored by members of the pooled fund.
- Performed precision and bias testing for asphalt-related performance test equipment.
- Conducted noise studies to develop quieter pavements.
- Performed forensic evaluations on materials or projects that have experienced premature distress.
- Prepared and gave presentations and reports of research activities at local, state, and national meetings when invited.
- Prepared research articles of regional and national interest.
- Supported agency personnel who attend regional and national meetings for technology transfer or participation in special committees or task force groups.
- Worked closely with the Southeastern Asphalt User/Producer Group to promote technology transfer from research to implementation.

3 TRAINING

Several participating state agencies used the funds they contributed to the SESC pooled fund for training to keep their agency personnel abreast of changes in asphalt technology. This section provides a summary of the training activities conducted for these agencies.

3.1 Puerto Rico DTOP Training

The Puerto Rico transportation department has utilized the SESC to support their training, testing, technical assistance, and research. The program started with pilot training in 2010. Table 1 shows the number of participants in the DTOP training program. Since 2013, over 1,100 individuals have participated in the certification courses. The courses meet the Federal Highway Administration requirements to train and certify technicians and inspection staff. The course attendees include Puerto Rico DTOP employees, consulting engineers, and contractor staff. There have been eight different certification courses offered over the years.

Table 1: Participants in DTOP Training Program Since 2013

Course	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Asphalt 1	23	105		7		26	15	10	9		195
Asphalt 2	17	33				10					60
PG Binder	13										13
Aggregate	14	54	73	44		16					201
Mix Design	13	15						9			37
Earthwork			23		18	41	78	37	23	16	236
Earthwork Lab							11				11
Roadway					37	137	108		23	67	372
Total	80	207	96	51	55	230	212	56	55	83	1125

3.2 Colorado Training

In the summer of 2021, the Colorado DOT held a virtual version of the NCAT Asphalt Engineers Workshop. This course spanned three weeks with several sessions a week. Each session was 3 hours or less. The training course covered the design, production, construction, testing, and rehabilitation of asphalt pavement to get their staff a rounded knowledge of asphalt pavements. Twenty-two individuals from varying backgrounds and experiences participated in this course.

In December 2021, the Colorado DOT and the Colorado Asphalt Paving Association hosted a joint Balanced Mix Design workshop to provide customized training for contracting staff and agency personnel. The workshop was in-person and based on the tests selected by the DOT and written into their draft specification. Two NCAT research engineers provided the training, including sample preparation and lab testing demonstrations.

3.3 North Dakota DOT Training

The North Dakota DOT planned to host the Asphalt Engineers Workshop in person in the spring of 2020. Because of the travel and in-person restrictions during the COVID pandemic, the course was held virtually in December of 2020. The training course covered the design, production, construction, testing, and rehabilitation of asphalt pavement to get their staff a rounded knowledge of asphalt pavements. Thirty-two North Dakota DOT staff members of varying experience and duties attended the course.

Because North Dakota DOT was so pleased with the outcome of their Asphalt Engineers Workshop, they chose to host a customized Advanced Mix Design course in December of 2021. They chose this course to be in-person in Bismarck, ND. The training course included discussions on using RAP, Superpave 5, and balanced mix design. Twenty-five technicians and engineers completed the course.

3.4 North Carolina DOT Training

In January 2022, the North Carolina DOT held a virtual version of the NCAT Asphalt Engineers Workshop. This 3-week course was attended by DOT staff with a wide range of experience and job duties. The training course covered the design, production, construction, testing, and rehabilitation of asphalt pavement to get their staff a rounded knowledge of asphalt pavements. Sixteen engineers and technicians attended the course.

4 RESEARCH

Several research projects were sponsored individually by a state DOT or collectively by a group of state DOTs. This section summarizes key findings. More information can be found in individual reports or papers cited in this section.

4.1 Evaluation of Recycling Agents

To improve the cracking resistance of asphalt mixtures with high recycled asphalt pavement (RAP) and reclaimed asphalt shingles (RAS) contents, one approach is to use a recycling agent (RA) (i.e., rejuvenator) to restore the performance properties of the aged binder potentially. This project was conducted to evaluate the effect of recycling agents on the laboratory test results and field performance of mixes with high recycled contents. The field study consisted of three mixtures: a control mix containing 20% RAP without RA and two experimental mixes with different rejuvenators containing 25% RAP and 5% RAS. The control mix was produced at a typical hot-mix asphalt (HMA) production temperature [149°C (300°F)], while the experimental mixes were produced as warm-mix asphalt (WMA) [129°C (265°F)]. Two rejuvenators were used in the study.

Compared to the control mix, both the experimental mixtures with 25% RAP plus 5% RAS showed similar rutting resistance but significantly lower resistance to cracking based on lab test results and early field performance data (approximately two years). The lab test results, especially for the overlay test (OT) and Illinois flexibility index test (I-FIT), agree with the field cracking performance of these mixes- the experimental mixtures with OT cycles below 125 and flexibility indexes below three cracked within two years in the field. Thus, further research can be conducted to refine these criteria for use in a mix design and quality control (QC)/quality assurance (QA) to avoid premature mixture cracking in the future.

This study was sponsored by ALDOT. More information about the construction of the test sections, laboratory test results, and early field performance (approximately two years) are documented in a published paper (Xie et al., 2017).

4.2 Open-Graded Friction Course Mix Design Verification

A modified open-graded friction course (OGFC) design method was recently used to design an OGFC mixture containing sandstone and slag that was placed on the NCAT Test Track in 2021 for a study sponsored by the Alabama Department of Transportation (ALDOT). To determine the impact this new design method will have on other more traditional aggregate types used in Alabama (beyond sandstone and slag), a limited-scope study was conducted by designing an OGFC mixture using granite aggregate. The study's objective was to provide a measure of assurance that the modified OGFC design procedure can be utilized with more conventional aggregate types.

Three Nova Scotia aggregate materials (#67 Stone, #7 Stone, and Screenings) produced by Martin Marietta Materials were sampled and tested. The aggregate was then blended with asphalt binder, compacted, and tested using the new mix design methodology. Aggregate tests included gradation, bulk specific gravity, unit weight, and voids in the coarse aggregate. Mixture tests included bulk and maximum specific gravity, Cantabro loss (after conditioning at 275°F for 4 hours), draindown, and moisture susceptibility. The Cantabro test results are summarized in Table 2.

Table 2: Cantabro Test Results

Binder Content (%)	Aging Time (hrs)	Aging Temperature (°F)	G_{mb}	G_{mm}	V_a	Cantabro Loss (%)
6.0	4	275	2.015	2.518	20.0	35.9
6.5	4	275	2.031	2.499	18.7	21.2
7.0	4	275	2.055	2.480	17.1	15.8

The optimum binder content was selected as the highest one that met the following criteria: (1) air voids of 15 - 20%, and (2) a maximum Cantabro loss of 20%. The optimum binder content selected was 7.0%. Draindown tests were then conducted on unconditioned samples at that binder content at two temperatures (325 and 350°F). Draindown values of 0.03% and 0.02% were determined, respectively, which met the maximum threshold of 0.3%. Moisture susceptibility tests were also performed, meeting the criteria for a minimum tensile strength ratio (TSR) of 0.70 and a minimum conditioned tensile strength of 50 psi.

This project demonstrated that the modified OGFC design methodology is practical for conventional Alabama aggregates and could successfully increase the optimum binder content in OGFC mixtures. These changes should improve the long-term performance of OGFC mixtures. Using the modified design methodology in this study resulted in an increased binder content of approximately 1.0% over that determined using the ALDOT conventional design methodology.

It is recommended that ALDOT consider modifying their OGFC design procedure based on the design procedure used in this study and the mix design used for the test section on the NCAT Test Track. Field test sections can be placed with mixtures designed with the modified design procedure to ensure that the increased binder content will not result in draindown or bleeding during construction. The continued use of stabilizing fibers or other additives is essential to helping prevent draindown. In addition, ALDOT may want to consider requiring a minimum percentage of liquid anti-stripping additives in their OGFC mixtures.

4.3 Preservation Implementation Assistance

The objective of this study was to assist ALDOT with implementing pavement preservation through a review of current practices and training. In this study, NCAT analyzed and reviewed pavement management data collected by the Southeast Alabama region from 2014 to 2018 to check for any systematic errors and inconsistencies in values and trends to determine if any corrections were necessary for the data collection and analysis processes.

Based on the information available and meetings with DOT personnel, NCAT proposed a process to identify appropriate pavement preservation candidates and develop a 2-year program for the Southeast Region. In addition, NCAT developed a 1.5-day workshop intended for District staff involved in the decision-making process to help them understand pavement distresses and pavement performance, how to assign treatments based on existing conditions, and how to implement the process developed by NCAT. Attendees performed hands-on exercises using their district data.

In summary, the ALDOT Southeast Region has appropriate data to make informed decisions. No changes to the data collection procedure are needed at this time. The current information may be used as proposed to develop a consistent pavement preservation program.

The approach is recommended to be extended to other ALDOT regions and local agencies in Alabama. Currently, the Southeast Region exhibits the highest level of maturity regarding its pavement preservation program. Identifying "champions" within the other regions can facilitate the implementation of successful pavement preservation programs. In addition, developing a mechanism to recognize those Districts that achieve outstanding performance in implementing their programs may be used as a strategy to motivate the implementation of a pavement preservation program.

4.4 Pavement Instrumentation on SH 144 in Colorado

The objective of this project was to support the Colorado DOT's effort with pavement instrumentation and data collection/processing scheme for gathering and interpreting mechanistic pavement responses (Leiva et al., 2019). To accomplish this objective, NCAT prepared an experimental plan to compare the measured field stresses and strains to those predicted by PMED, to determine the local calibration factors to include in the fatigue transfer function used in hot mix asphalt pavement in Colorado and to develop a synthesis of past research studies completed on this topic.

The research team formulated a customized instrumentation plan suited to the project location on SH 144. Geometric considerations (i.e., right-of-way), power supply options, and pavement cross-section were considered when formulating the plan. The instrumentation scheme provided tensile strain measurements at the bottom of the asphalt layer and vertical pressure readings at the top of each non-asphalt concrete layer. Temperature and moisture probes were installed to monitor in situ environmental conditions. Data acquisition enclosure and weather station were also included at the SH 144 test site.

Data were collected and processed by the University of Colorado personnel using a companion software application designed for this project, with NCAT personnel conducting quality control and analyses. Pavement responses were evaluated for redundancy, repeatability, and tendency. Two asphalt strain gauges failed after the construction of the asphalt layer; however, there were enough sensors left to capture strain responses at the selected locations. A good to excellent match was obtained for all the redundant sensors.

Differences in the results were attributed to differences in layer thickness, layer density, sudden changes in travel patterns and speed, and differences in layer moduli. Based on the results of this study, it is recommended that CDOT use these factors with caution understanding their limitations and applicability. Therefore, these factors should be used only for Level 3 design and analysis. Tensile strain values collected in this project did not exceed a strain level of 300 microstrains, even during August 2019. Therefore, applications of these factors may not apply for greater strain levels. Since the objective of this research project was partially met, the construction and instrumentation of more flexible pavements representative of additional traffic, weather conditions, and materials of Colorado is recommended. Using equipment to capture traffic loads is critical for pavement modeling and response estimation. Laboratory materials testing should also be conducted according to the PMED requirements for Level 1 analysis.

4.5 Evaluation of Strain Responses related to Typical Pavement Cracks in Mississippi

The primary overall objective of this two-phase project is to validate strain responses at shallower depths on a typical stabilized foundation asphalt pavement in Mississippi. This Phase I research proposal aims to acquire and validate instrumentation equipment for a full-scale instrumented section and conduct preliminary materials testing before construction. The research plan included selecting a stabilized foundation asphalt pavement in Mississippi, acquiring customized instrumentation equipment, and initial instrument preparation. Additionally, the subcontractor conducted preliminary testing of stabilized subgrade/base materials and reported directly to the sponsor.

Results of this Phase I study provided MDOT with (1) equipment required for instrumenting a test section; (2) Sensors and equipment that have been locally calibrated before Phase II work; (3) installation of Moisture sensors in the subgrade; (4) preliminary materials characterization of the stabilized layers before construction; and (5) a detailed proposal and experimental plan for Phase II.

4.6 Testing and Evaluation of Puerto Rico GTR Modified Asphalt Pilot Projects

The objective of this study was to evaluate laboratory and field performance through the GTR asphalt test sections on two pilot projects on PR-10 and PR-184 (Leiva et al., 2020). One GTR mixture was placed in the PR-10 pilot project, and two mixtures, including a control Marshall mixture and a GTR mixture, were placed in the PR-184 project.

Test results included representative pavement condition surveys in August 2019. Other on-site testing included surface dynamic friction measurements with the Dynamic Friction Tester, surface texture measurements with the Circular Texture Meter, and noise testing by the On-Board Sound Intensity method.

Cores were also taken from the PR-10 and PR-184 pavement sections by the Puerto Rico Highway and Transportation Authority (PRHTA) and evaluated by NCAT after the mixtures had been in place for approximately 10 and 6 years, respectively. Laboratory testing of field cores included the Hamburg wheel tracking test for rutting potential and moisture susceptibility, Tensile Strength Ratio for moisture susceptibility, Flexibility Index test for fatigue cracking potential, and dynamic modulus (mechanical properties – stiffness), permeability, asphalt binder content, and gradation.

Low severity weathering was observed on both PR-184 pavements. However, localized potholes on the Marshall sections showed higher susceptibility to moisture damage. Higher mean depth texture and higher friction coefficients were measured on the PR-184 GTR mixture compared to the Marshall mixture. The PR-10 pavement exhibited the highest texture, but at the same time, it is the oldest. OBSI noise testing showed no difference in noise level between the GTR and conventional (Marshall) sections. Therefore, the presence of GTR did not significantly benefit noise reduction.

All three mixtures met the HWTT rutting criteria of 20,000 passes before reaching 0.5 inches (12.5 mm) rut depth. All three mixtures complied with at least 10,000 passes for the stripping inflection point. All roadway cores were considered impermeable based on the commonly accepted threshold of 125×10^{-5} cm/s. Both GTR mixtures showed significantly higher fracture indices (according to the IFIT test) than the Marshall mixture (better cracking performance). All samples showed finer gradations compared to JMF gradations. However, similar or slightly lower asphalt contents were measured, most likely due to the aging of the binder and stripping. Significantly higher air voids were obtained on GTR cores relative to Marshall cores. These results played a significant role in the conditioning of the samples according to AASHTO T283.

In summary, GTR-modified asphalt mixtures performed comparably or better than a conventional dense-graded mixture in Puerto Rico. This also means that using GTR in asphalt mixes would represent a significant environmental benefit to Puerto Rico and avoid the possibility of having to export waste tires.

4.7 Evaluation of IDEAL-CT Testing Equipment

The IDEAL-CT has become a popular cracking test in the asphalt industry. Many sources of variability in the IDEAL-CT testing results have been studied, but a comprehensive assessment of the testing equipment remained lacking. In this study, NCAT evaluated six different IDEAL-CT testing devices to assess if they complied with the equipment specification in ASTM D8225-19, *Standard Test Method for Determination of Cracking Tolerance Index of Asphalt Mixture Using the Indirect Tensile Cracking Test at Intermediate Temperature*, and to see how the results from different devices compared with each other. A total of 328 tests were conducted from seven unique asphalt mixes. Each specimen was prepared with meticulous attention to detail to minimize the variability from specimen preparation, thus magnifying the variability from the devices themselves. The Two One-Sided Tests (TOST) equivalence test was conducted to determine whether the devices could be considered equivalent. The TOST compares testing processes (i.e., testing devices) that possess measurable variability and account for this variability during the comparison.

Only two of the six devices operated within the required deformation rate of 50 ± 2.0 mm/min. However, all the rates measured with an external measurement device were within a 2.0 mm/min tolerance of 51 mm/min. The differences in the devices' deformation rates did not affect the test results. All devices, except one, showed statistically similar test results. In this case, the specific manufacturer discovered an issue with their device and made appropriate changes to resolve the issue.

The TOST procedure is an excellent method to determine testing device equivalence. A step-by-step guide can be found in ASTM E2935-20e1, *Standard Practice for Conducting Equivalence Tests for Comparing Testing Processes*.

As a result of this work, all device manufacturers made changes to their equipment to either comply with the specification or make their products more user-friendly. These changes have since been updated in the devices currently in use in the industry.

4.8 Evaluation of Locked-Wheel Skid Trailer and SCRIM Friction Measurements

The objective of this study was to evaluate the repeatability of locked-wheel skid trailer (LWST) and sideway-force coefficient routine investigation machine (SCRIM) measurements for asphalt pavements and investigate the influences of test speed and test temperature on the friction measurements. This study selected 14 test sections from the NCAT Test Track, which had different surface textures and friction characteristics. The LWST and SCRIM tests were conducted at different speeds (i.e., 30, 40, and 50 mph) and other test times (or temperatures) on two consecutive days. The repeatability analysis indicates that LWST skid number (SN) and SCRIM reading (SR) measurements were most repeatable at a test speed of 50 mph and tangent section. The SN measured in the late afternoon and SR measured at noon were more repeatable than those measured at other times. This study recommended that an acceptable precision of friction measurement be within 2.5 SN units or 3 SR units. In addition, this study concluded that the SN and SR had a good linear correlation, particularly in the tangent sections. The statistical regression analysis demonstrates that test speed, air temperature, mean profile depth of pavement surface, and pavement type were significant variables affecting asphalt pavement friction. This study confirmed that increasing test speed or temperature reduced the measured SN or SR values. The developed regression models for SN and SR helped correct the friction measurements at any given speed or temperature to a reference speed or temperature.

4.9 Refinement, Optimization, and Guidelines for 4.75 mm Asphalt Mixes in Georgia

This study compared the resistance of 4.75 mm mixtures to rutting, stripping, and cracking to that of a typical 9.5 mm Type 2 surface course with PG 67-22 asphalt binder (Watson, 2014). The Hamburg wheel tracking test (AASHTO T 324) was conducted to evaluate resistance to rutting and moisture susceptibility. The overlay test (OT) was performed to evaluate resistance to cracking using the Asphalt Mixture Performance Tester (AMPT) equipped with a special test jig. Testing for the 4.75 mm mix was performed with four aggregate sources, two each from North and South Georgia, and three asphalt binders (PG 64-22, PG 67-22, and modified asphalt binder). The PG 76-22 binder used for testing with North Georgia aggregates was polymer-modified at the terminal, while the PG 76-22 binder used for South Georgia aggregates was modified with crumb rubber incorporated into the mix via a dry process.

Based on the Hamburg test results (**Figure *1***) conducted at 50°C, the 4.75-mm mix showed better resistance to rutting and stripping than the 9.5 mm control mix. The 4.75 mm mixes rutted less than 0.5 inches (12.5 mm) after 20,000 passes, while the 9.5 mm control mix failed to meet the same criteria.

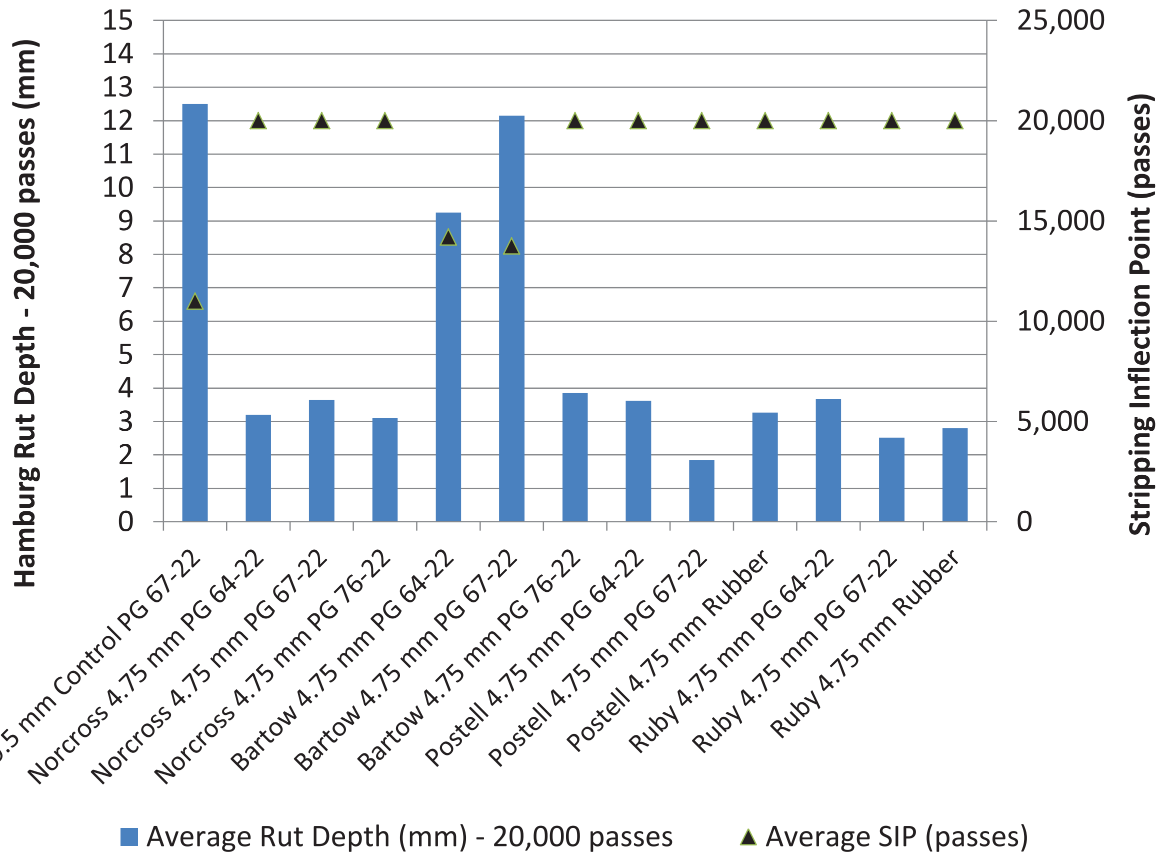

Figure 1: Hamburg Results (Control Mix Reached 12.5 mm Rut Depth after 14,963 Passes)

The OT was conducted at 25°C in controlled displacement mode with samples prepared at 7.0 ± 1.0 percent air voids. Results from the OT were inconclusive, except that the polymer-modified mixes were more resistant to cracking than the mixes with crumb rubber modifiers.

In summary, differences in mixture performance are sensitive to compatibility between the asphalt binder/modifier and aggregate source. The 4.75 mm mixes used in this study generally provided similar, if not better, results than the control 9.5 mm mix. In addition, the crumb rubber mixtures were comparable to polymer-modified mixes in rutting resistance, but the polymer mixes were more resistant to cracking. Finally, the polymer-modified binder significantly improved the rutting resistance of the mixture using Bartow aggregate.

Based on the excellent rutting resistance of the 4.75 mm mix compared to the 9.5 mm mix, it is recommended that the 4.75 mm mix with either PG 67-22 or PG 64-22 be considered for the surface course on projects with less than 4,000 ADT. The placement rate should be 90- 110 lbs/sy.

4.10 Investigation of Raveling in South Carolina OGFC Asphalt Mixtures

This proposed research examined OGFC mix performance from four aggregate sources that have yielded less than satisfactory performance and compared performance with an aggregate source that has provided excellent results for resistance to raveling (Watson et al., 2015). The research included a petrographic analysis of aggregate from each source, determination of the amount of aggregate breakdown in a gyratory compactor, determination of the percent wear (or stone loss) in the Cantabro test procedure, and evaluation of stripping susceptibility after a freeze-thaw cycle.

A Nikon Eclipse E400 petrographic trinocular microscope with the plane and polarized light capabilities equipped with a Canon G5 digital camera and a mechanical stage was used to conduct the petrographic analysis. Thin sections of aggregate grain mounts were placed on a 2-inch by 3-inch microscope slide and analyzed for mica content. Mica included biotite, muscovite, chlorite, and chloritoid for this study. The Vulcan quarry at Blacksburg, SC, was the only source with a relatively high total mica content (exceeding 10%). Several individual particles contained proportions of mica that averaged as high as 62.9 percent.

The aggregate abrasion loss ranged from 21 to 31 percent and met the maximum of 52 percent loss specified by SCDOT. Blended dry aggregate samples were put into a gyratory mold and subjected to 50 gyrations. The amount of breakdown was determined by comparing the gradation before and after gyration. Surprisingly, the Vulcan at Columbia, SC source (used for control in this research) had the highest aggregate breakdown.

All samples failed to meet a maximum stone loss of 20 percent at the optimum asphalt content of 6.0 percent approved by SCDOT. Increasing the asphalt content to 7.0 percent is needed to meet Cantabro requirements. Results in Figure 2 show that the Cantabro test is sensitive to changes in asphalt content and that air voids were barely affected.

Tensile strength testing showed that hydrated lime could be added in dry or slurry form with comparable results. All samples failed to meet the minimum required tensile strength of 65 psi for conditioned and unconditioned samples.

In summary, the Vulcan at Columbia, SC source used as the control mix had the most aggregate breakdown. Aggregate from Vulcan at Blacksburg, SC, had the highest total mica content, with individual particles as high as 62.9 percent. All samples failed to meet a maximum Cantabro loss of 20 percent at the optimum binder content of 6.0 percent. In addition, the conditioned tensile strength of all mixes was unable to meet the required minimum of 65 psi.

It is recommended that the asphalt content of OGFC mixtures should be increased to meet a maximum Cantabro loss of 20 percent. In addition. Mixture adjustments, such as increasing binder content should be made to meet the minimum tensile strength requirements.

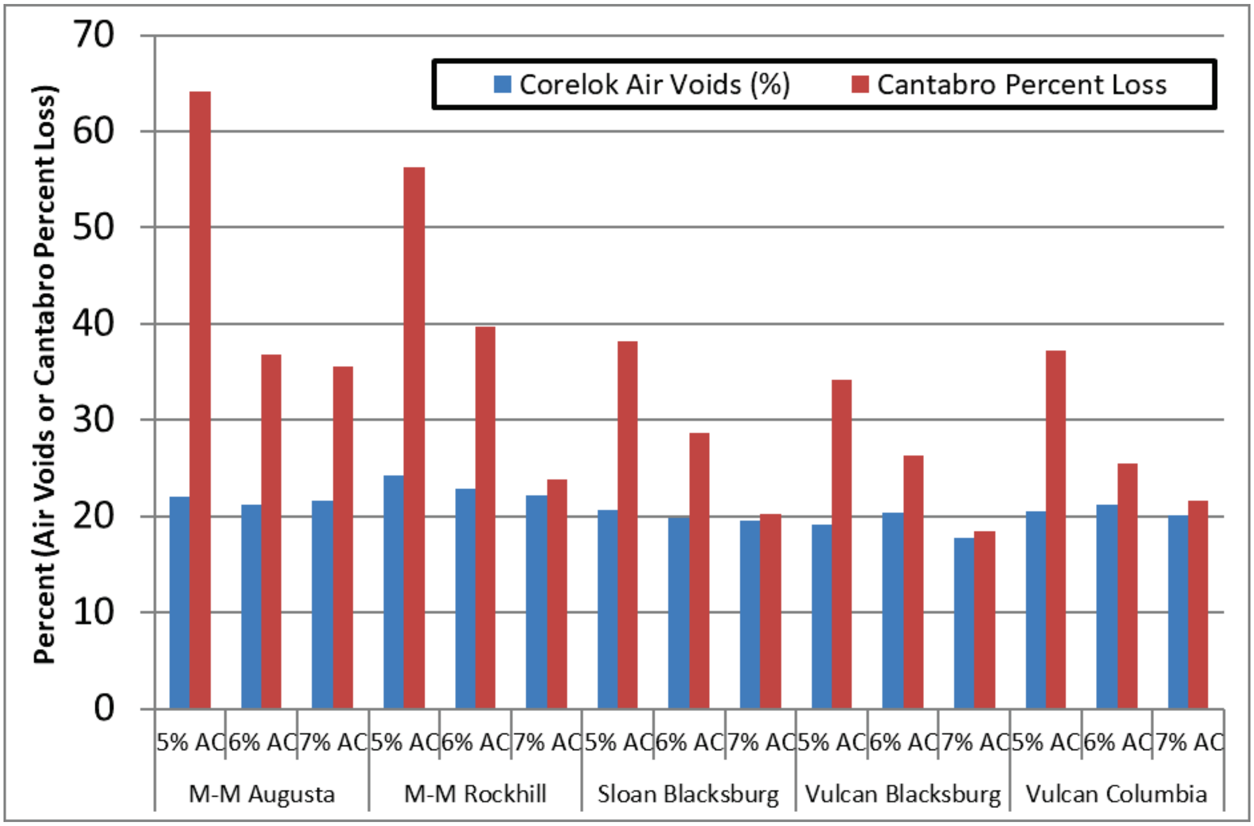

Figure 2: Effect of Percent AC on Cantabro Stone Loss and Air Voids

4.11 Effect of Flat and Elongated Aggregate on Stone Matrix Asphalt Performance

The objective of this study was to evaluate the performance of Stone Matrix Asphalt (SMA) mixes with varying proportions of flat and elongated aggregate particles (Watson et al., 2017). The experiment included (a) three aggregate sources adjusted to meet and fail the SMA aggregate requirements and (b) two aggregate sources that failed the SMA aggregate requirements. Mixtures were tested for Cantabro loss (AASHTO TP 108-14), rutting resistance, and moisture susceptibility.

A comparison of aggregate degradation was made by placing combined aggregate proportions into a gyratory mold and gyrating for 100 gyrations. The gradation before and after compaction was used to determine the effect of flat and elongated (F&E) aggregate on aggregate breakdown.

GDT 129 test procedure was used to determine F&E particles. It is similar to ASTM D4791 Method B, except that the length of the particle is compared to the average thickness. Values ranged from 0.0 to 6.5 percent F&E when tested at the conventional 5:1 ratio. When tested at the 3:1 ratio required for SMA aggregate, values ranged from 15.5 to 43.6 percent.

The Asphalt Pavement Analyzer (APA) was used to test for rutting resistance using the GDT 115 test procedure with a target of 5.0 ± 1.0 percent air voids. The GDT 66 test procedure determines moisture susceptibility.

An Analysis of Variance (ANOVA) showed no significant difference between SMA and non-SMA aggregate breakdown at a 95 percent confidence level. However, it was found that sources with high F&E properties also had a lower abrasion loss. A two-sample t-test indicated no significant difference in Cantabro performance between SMA and non-SMA aggregate mixes.

All APA test results were less than the 5 mm maximum rut depth allowed. The results indicated no correlation between rut depth and F&E properties. Results shown in Table 3 suggested that the tensile strength of SMA mixes was not adversely affected by aggregate F&E values.

Table 3: Tensile Strength Results

Aggregate Source	Agg. A SMA	Agg. A Non-SMA	Agg. B SMA	Agg. B Non-SMA	Agg. C SMA	Agg. C Non-SMA	Agg. D Non-SMA	Agg. E Non-SMA
TS-Conditioned (psi)	88.3	89.9	78.3	92.6	85.1	84.7	76.4	77.1
TS-Control (psi)	79.4	104.8	72.5	93.7	78.8	77.6	85.2	86.4
TSR, % (≤ 80)	111.3	85.8	108.0	98.8	108.0	109.1	89.6	89.3

In summary, there was no significant difference in Cantabro loss between SMA and non-SMA aggregate sources. There was no correlation between rut depth and F&E properties. The tensile strength of SMA mixes is not adversely affected by aggregate F&E properties.

Based on the results, the maximum F&E limit of 20 percent at a 3:1 ratio should be reconsidered based on satisfactory performance results in this study. Superpave aggregate criteria specified in AASHTO M323 may also be suitable for SMA mixes.

This study used laboratory mixed, and laboratory compacted samples. Results should be validated with plant-produced, field compacted specimens. This study's aggregate sources with high F&E also had low L.A. abrasion loss. Similar research is needed for aggregate sources with high F&E and abrasion loss.

5 SUMMARY

This report documents the training, research, and technology transfer activities for the SESC pooled fund, SPR-2(064) (i.e., TPF-5(228)), from 2010 through 2022. Eleven states and Puerto Rico contributed more than $3.4 million to the second pooled-fund project.

Several participating state agencies, such as Puerto Rico DTOP, Colorado DOT, North Dakota DOT, and North Carolina DOT, used the funds they contributed to the SESC pooled fund for training to keep their agency personnel abreast of changes in asphalt technology.

In addition, several research projects were sponsored individually by a state DOT or collectively by a group of state DOTs. The key findings of these studies are discussed in this report with the more detailed information provided in individual reports or papers.

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