FDOT Contract Number: BEC97

# A Review of Protocols Used for Evaluating Defective Asphalt Materials and Pavements

Final Report-Deliverable 5

July 2024

## DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Florida Department of Transportation.

**SI* (MODERN METRIC) CONVERSION FACTORS**
**APPROXIMATE CONVERSIONS TO SI UNITS**

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or “t”) |
| | | **TEMPERATURE** | | |
| ºF | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | ºC |
| | | **FORCE, PRESSURE** | | |
| lbf | Pound force | 4.45 | newtons | N |
| $lbf/in^2$ | Pound force per square inch | 6.89 | kilopascals | kPa |

NOTE: volumes greater than 1000 L shall be shown in $m^3$

**APPROXIMATE CONVERSIONS FROM SI UNITS**

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE** | | |
| ºC | Celsius | 1.8C+32 | Fahrenheit | ºF |
| | | **FORCE, PRESSURE** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | $lbf/in^2$ |

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

(Source: FHWA)

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<tr><td colspan="4">16. Abstract<br>The Florida Department of Transportation (FDOT) construction specifications include procedures to deal with unacceptable materials that do not meet the specification requirements. When the materials are considered "defective," the engineer can reject those materials, whether in place or not. The contractor is then directed to remove and replace all rejected materials, or if approved by the engineer, an engineering analysis can be conducted on the in-place material to determine if the material should be removed or remain in place. This project examines the adequacy of current FDOT practices to evaluate defective materials and whether additional test procedures can improve current practices. The evaluation included the review and analysis of in-place pavement sections where defective materials were left in place and a laboratory evaluation to assess the performance of dense-graded mixes and FC-5 mixes produced in the laboratory to simulate different production and construction scenarios. The evaluation of the in-place pavement sections for specific mix and failure type combinations suggested that leaving the defective materials in place did not result in post-construction pavement failures. The laboratory evaluation showed that for dense-graded mixes, the APA and HT-IDT tests were able to discriminate mixes among the different production construction scenarios and that both tests have a fair correlation. For FC-5 mixes, the Cantabro test was also able to discriminate mixes among different production scenarios. The laboratory results suggest that the APA, HT-IDT, and Cantabro tests could be used to improve current FDOT practices in evaluating defective materials.</td></tr>
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## EXECUTIVE SUMMARY

The Florida Department of Transportation (FDOT) construction specifications include an unacceptable materials clause that states that any materials that do not meet the specification requirements will be considered "defective" and that the engineer will reject those materials. The contractor is then directed to remove and replace all rejected materials at no expense to the FDOT. As an alternative to removing and replacing the defective material, if approved by the engineer, an engineering analysis can be conducted on the in-place material to determine if the material should be removed or remain in place.

Asphalt materials may be defective if they do not meet specific requirements during production and placement, such as low composite pay factors for a lot or not meeting the master production ranges (MPRs) specified in Sections 334 and 337. For dense-graded mixtures, the MPR requirements include lab compacted air voids, in-place density, asphalt binder content, and percent passing the No. 200 sieve. For open-graded mixtures, the MPR requirements include asphalt binder content, percent passing the 3/8-inch sieve, percent passing the No. 4 sieve, and percent passing the No. 8 sieve.

This project evaluates if current FDOT practices to evaluate defective materials are adequate and if additional test procedures can be used to improve current practices. The evaluation included the review and analysis of in-place pavement sections where defective materials were left in place and a laboratory evaluation to assess the performance of dense-graded mixes and FC-5 mixes produced in the laboratory to simulate different production and construction scenarios.

The major findings and conclusions of the project are summarized below:

- To assess the adequacy of current FDOT practices for evaluating defective materials, project records for pavement sections with defective materials that were left in place were selected, reviewed, and analyzed in conjunction with pavement condition survey results of the projects. It should be noted the defective areas, as determined by production test results, had been evaluated via an Engineering Analysis Report or delineation and were determined to be acceptable to remain in place without milling and resurfacing the "defective" areas. The analysis focused on projects with three mix and failure type combinations.
    - For dense-graded mixes with low air voids, the QC failures corresponded to air voids < 2.3%. No defective material exceeded an average rutting of 0.2 in. For 7 out of 19 comparisons, the average rutting of the defective materials was higher than that of the non-defective but still relatively low, indicating no significant concern for rutting for any of the projects.
    - For FC-5 mixes with low binder content, the QC failures corresponded to low binder content (AC = target − 0.6%.) Raveling was not a concern for any of the projects. In addition, the average percentage of cracking for all the projects did not exceed 8.0%, and the performance of defective and non-defective materials was comparable. Finally, the average IRI results for the defective materials were higher than the ones for non-defective materials, but the IRI average results for all the projects did not exceed 77 in/mi.
    - For FC-5 mixes with high binder content, the QC failures corresponded to high binder content (AC = target + 0.6%). All the projects used a PG 76-22 binder or higher. No project exceeded an average rutting of 0.25 in. For 3 out of 7

comparisons, the average rutting results of the defective material were higher than the ones for non-defective material but still relatively low. Based on these results and considering that these projects have been in place for 9−12 years and that all used, at a minimum, a PG 76-22 binder, the rutting performance of these projects is adequate.

- For the three mixture/failure type combinations evaluated, it can be concluded that an acceptable decision was made when the defective materials were left in place.
- A laboratory evaluation that included five existing dense-graded mix designs was conducted to assess the impact of different scenarios for low lab-compacted air voids (<2.3%) and varying in-place density levels on mixture rutting potential using the APA and the HT-IDT tests. The four production and construction scenarios included (1) good production and good density (original blend), (2) poor production with high density, (3) poor production with good density, and (4) poor production with low density (worst case scenario).
    - APA results are summarized as follows:
        - For each of the five mixes, the mix with poor production (high-dust/high-AC) and poor density (9% to 10% air voids) had the highest rutting, which was expected because this condition represented the worst-case scenario.
        - The original blend or the poor production with good density yielded the lowest rutting results. This is rational because poorly produced mixes may have improved rutting resistance with better density in the field. The only exception was the Camak 40% RAP mix with the softer PG 52-28 binder.
        - APA test results for each data set were compared to the FDOT defective material threshold of 5.0 mm used on field cores. Three of the five mixes failed the APA criterion for the poor production with low density scenario, two failed the criterion for the poor production with good density, and one failed the criterion for the good production with good density scenario. Finally, no mix for the poor production with high density scenario failed the APA criterion.
    - HT-IDT results are summarized as follows:
        - HT-IDT test results showed a similar trend to the APA results regarding the poor production (high-dust/high-AC) mix performance at different in-place densities relative to the original mix. For each of the five mixes, the mix with poor production and poor density had the lowest ITS results. The poor production with high density yielded the highest ITS for the five mixes, followed by the poor production mix with good density.
        - HT-IDT test results for each data set were compared to the HT-IDT criterion of 20 psi that has been recommended by the Alabama Department of Transportation (ALDOT). Three of the five mixes failed the criterion for the poor production with low density scenarios, and one failed the criterion for the poor production with good density scenario. All the mixes with poor production and high density and good production and good density met the HT-IDT criterion.

- The HT-IDT and APA results showed a strong correlation with an $R^2$ at or above 0.9 when the results by mix type were compared. The correlation was still reasonable ($R^2$=0.69) but more scattered when all the data points were included. This suggests that the HT-IDT test has the potential to be considered in lieu of the APA test, but further research is needed to support these results and refine the current threshold recommended by ALDOT.
- A laboratory evaluation that included three FC-5 mixtures was conducted to evaluate different scenarios that included the effect of changes in gradation and asphalt content on their durability and permeability using the Cantabro test on gyratory compacted specimens and the FDOT field permeameter on lab-compacted slab specimens, respectively. The five scenarios included (1) as-designed mixes, (b) high binder content and finer gradation, (3) low binder content and finer gradation, (4) high binder content and coarser gradation, and (5) low binder content and coarser gradation.
  - Cantabro and permeability results are summarized as follows:
    - Two of the three original blends had average Cantabro loss values above 20 percent.
    - The mixes with the low binder content and coarser gradation scenario yielded the highest Cantabro mass loss for the three mixes. These mixes also had the highest air void content among the five scenarios.
    - The mixes with the high binder content and fine gradation scenario yielded the lowest average Cantabro loss for the three mixes. These mixes also had the lowest air void content among the five scenarios. However, two of these mixes had air voids above the recommended minimum value of 15%.
    - Two of the three mixes with the low binder content and fine gradation scenario had average Cantabro results above 20 percent, but the results were lower than the results of their corresponding original blend. Similarly, two of the three mixes with the high binder content and coarser gradation had average Cantabro results above 20 percent, but the results were lower than the results of their corresponding original blend.
    - A strong correlation between air voids and Cantabro loss was found for each of the three FC-5 mixes. For the combinations evaluated in this study, increasing the binder content decreased the air voids and improved Cantabro results. In addition, coarser gradation increased air voids but increased Cantabro mass loss.
  - A strong correlation between air voids and permeability results was found for each of the three FC-5 mixes. In general, increasing binder content decreased permeability results. Moreover, coarser gradation increased permeability but increased Cantabro mass loss.
- Based on the findings of the study, the following recommendations are made:
  - The results of Subtask 1 suggested that for the mix and failure type combinations under evaluation, the FDOT's current analysis procedures for defective materials were adequate and that leaving the materials in place did not result in post-construction pavement failure.

- The results of Subtask 2 conducted with dense-graded mixes indicated that the APA and HT-IDT were able to discriminate among different production and construction scenarios and showed a fair correlation with each other. This suggests that these tests could be used to improve current FDOT practices to evaluate defective pavements for dense-graded mixes. The most critical scenario was the mix with unsatisfactory (high dust and AC) and poor in-place density (9%-10% air voids), followed by the mix with poor production (high dust and AC) and good density (7% air voids). A follow-up evaluation with field performance data not included in this project is recommended for these scenarios.
- The results of Subtask 3 conducted with FC-5 mixes indicated that the Cantabro test was able to discriminate among different production scenarios. This suggests that the Cantabro test could be used to improve current FDOT practices to evaluate defective pavements for FC-5 mixes. The most critical scenario was the mix with low binder content and coarser gradation. For this scenario, a follow-up evaluation with field performance data is also recommended.

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# 1. INTRODUCTION

## 1.1 Problem Statement

The Florida Department of Transportation (FDOT) construction specifications include an unacceptable materials clause that states that any materials that do not meet the specification requirements will be considered "defective" and that the engineer will reject those materials. The contractor is then directed to remove and replace all rejected materials at no expense to the FDOT. As an alternative to removing and replacing the defective material, if approved by the Engineer, an engineering analysis can be conducted on the in-place material to determine if the material should be removed or remain in place. The engineering analysis must be conducted by an independent laboratory (approved by the Engineer), and the engineering analysis report (EAR) must be signed and sealed by a professional engineer licensed in the State of Florida.

Asphalt materials may be found defective if they do not meet specific requirements during production and placement, such as low composite pay factors for a lot or not meeting the Master Production Ranges (MPRs) specified in Sections 334 and 337. For dense-graded mixtures, the MPR requirements include lab compacted air voids, in-place density, asphalt binder content, and percent passing the No. 200 sieve. For open-graded mixtures, the MPR requirements include asphalt binder content, percent passing the 3/8-inch sieve, percent passing the No. 4 sieve, and percent passing the No. 8 sieve.

In situations where materials are found defective, and the contractor elects to have the in-place material evaluated, there are two evaluation methods: delineation and EARs. If the material is defective due to gradation, asphalt binder content, or density, the contractor may perform delineation tests on roadway cores to determine the limits of the defective material. An EAR is typically required for materials that are defective due to air voids.

Evaluations by delineation are fairly straightforward. The contractor cuts cores in locations approved by the engineer, and quality control (QC) personnel test the cores while being monitored by the Engineer. The test results for these cores are compared to the master production range with a pass/fail decision to assess the results.

However, EARs for lab air void failures are more complex. The scope of the engineering analysis is sent to the District Bituminous engineer for review before any coring or testing is conducted. Chapter 3.1 of the FDOT Materials Manual provides guidance on what should be considered in the scope, including where the cores should be located (in or between wheel paths) and what tests should be conducted on the cores (typically binder content, gradation, and volumetrics). Analysis of these data can be challenging, as the results from the roadway cores may often be inconsistent with the plant production results and not lead to an assignable cause. A common recommendation of the engineer doing the analysis is to leave the material in place at the appropriate composite pay factor. In some instances, FDOT requires additional testing for the analysis. For example, the use of the asphalt pavement analyzer (APA) has been used in some instances to test field cores extracted from pavement sections with low air void failures, especially when an assignable cause of the low air voids (e.g., high asphalt binder content, high 200 content, shift in gradation, or significant divergence of $G_{mm}$) is not evident in the test results. While this appears to be a more rational approach for evaluating the in-place material using a performance-related test, there are concerns related to the validity of using the APA test on field cores for this purpose, especially since it was not required for mix design approval.

While the FDOT process for evaluating defective materials seems to be effective, as evidenced by the overall performance of their asphalt pavements, there are a few questions that should be addressed: 1) How effective are the current FDOT methodology and criteria at assessing defective materials, and 2) Are there additional tools or methodologies that can be used to refine FDOT's method for evaluating defective materials?

## 1.2 Research Objectives

This project aims to evaluate the current practices and procedures used by FDOT to evaluate defective asphalt materials that fail to meet the criteria in Sections 334 or 337 of the FDOT Specifications. The practices and procedures for assessing defective material to be evaluated in this project include those outlined in Section 3.1 of the FDOT Materials Manual. In addition, the use of the APA for testing pavements with low air void failures will also be evaluated. To accomplish the objective of this project, the following will be conducted:

- A review and assessment of the long-term performance of 30 in-place pavement sections where defective material was left in place after an assessment of the material. The review and assessment of the performance of these sections will be used to refine the recommendations for the assessment of defective material.
- A laboratory experiment designed to evaluate the Department's current assessment procedures, including the APA for low air voids evaluation and procedures for testing OGFC mixes for durability and adequate air void content when the binder content and/or gradation fails.

## 1.3 Organization of the Report

The report is divided into five chapters. Chapter 1 introduces the challenges associated with current FDOT procedures to evaluate materials that do not meet specific requirements during production and placement and explains the objectives of this study. Chapter 2 presents a literature review that focuses on two general topics: a) production and construction variability effects on volumetric properties and performance of asphalt mixtures, and b) laboratory testing of pavement cores to evaluate the field performance of asphalt mixtures. Chapter 3 presents the results of a survey of state highway agencies that focuses on determining what methodologies are currently in use to assess in-place defective materials. Chapter 4 describes the experimental plan, including assessing records of defective materials left in place and a laboratory testing program for dense-graded and FC-5 mixes. Chapter 4 presents the results of the experimental plan. Lastly, Chapter 5 offers conclusions and recommendations based on the research results.

## 2. LITERATURE REVIEW

The literature review presented focuses on two general topics: a) production and construction variability effect on volumetric properties and performance of asphalt mixtures, and b) laboratory testing of pavement cores to evaluate the field performance of asphalt mixtures. The survey focuses on determining what methodologies are currently in use to assess in-place defective materials.

### 2.1 Factors Affecting Quality of Asphalt Mixtures

While the goal of every paving project is to construct an asphalt pavement that meets all specification requirements, a number of problems can occur, which can increase production and/or construction variability, resulting in defective materials. Some of these problems are briefly discussed below, including asphalt binder issues (e.g., asphalt content), aggregate issues (e.g., gradation), mixture issues (e.g., volumetric properties), and construction issues (e.g., in-place density).

- ***Asphalt Binder Content.*** Binder content is a key factor in the performance of asphalt mixes. Insufficient binder in the mix can lead to high air voids, high permeability, and thin asphalt coatings of the aggregate, which may result in durability problems. On the other hand, better fatigue resistance may be achieved with an increased asphalt binder content. Christensen and Bonaquist (2006) indicated that a 1 percent increase in the effective binder content corresponds to an increase in fatigue life of 13 to 15 percent. In a drum mix plant, the aggregate belt scales and the asphalt meter must be properly calibrated to measure the asphalt content accurately. During production, the weight on the belt must be adjusted for the moisture in the aggregate. In addition, for recycled mixtures, the amount of virgin asphalt binder added to the mix must be adjusted for the amount of binder in the recycled materials. If the equipment malfunctions or if the moisture or recycled binder content varies unexpectedly, the amount of virgin asphalt binder added to the mixture will be incorrect. A change in asphalt content can affect the mix volumetric properties. If the asphalt content is high, the air voids will typically be low, and vice versa. Also, if the theoretical maximum specific gravity ($G_{mm}$) is lower than normal, this is an indication that the asphalt content is higher, and vice versa.
- ***Aggregate Gradation.*** Several steps are necessary to control the aggregate gradation in the asphalt mixture. The first step is to ensure that the gradation of the aggregate received from the aggregate supplier is satisfactory and that the aggregate is not segregated or contaminated with other materials. The material must then be consistently fed by the loader into the correct cold feed bins that proportion the aggregate into the drum. The aggregate feed rates can get out of calibration when equipment is not properly maintained or when the materials change in moisture content, resulting in a change in the rate of feed. In addition, the aggregate will also break down as it flows through the plant, resulting in a higher dust content, thus reducing the amount of air voids in the mixture. It is important to note that while the aggregate gradation can fall outside of the specification requirements due to one or more of the above issues, it can also be caused by sampling problems, resulting in errors in measuring the gradation of the aggregate.
- ***Mixture Volumetrics.*** Several factors can affect the volumetric properties, especially the laboratory-compacted air voids of a compacted mixture. One factor is the compactive effort applied to the mixture, which can be different between gyratory compactors and/or molds.

When the compactive effort is increased, the air voids are likely reduced, and vice versa. Another factor that affects volumetric properties is variations in asphalt absorption for the mixture sample. The time and temperature of mixture conditioning can affect the amount of asphalt absorbed in the aggregate, thus changing the $G_{mm}$ and, to a lesser extent, the $G_{mb}$ results. This effect is more significant for asphalt mixtures produced with highly absorptive aggregates frequently used in Florida. The volumetric properties of a mixture are also affected by the amount of asphalt binder used and the aggregate gradation. Low air voids are typically caused by either a high asphalt content or a decrease in the VMA, which is controlled by the aggregate gradation, particle shape, and/or texture. In most cases, gradation-related decreased in the voids in the mineral aggregate (VMA) are due to excess fines ($P_{200}$). When the acceptance testing plans only require monitoring air voids in the mix, not VMA, the VMA can unknowingly decrease. A common adjustment is reducing the amount of binder added to the mix to restore the specified air voids level. However, the real reason for the lower air voids is the collapse of VMA or insufficient conditioning time for the binder to be absorbed into the aggregate. Simply reducing the binder content may correct low air voids but leaves the mix dry with an insufficient binder to provide durability. In such cases, the best practice is to evaluate sampling and testing procedures to ensure consistent mixture conditioning and then consider other options to restore the VMA.

- ***In-Place Density of Mixture.*** When asphalt mixtures are compacted to an acceptable density level, they will provide good performance for an extended period of time. However, if the pavement density is inadequate, these mixtures will experience premature distress. A number of studies have indicated that asphalt mixtures must be constructed with an initial in-place air void content below 8 percent to minimize permeability, and the terminal air voids should be above 3 percent to ensure resistance to rutting (Brown 1990, Brown and Cross 1989, Huber and Heiman 1987). To obtain adequate compaction, contractors must have sufficient rollers in good condition and experienced operators to apply an appropriate rolling pattern. Achieving the density target can be difficult to obtain when the asphalt mixture is placed too thin or the mixture temperature is inadequate. Conversely, if the temperature is too high, the mixture will tend to shove and move underneath the roller, resulting in check cracking and lack of adequate density. If the mixture is too cold, the mix will be stiff and not workable enough to compact. In addition, when the asphalt content in the mixture is low, it is difficult to obtain adequate density. A sudden difficulty in compaction may indicate an asphalt content problem in the mixture. Too low of an asphalt content could make the mix less workable. Too much asphalt could make the mix too workable (tender).

The following sections present a literature review focusing on two topics: (a) production and construction variability effects on volumetric properties and field performance of asphalt mixtures and (b) laboratory testing of pavement cores to assess the field performance of asphalt mixtures.

### *2.1.1 Effects of Mix Production and Construction Variability Factors in the Volumetric Properties and Field Performance of Asphalt Mixtures*

A comprehensive study was conducted by Mohammed et al. (2016) to quantify sources of variability in volumetric and mechanical properties of three specimen types: design - lab mixed and lab compacted (LL), production - plant mixed and lab compacted (PL), and construction – plant mixed and field compacted (PF) using 11 mixtures from different states across the US. The experiment evaluated the effects of process-based factors, including baghouse fines, sample reheating, aggregate absorption, aggregate degradation, and aggregate stockpile moisture. The researchers reported that the effects of the process-based factors on some of the volumetric properties were only significant between laboratory samples (LL) and plant-produced samples (PL and PF). This observation was expected since both PL and PF samples were prepared from plant-produced mixtures subjected to the same process conditions. Their analysis showed that the process-based factors did not significantly affect the VMA, voids filled with asphalt (VFA), $G_{mm}$, and the bulk specific gravity of the aggregate ($G_{sb}$) of the mixtures evaluated. In addition, the process-based factors did not significantly affect the differences in mechanical properties when comparing the three sample types. Table 1 presents the factors that had a significant effect on some of the volumetric parameters, which are summarized as follows:

- Stockpile moisture significantly affected the difference in air voids between LL and PL samples, which could be attributed to aggregate not drying completely during production or improper estimation of stockpile moisture content.
- Return of the baghouse fines significantly affected the differences in asphalt content when comparing LL samples with PL and PF samples. This finding supports the use of baghouse fines as part of the mix design process when baghouse fines are returned during mix production.
- Return of baghouse fines, aggregate hardness, and stockpile moisture significantly affected the gradation differences when comparing LL samples with PL and PF samples, suggesting that LL samples should account for baghouse dust and aggregate breakdown.

**Table 1. Effect of Process-Based Factors on Volumetric Properties (Mohammad et al., 2016).**

| Property | Comparison | Significant Process |
|---|---|---|
| AV | Design (LL) – Production (PL) | Stockpile Moisture |
| VMA | | None |
| VFA | | None |
| AC | Design (LL) – Production (PL) | Baghouse fine return and aggregate absorption |
| | Design (LL) – Construction (PF) | Baghouse fine return |
| | Production (PL) – Construction (PF) | None |
| $G_{mm}$ | Design (LL) – Production (PL) | None |
| | Design (LL) – Construction (PF) | None |
| | Production (PL) – Construction (PF) | None |
| $G_{sb}$ | Design (LL) – Production (PL) | None |
| | Design (LL) – Construction (PF) | None |
| | Production (PL) – Construction (PF) | None |
| Gradation | Design (LL) – Production (PL) | Baghouse fine return and aggregate hardness |
| | Design (LL) – Construction (PF) | Baghouse fine return, aggregate hardness, and stockpile moisture |
| | Production (PL) – Construction (PF) | None |

Although the project did not find significant effects of the selected process-based factors on several volumetric properties, as indicated in Table 1, many of the individual mixture comparisons showed that PF samples were significantly different from LL and PL samples. These differences were attributed to the different compaction efforts and confinement conditions in the lab and field compaction processes.

Based on the study's results, volumetric properties tolerance values presented in Table 2 were proposed using the average difference between the different samples. These values could potentially be used by agencies to evaluate and adjust their current tolerance values.

**Table 2. Volumetric Tolerance Recommendations between LL, PL, and PF Samples (Mohammad et al., 2016).**

| Property | Comparison | Tolerance Recommendation |
|---|---|---|
| AV, % | Design (LL) – Production (PL) | ± 0.8 |
| VMA, % | | + 1.2 |
| VFA, % | | ± 5.4 |
| AC, % | Design (LL) – Production (PL) | ± 0.2 |
| | Design (LL) – Construction (PF) | |
| | Production (PL) – Construction (PF) | |
| $G_{mm}$ | Design (LL) – Production (PL) | ± 0.020 |
| | Design (LL) – Construction (PF) | ± 0.013 |
| | Production (PL) – Construction (PF) | ± 0.018 |
| $G_{sb}$ | Design (LL) – Production (PL) | ± 0.014 |
| | Design (LL) – Construction (PF) | ± 0.019 |
| | Production (PL) – Construction (PF) | ± 0.017 |

As part of the 2006 NCAT Test Track research cycle, the Indiana Department of Transportation (INDOT) sponsored a low quality control (QC) air voids experiment to determine the risk of a rutting failure when a surface layer with less than 4.0 percent QC air voids is left in place (Willis et al., 2009). At the time of the experiment, mixtures placed in Indiana with less than 2.0 percent air voids were removed and replaced, while those placed with air voids of 2.0 - 4.0 percent were accepted with disincentives.

The Test Track experiment included four 100-foot subsections. The first four mixtures placed in the fall of 2006 used virgin aggregates and an unmodified PG 64-22 binder. Three mixtures were produced with low QC voids by increasing the asphalt content, and one mixture was produced by increasing the asphalt content and adjusting the aggregate blend percentages. These sections failed with significant rutting when pavement temperatures increased in May of 2007 (after approximately 2.4 million ESALs). These mixtures were removed in February of 2008 (at approximately 5.6 million ESALs) and replaced with new mixtures at QC air void levels that were intended to better define the relationship between QC air voids and rutting performance. Rutting was again observed beginning in May 2008 (after approximately 2 million ESALs from the time of replacement). Figure 1 shows the rutting performance of both the original and replacement mixtures in one of the subsections. Similar results were also observed in the other subsections.

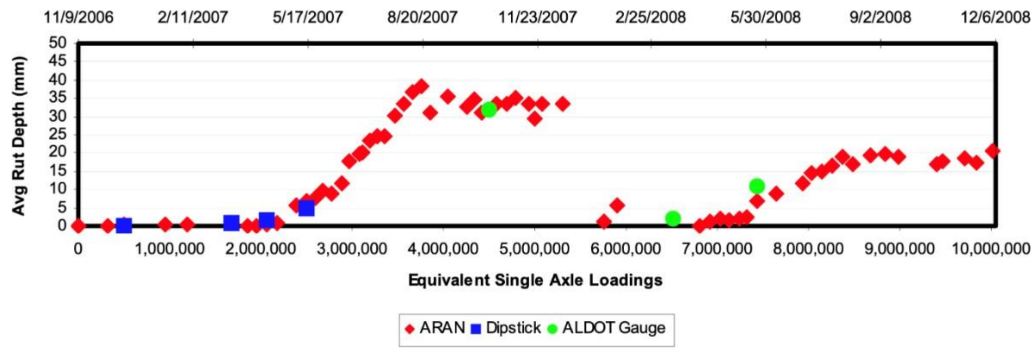



**Figure 1. Rutting in Section S8B for Original and Replacement Mixtures (Willis et al. 2009).**

Figure 2 shows the correlation between QC air voids and maximum measured field rut depths. The field rutting performance was satisfactory after 10 million ESALs for the mixtures with QC air voids above approximately 2.75 percent. However, the field rut depths increased significantly below this level, warranting removal and replacement. It is important to note that these limits may not apply to lower pavement structure layers.

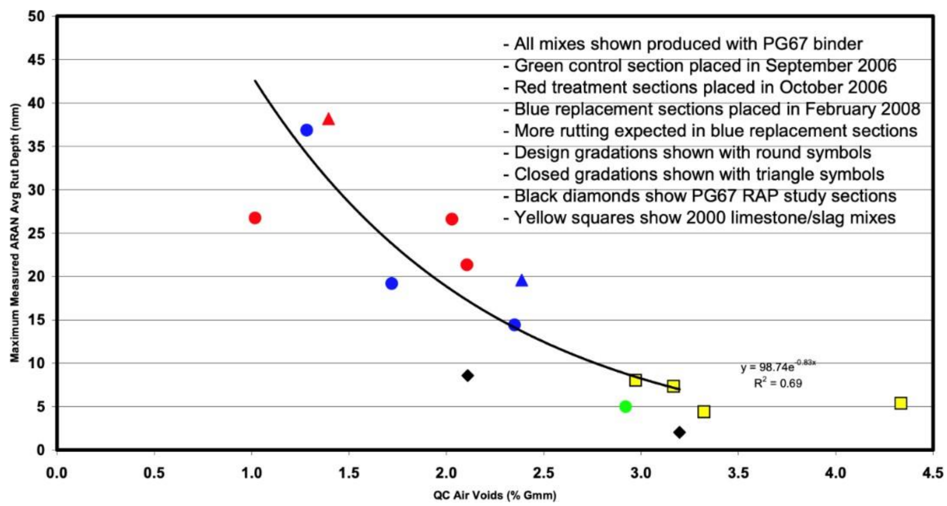
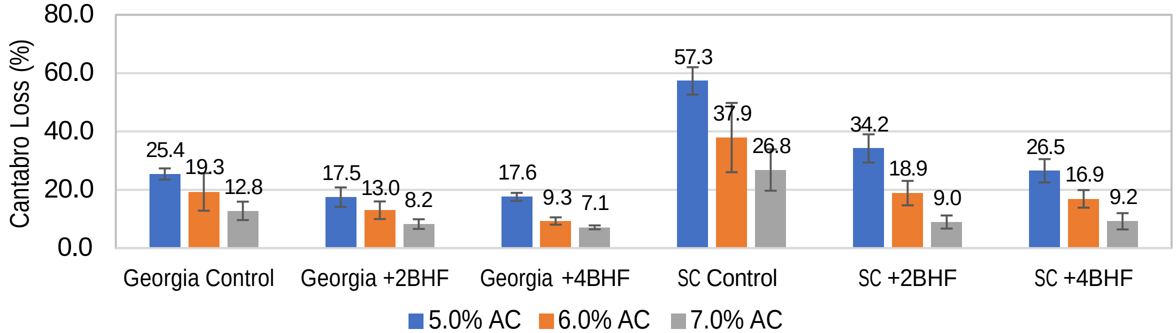



**Figure 2. Correlation between Field Rutting and QC Air Voids (Willis et al. 2009).**

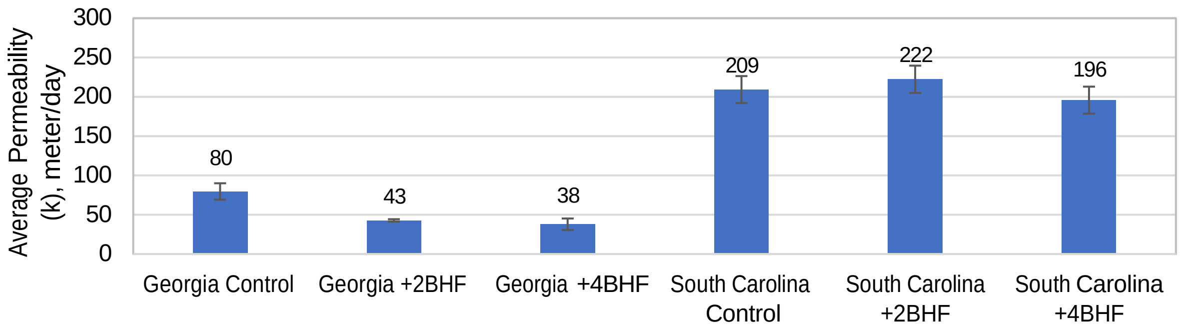
As part of Project NCHRP 01-55, a performance-based OGFC mix design procedure was developed to address the common distresses experienced on roadways (Watson et al., 2018). The new mix design procedure includes performance tests and their acceptance thresholds for permeability and durability, among other distresses. A laboratory permeability test with a minimum permeability rate of 50 meters/day was recommended, and since air voids were found to be directly related to permeability, a minimum design air void content of 15 percent was also proposed based on the minimum permeability rate. In addition, the Cantabro test was found to be a good indicator of mix durability and resistance to raveling with a recommended maximum loss of 20 percent.

Using the proposed performance tests and thresholds, the researchers also evaluated the effects of gradation changes, especially the percent passing the No. 200 sieve ($P_{200}$), and asphalt binder contents on the durability and laboratory measured permeability of OGFC mixtures.

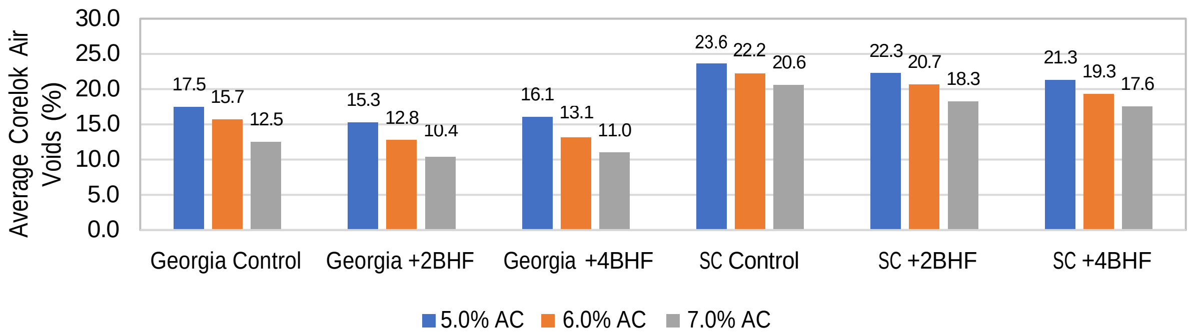
Figure 3(a) shows that the Cantabro loss of the control OGFC mixtures can be significantly affected by changes in binder content and $P_{200}$ (i.e., adding 2 and 4 percent baghouse fines (BHF)). However, as shown in Figure 3(b), increasing $P_{200}$ can significantly affect the permeability of the Georgia OGFC mixture, but it had a minimum effect on the permeability of the South Carolina OGFC mixture due to the difference in air void levels [Figure 3 (c)].




(a) **Cantabro Loss**




**(b) Permeability at 6.0 Percent Binder Content**




**(c) Air Voids**

**Figure 3. Effect of Binder Content and $P_{-200}$ on Durability and Permeability of OGFC Mixes (Watson et al., 2018).**

## 2.2 Laboratory Testing of Pavement Cores to Assess the Performance of Asphalt Mixtures

### *2.2.1 Asphalt Pavement Analyzer (APA) Test*

Since its development, the APA test has been used in numerous research studies to evaluate the rutting of asphalt mixtures. As part of project NCHRP 9-17, Kandhal and Cooley (2003) conducted a study to determine the potential of the APA to predict the rutting of asphalt mixtures. Although the project did not use field cores, it offered important findings related to the effect of sample air voids and its correlation to field performance. The project included materials and in-service performance data from WesTrack, MnROAD, NCAT Test Track, the FHWA Accelerated Loading Facility (ALF), and the Nevada DOT I-80 field experiment. The study assessed variables that included specimen type (gyratory compacted cylinder vs. vibratory compacted beam), nominal maximum aggregate size, specimen air void content (4 and 7 percent for cylinders and 5 and 7 percent for beams), asphalt binder type, and test temperature (PG high temperature vs. PG high temperature plus 6°C). Among the study findings, it was reported that gyratory specimens compacted to 4 percent air voids, and beam samples compacted to 5 percent air voids correlated best with field performance. In addition, samples tested at a test temperature corresponding to the high temperature of the standard performance grade for a project location showed a better correlation with field performance. The authors also concluded that although laboratory rut depths measured by the APA had good correlations on an individual project basis, it was not possible to predict field rutting from APA results on a specific project using relationships developed from other projects in different traffic and geographic locations.

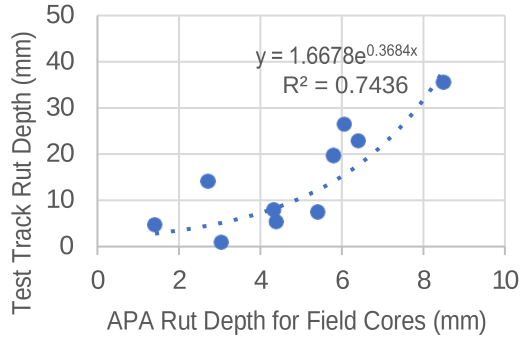
Kandhal and Cooley (2003) also conducted a limited evaluation to compare field rut depths from MnROAD, ALF mixes, and APA and Hamburg Wheel Tracking Test (HWTT) results. The test parameters used with the HWTT were target air voids of 6±0.5 percent, a test temperature of 55°C, and a wheel load of 667 N. The results showed a good correlation between the two tests and the expected trend between field rutting and results from both tests, with the HWTT yielding the best correlation.

Buchanan et al. (2004) conducted a study for the Mississippi Department of Transportation (MDOT) with the APA to evaluate the in-service performance of 24 pavements. APA testing was conducted at a temperature of 64°C on field cores obtained between wheel paths and on laboratory-prepared specimens that were prepared with the original raw materials. Cores with air voids closest to 7 percent were selected for testing. Since the surface layers evaluated in this project were less than 50 mm thick, and the APA required samples to be 75 mm ± 5 mm in height, plaster was used to achieve the required height. The pavements evaluated were constructed between May 1998 and October 2000 and were evaluated for performance during the summer of 2003. Therefore, the pavement ages ranged from 2 to 5 years. Core samples for testing were obtained during the field performance evaluations. The average field rutting reported for all field sections was only 1.9 mm, with a maximum average rut depth of 5.5 mm. The researchers indicated that this was anticipated since Mississippi DOT had success with Superpave mix designs that resulted in mixes with better resistance to rutting. The study found inverse relationships for field rutting rate versus APA rutting of cores, which was partially attributed to asphalt oxidation resulting in increased viscosity and less propensity to densification since all pavements had been in service for at least 2 years when the cores were obtained. Better correlations were determined for field rutting and lab-prepared specimen rut depths, with the best relationship being found for low traffic level mixes. Based on these results, it was reported that bias existed between APA rutting of cores and lab-prepared samples with higher rut depth values reported for the lab samples. The study concluded that although the APA was sensitive to changes in mix design parameters and able to determine the relative performance of the mixes, it was not recommended to predict mix field rutting.

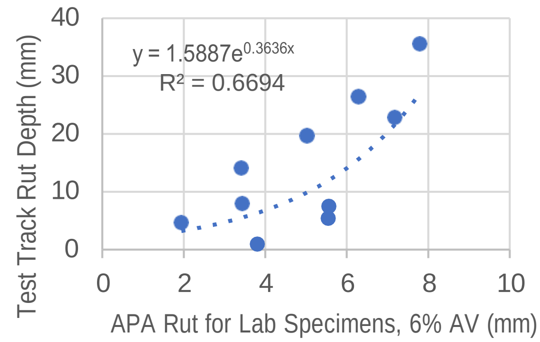
Another evaluation was conducted by Cross (2004) for the Kansas Department of Transportation (KDOT) to evaluate if the APA test was capable of identifying the rutting susceptibility of Kansas mixtures. Six pavements in Kansas with heavy truck traffic and different rutting performance were sampled for testing and evaluation. The project utilized cores and laboratory-compacted specimens evaluated at different test temperatures. Cores from pavement sections were obtained after 4 to 6 years in service. All the mixtures used an AC-20 asphalt binder that met the high-temperature requirements for a PG 64 asphalt. The correlations between field rut depths and APA rut depths from cores at different temperatures were low, with $R^2$ values of 0.08, 0.42, and 0.51 at 58°C, 64°C, and 70°C, respectively. It was reported that 58°C was too low to evaluate aged cores. The correlations between field rut depths and APA rutting from laboratory compacted specimens had $R^2$ values of 0.5, 0.45, and 0.57 for testing conducted at 52°C, 58°C, and 64°C, respectively.

In 2009, correlations were made between APA results and the rutting performance of surface mixtures at the NCAT Test Track (Willis et al. 2009). For this effort, APA tests were conducted at 64°C, the standard high temperature for the Test Track climate, with 100-lb loads and a 100-psi hose pressure. Three types of specimens were tested in this experiment, including field cores extracted right after construction, laboratory specimens compacted to $N_{design}$, and laboratory specimens compacted to target air voids of 6 to 7 percent to represent the target in-place density at the Test Track.

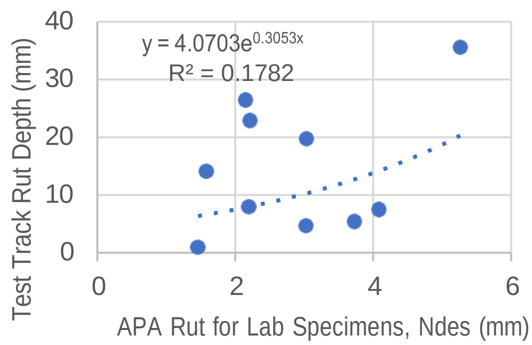
Figure 4 shows the correlations between the rut depths measured at the Test Track and the APA rut depths for the three specimen types based on an additional analysis conducted for this project. The APA rut depths measured on the field cores show the best correlation to the field rutting performance [$R^2$ = 0.74, Figure 4(a)], followed by those for laboratory specimens compacted to the target air voids of 6 to 7 percent [$R^2$ = 0.67, Figure 4(b)], and then those for laboratory specimens compacted to $N_{design}$ [$R^2$ = 0.18, Figure 4(c)]. As shown in Figure 4(a), A maximum APA rut depth of 5.5 mm can be used to separate the mixes, with field-measured rut depths above 12.5 mm. In addition, as shown in Figure 3(d), compared to the lab specimens compacted to $N_{design}$, the lab specimens compacted to 6 to 7 percent air voids have a stronger APA rutting correlation to the field cores.



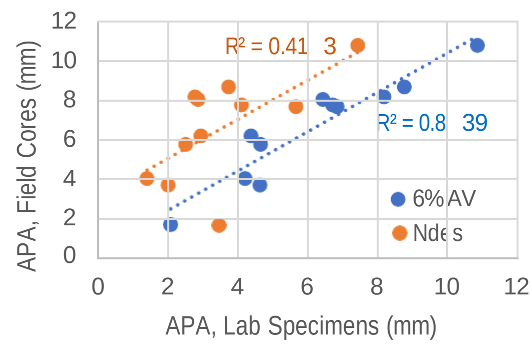

**(a) APA for Field Cores vs TT Rutting**




**(b) APA for Specs @ 6-7% AV vs TT Rutting**




**(c) APA for Specimens @ $N_{des}$ vs TT Rutting**




**(d) APA for Lab Specimens vs Field Cores**

**Figure 4. Correlations between APA Rut Depths and Field Rutting**

Since the APA test will be part of the experimental program of this study, Table 3 presents the list of eleven states that used it, and their corresponding criteria. As presented in this table, different test temperatures between 40 and 67°C are specified by the different DOTs. (West et al. 2018).

**Table 3. APA Criteria by State (West et al., 2018)**

| States | Binder/Mixture Types | Criteria (rut depth at 8000 cycles) | Type of Specimen |
|---|---|---|---|
| Alabama | 10 to 30 million ESALs | Max. 4.5 mm at 67°C | NA |
| Alaska | all | Max. 3.0 mm at 40°C | 150 mm dia. × 75 mm compacted to 6.0 ± 1% air voids |
| Arkansas | 75 and 115 gyrations | Max. 8.0 mm at 64°C | 150 mm dia. × 75 mm compacted to 7.0 ± 1% air voids |
| | 160 and 205 gyrations | Max. 5.0 mm at 64°C | |
| Georgia | 19- & 25-mm NMAS | Max. 5.0 mm at 49°C | 150 mm ×115 mm compacted to $N_{design}$ |
| | 9.5- & 12.5-mm NMAS | Max. 5.0 mm at 64°C | |

**Table 3. (Continue)**

| | | | |
|---|---|---|---|
| Idaho | 75 and 100 gyrations | Max. 5.0 mm at binder high PG temperature | 150 mm dia. × 75 mm compacted to 7.0 ±0.5% air |
| North Carolina | 9.5mm NMAS, < 0.3 million ESALs | Max. 11.5 mm at binder high PG temperature | 150 mm dia. × 75mm compacted to 4.0 ±0.5% air voids |
| | 9.5mm NMAS, 0.3 to 3 | Max. 9.5 mm at binder high PG temperature | |
| | 9.5mm NMAS, 3 to 30 million ESALs | Max. 6.5 mm at binder high PG temperature | |
| | 9.5mm NMAS, > 30 million ESALs | Max. 4.5 mm at binder high PG temperature | |
| | 12.5mm NMAS, 3 to 30 million ESALs | Max. 6.5 mm at binder high PG temperature | |
| | 12.5mm NMAS, > 30 million ESALs | Max. 4.5 mm at binder high PG temperature | |
| New Jersey | High performance thin overlay | Max. 4.0 mm at 64°C (mix design) Max. 5.0 mm at 64°C (production) | 150 mm dia. × 77 mm compacted to 5.0 ±0.5% air voids |
| | Bituminous rich intermediate course | Max. 6.0 mm at 64°C (mix design) Max. 7.0 mm at 64°C (production) | |
| | Bridge deck waterproof surface course | Max. 3.0 mm at 64°C | |
| | Bituminous rich base course | Max. 5.0 mm at 64°C | |
| | High RAP mix, PG 64-22 | Max. 7.0 mm at 64°C | |
| | High RAP mix, PG 76-22 | Max. 4.0 mm at 64°C | |
| Ohio | Non-polymer mix | Max. 5.0 mm at 48.9°C | 150 mm dia. × 75 mm compacted to 7.0 ± 1% air voids |
| Oregon | 80 gyrations, PG 58-xx<br>80 gyrations, PG 64-xx | Max. 6.0 mm at 64°C | 150 mm dia. × 75 mm compacted to 7.0 ±0.5% air voids |
| | 80 gyrations, PG 70-xx<br>100 gyrations, PG 64-xx | Max. 5.0 mm at 64°C | |
| | 100 gyrations, PG 70-xx<br>100 gyrations, PG 76-xx | Max. 4.0 mm at 64°C | |
| South Carolina | PG 76-22 | Max. 3.0 mm at 64°C | 150 mm dia. × 75 mm compacted to 7.0 ±0.5% air voids |
| | PG 64-22 | Max. 5.0 mm at 64°C | |
| South Dakota | Truck ADT < 75 | Max. 8.0 mm at binder high PG temperature | 115 mm compacted to $N_{design}$ |

### *2.2.2 Indirect Tensile Test (IDT)*

The IDT has been explored over the years to assess both permanent deformation and fatigue cracking resistance of asphalt mixtures. Although documented research with this test does not include evaluations with field cores, the test is considered practical for quality control of asphalt mixtures, and when tests are conducted at high temperatures representative of project climate, they have shown a good correlation with other rutting tests. Based on the test data from projects NCHRP 9-25, 9-31, and 9-33, Christensen and Bonaquist (2007) refined the test to be conducted for evaluating rutting resistance. The test can be conducted with a loading rate of 50 mm/min at a test temperature of 10°C lower than the average annual 7-day maximum pavement temperature determined by the Long-Term Pavement Performance Bind Program (LTPPBind) at 20 mm below the pavement surface. The minimum IDT strength thresholds are shown in Table 4 or can be determined based on Equation 1 as a function of design traffic level to minimize rutting.

**Table 4. Guidelines for IDT Strength Test at High Temperatures (Christensen and Bonaquist, 2007)**

| Design Traffic Level[1] (ESALs) | Rut Resistance Category | IDT Strength Range (KPa) |
|---|---|---|
| - | Very Poor | <50 |
| < 0.3 | Poor | 50 to < 110 |
| 0.3 to < 3 | Minimal | 110 to < 170 |
| 3 to < 10 | Fair | 170 to < 270 |
| 10 to < 30 | Good | 270 to < 430 |
| 30 to < 100 | Very Good | 430 to < 660 |
| 100 to < 300 | Excellent | ≥660 |

[1]At 70 km/h (44 mph). To adjust the estimated traffic level to 70 km/h, multiply by (70/v), where v is the average traffic speed in km/h.

$$TR_{max} = 1.97x10^{-5}(IDT)^{2.549} \quad \text{(Equation 1)}$$

Where:

$TR_{max}$ = maximum allowable traffic for a given mix, million ESALs, and
IDT = high-temperature IDT strength, kPa.

Bennert et al. (2018) evaluated the high-temperature IDT (HT-IDT) as a potential indicator of the rutting performance of asphalt mixtures for quality control testing during production as an alternative to the APA, which is used as the test method to assess rutting by the New Jersey Department of Transportation (NJDOT). The researchers evaluated a variety of plant-produced and laboratory-produced asphalt mixtures that covered a wide range of binder grades, volumetrics, aggregate gradations, aggregate types, and recycled asphalt binder percentages. Samples were compacted to within ± 0.5 percent of the mix design target air voids of the specific mix type. Thus, dense-graded mixtures, high-performance thin overlays, and bituminous-rich intermediate course mixtures were compacted to target 6.5, 5.0, and 3.5 percent air voids, respectively. The APA was conducted at a temperature of 64°C as specified by NJDOT. The HT-IDT was conducted at 44°C, which corresponds to a temperature of 10°C below 54°C (the average annual 7-day maximum pavement temperature at 20 mm below the pavement surface as determined by LTPPBind 3.1).

Figure 5 shows a comparison of APA vs. HT-IDT test results, indicating a strong relationship with an $R^2$ of 0.8. The proposed pass/fail criteria shown in the figure incorporated the effects of variability based on the coefficient of variation (COV) as a conservative measure. The figure also superimposed the recommended criteria from the NCHRP 9-33 project which agreed with the data in this study.

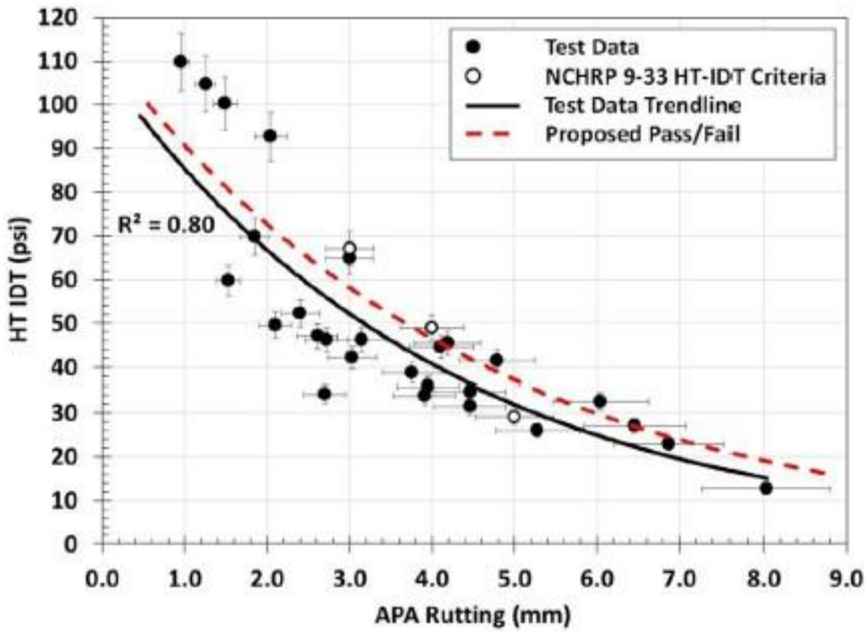



**Figure 5. HT-IDT vs. APA (Bennert et al. 2018)**

### *2.2.3 Hamburg Wheel Tracking Test (HWTT)*

Zhang et al. (2021) conducted a study to determine if the ranking of HWTT results from pavement cores was comparable to the ranking of field rut depths of different asphalt mixtures. The study included data collected as part of NCHRP Project 9-49A. Fifty pavement sections from 21 projects were included in the evaluation, and different mix designs, volumetric properties, pavement ages, RAP content, traffic levels, asphalt modifications, structural thicknesses, and climatic zones in the United States were included. Field cores were obtained from the non-wheel path areas after the sections had been in service for 4 to 9 years, indicating that the cores had experienced moderate field aging to different extents. HWTT tests were conducted per AASHTO T 324 with samples submerged under water at 50°C. The test was conducted for 20,000 passes or until a deformation of 20 mm was reached. A constant temperature was used to better compare the rutting resistance of mixtures by eliminating the effect of different testing temperatures. Rut depth measurements were conducted at the time cores were obtained. The statistical comparison between HWTT results and field-measured rut depth indicated that HWTT was under-predicted, and over-predicted and showed no statistical difference for 6, 37, and 7 pavement sections, respectively. Therefore, the authors concluded that the HWTT over-predicted the rutting of the sections in most cases. The data obtained in this study was used to develop a predictive model of field rut depth based on a statistical machine learning method. The final predictive variables in the model included pavement age, number of high-temperature hours, truck traffic AADTT, and HWTT rut depth. Equation 2 presents the final model for predicting the field rut depth. As presented in this equation, a lower field rut depth is expected for lower values of pavement age, number of hours above 25ºC, AADTT, and HWTT rut depth. The model had a strong coefficient of determination ($R^2 = 0.79$), indicating its adequacy in predicting field rutting. In addition, a sensitivity analysis conducted with the model indicated that pavement age had the most significant effect on the rutting prediction, followed by HWTT results and AADTT.

$$Y = 0.05X_1 + 0.00001X_2 + 0.0017X_3 + 0.099X_4 - 1.2 \quad \text{(Equation 2)}$$

Where:
Y = field-measured rut depth (mm);
$X_1$ = pavement age (months);
$X_2$ = number of hours greater than 25°C;
$X_3$ = AADTT; and
$X_4$ = HWT rut depth (mm).

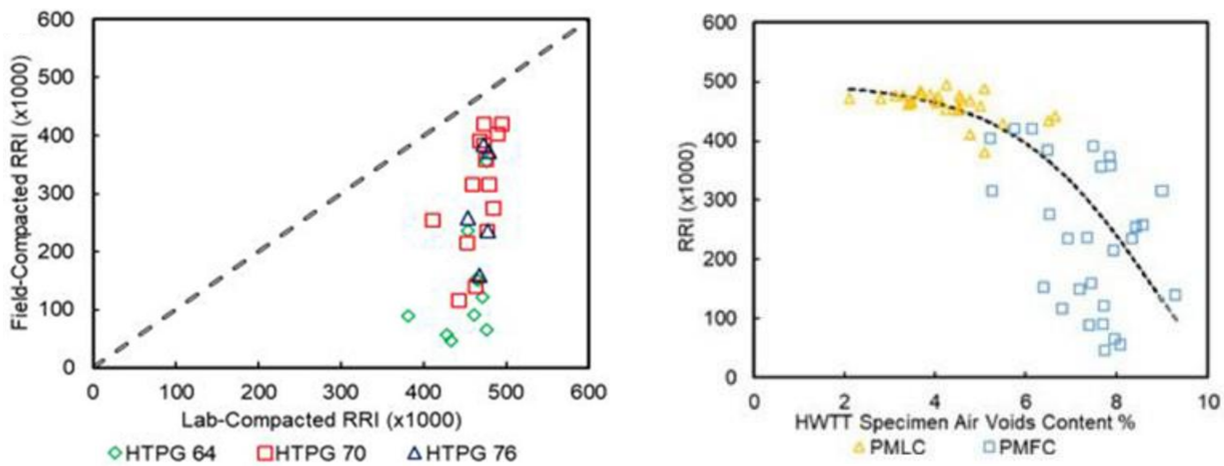
In the study by Mohammed et al. (2016), previously discussed in this report, HWTT tests were also conducted according to AASHTO T 324 on LL, PL, and PF samples to assess differences in the test results. Tests were conducted at a standard temperature of 50°C for all mixtures, with LL and PL samples compacted to 7 ± 1.0 percent. Rut depths at 1,000, 5,000, and 20,000 cycles were measured and used in the analysis. It was reported that, on average, the LL and PL samples yielded 33 percent less rutting than the PF samples. Therefore, adjustments to the requirement for the different samples used for acceptance would be needed for agencies transitioning toward performance-based specifications.

Batioja-Alvarez et al. (2020) investigated the suitability of the HWTT for acceptance of asphalt mixtures using plant-mixed, laboratory-compacted samples (PMLC) and field-compacted samples (PMFC). The plant mix and asphalt samples were obtained from 47 mixtures in Indiana. The mixtures included surface, intermediate, and base courses with different NMAS designed with some RAP, not to exceed 25 percent asphalt binder replacement (ABR) as specified by INDOT. In addition, the mixtures utilized different binder grades typically used in Indiana (PG 64-22, PG 70-22, and PG 76-22). Plant mix samples used to produce the PMLC specimens were sampled during construction from behind the paver. PMFC samples were obtained soon after construction. PMLC samples were prepared at a target air void content of 4 percent. All PMLC and PMFC samples were tested in the HWTT at 50°C until reaching a rut depth of 12.5 mm or 20,000 passes. To analyze the HWTT data, the researchers used a rutting resistance index (RRI) that considers the number of passes and rut depths as indicated in Equation 3. The study showed that HWTT results were influenced by the specimen air voids. As indicated in Figure 6a, the RRI values of all the PMLC samples are higher than those of corresponding PMFC samples, which was attributed to the difference in specimen air voids. In addition, no correlations were observed between the HWTT results for the two types of specimens. Figure 6b showed a distinct correlation between specimen air voids and RRI values, indicating the RRI values decreased for both types of samples as the specimen air voids increased. In addition, RRI values for PMFC samples are highly variable within a range of 6 to 8 percent air voids and decrease as the specimen air voids increase. The researchers concluded that the correlation between air voids and RRI can be useful to assess the effect of in-place density on pavement performance.

$$RRI = N\ X\ (25.4 - RD) \quad \text{(Equation 3)}$$

Where:

N is the number of passes at the completion of the test;
RD is the rut depth (mm) at the completion of the test.
The equation assumes that the final rut depth is less than 25.4 mm.




(a) (b)

**Figure 6. RRI Values: (a) Laboratory-compacted vs. Field-compacted Samples; and (b) RRI vs. Air Voids Content**

Many agencies have used HWTT to assess the rutting of asphalt mixtures, and the criteria specified by these state DOTs are summarized in Table 5. As indicated, agencies require a maximum rut depth at a certain number of passes or a minimum number of passes at a certain rut depth. In addition, several agencies require a minimum stripping inflection point (SIP) for evaluating moisture susceptibility (West et al. 2018).

**Table 5. HWTT Criteria by State (West et al., 2018)**

| States | Binder/Mixture | Criteria |
|---|---|---|
| California | PG 58-xx | Min. 10,000 passes at 12.5 mm rut depth |
| | PG 64-xx | Min. 15,000 passes at 12.5 mm rut depth |
| | PG 70-xx | Min. 20,000 passes at 12.5 mm rut depth |
| | PG 76-xx | Min. 25,000 passes at 12.5 mm rut depth |
| Colorado | all | Max. 4.0 mm rut depth at 10,000 passes |
| Iowa | all | Max. 8.0 mm rut depth at 8,000 passes<br>Min. 10,000 or 14,000 passes with no SIP |
| Illinois | PG 58-xx (or lower) | Max. 12.5 mm rut depth at 5,000 passes |
| | PG 64-xx | Max. 12.5 mm rut depth at 7,500 passes |
| | PG 70-xx | Max. 12.5 mm rut depth at 15,000 passes |
| | PG 76-xx (or higher) | Max. 12.5 mm rut depth at 20,000 passes |
| Louisiana | Level 1 high traffic | Max. 6.0 mm rut depth at 20,000 passes |
| | Level 2 medium/low | Max. 10.0 mm rut depth at 20,000 passes |
| Maine | all | Max. 12.5 mm rut depth at 20,000 passes<br>Min. 15,000 passes with no SIP |
| Massachusetts | all | Max. 12.5 mm rut depth at 20,000 passes<br>Min. 15,000 passes with no SIP |
| Montana | all | Max. 13.0 mm rut depth at 15,000 passes |
| Oklahoma | PG 64-xx | Min. 10,000 passes at 12.5 mm rut depth |
| | PG 70-xx | Min. 15,000 passes at 12.5 mm rut depth |
| | PG 76-xx | Min. 20,000 passes at 12.5 mm rut depth |
| Texas | PG 64-xx | Min. 10,000 passes at 12.5 mm rut depth |
| | PG 70-xx | Min. 15,000 passes at 12.5 mm rut depth |
| | PG 76-xx | Min. 20,000 passes at 12.5 mm rut depth |
| Utah | $N_{design} > 75$ | Max. 10.0 mm rut depth at 20,000 passes |
| Washington | all | Max. 10.0 mm rut depth at 15,000 passes<br>Min. 15,000 passes with no SIP |

## 2.3 Summary of Literature Findings

- Production and construction variability, even if within specification tolerances, can affect the volumetric properties and performance of asphalt mixtures. An additional source of variability occurs when samples utilized for quality control/acceptance are prepared using different procedures (i.e., plant-mixed and laboratory-compacted, versus plant-mixed and field-compacted).
- Most research efforts have used samples fabricated in the laboratory under controlled conditions to evaluate the impact of different factors on performance test results and the

ability of the APA and HWTT to predict field rutting. Research conducted with performance tests using pavement cores to assess field performance and pavement acceptability has generally not been successful. The possible exception was the recent study by Zhang et al. (2021), which added pavement age, truck traffic, and a factor for project climate along with HWTT results to reasonably predict rutting in the field.

- APA and HWTT results are affected by the test samples' compaction method (laboratory vs. field). Tests conducted on laboratory-prepared samples have been found to correlate better with field performance than those conducted on pavement cores taken after several years. However, when cores are taken immediately after construction, they seem to provide a better correlation with field performance.
- Rutting test results are affected by the specimen air voids; however, mixed results regarding an optimum air void content that would provide the best correlations to field performance have been reported.
- Although limited studies have been conducted using field cores, the APA, HWTT, and HT-IDT tests on lab compacted specimens have indicated good potential to assess the rutting performance of asphalt mixtures.

# 3. SURVEY OF STATE HIGHWAY AGENCIES

## 3.1 Introduction

A brief survey of state DOTs was conducted to determine what methodologies are currently being used to assess in-place defective materials. The survey was sent to the bituminous engineer in all fifty state DOTs, and as of the time of this report, responses had been received from 23 states. A summary of the questions and responses are as follows:

1. *In your state, what are the most common types of asphalt testing failures that occur during construction (production and placement) where the specifications require removal and replacement?*

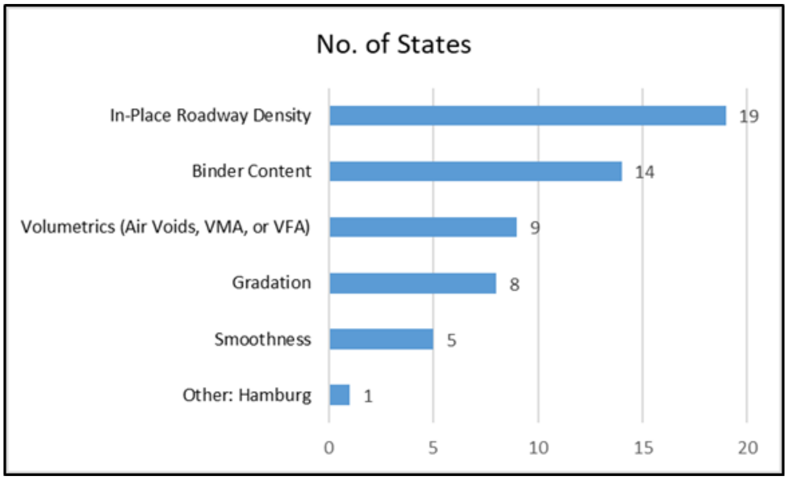



**Figure 7. Most Common Types of Testing Failures Requiring Removal and Replacement**

Of the responses received, failing in-place densities and binder contents were the most common failures requiring removal and replacement. Volumetric failures only accounted for 8 of the 23 responses (35%).

2. *Do your specifications allow exceptions to removal and replacement based on an evaluation of the in-place materials? (Yes/No)*

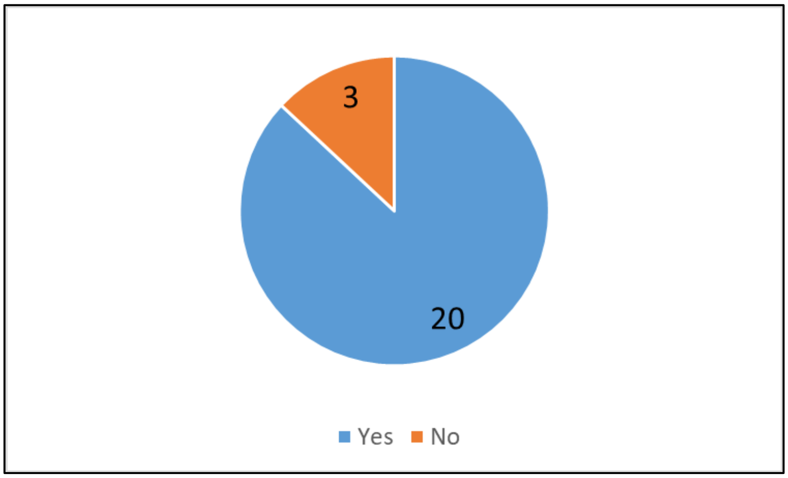



**Figure 8. Number of States That Allow Exceptions to Removal and Replacement**

3. *For what types of failures from the list included in Question 1 are exceptions allowed?*

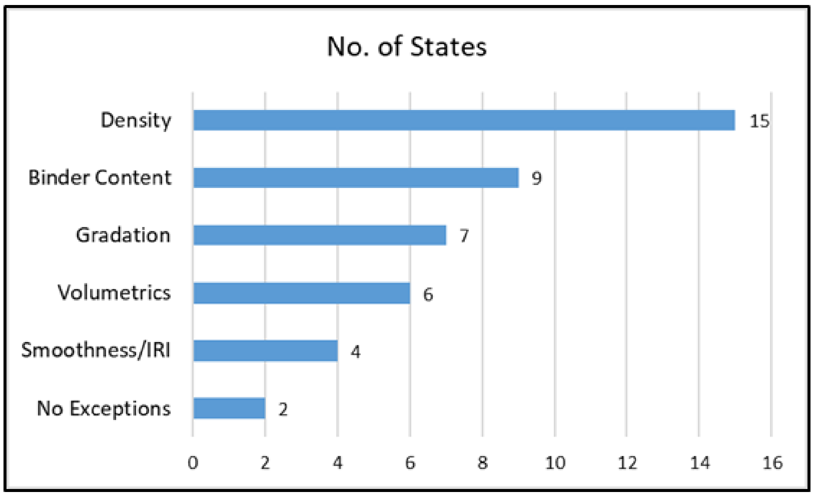



**Figure 9. Types of Failures Where Removal Exceptions Are Allowed**

A breakdown of the individual responses to this question is as follows:

- Alabama: Binder content, voids, density.
- Alaska: Binder content, gradation, and density.
- Colorado: No exceptions.
- Connecticut: Test results that trigger removal and replacement (R&R) based on in-place density requirements may prompt the Contractor to request dispute resolution. R&R may still be the recommendation. Remedial action may be considered on a case-by-case basis.
- Florida: Exceptions are allowed for each of the failures listed above: Volumetrics (Air Voids), Binder Content, In-place roadway density, and Smoothness.
- Hawaii: No exceptions.
- Indiana: Outside of certain ranges, the Division of Materials and Tests refers to material as failed. Then, it is an engineering judgment as to whether a monetary assessment or removal is warranted.

- Kansas: Broad authority is given to the engineer for acceptance when specification requirements for any property are not met – remove and replace the lot, remove and replace a portion of the lot, or accept the lot with a deduction. The engineer may perform additional testing or investigation to help better inform decisions. For air voids and in-place density, the contractor may dispute the results only if the t-test fails and DOT results are going to be used for acceptance or pay adjustment.
- Maine: In-place density.
- Maryland: Districts will decide to remove and replace bad sections of pavement if smoothness does not meet the criteria. We will have them microgrind if IRI is too bad. If the mix fails at volumetrics, we mostly impose penalties, and if it is at an unacceptable level, we will ask for removal and replacement as per specifications.
- Michigan: The project engineer can impose a 50% penalty instead of removal, usually based on the mix results.
- Minnesota: Volumetrics (air voids, VMA; or VFA), in-place roadway density.
- Montana: Volumetrics, density, and smoothness. We rely on volumetrics to ensure correct gradation and binder content. During the "P-value" evaluation, if the P-value is greater than 25, the project manager can choose to remove and replace or leave material in place at a significant penalty, based on the evaluation of material, placement, traffic, etc. The contractor also has the option to remove the defective material and replace it with specification material at full price in lieu of accepting a penalty.
- Nevada: Binder content, gradation, and in-place roadway density.
- Oregon: Binder content or gradation – Exceptions may be allowed depending on location. In a shoulder, we are more tolerant of high binder content than a travel lane. In-place density – We typically test and accept based on core-correlated nuclear density gauges, but we virtually always core an area with low-density results before R&R. We may accept an area with failing density with price adjustment, considering how low the density is and the location.
- Pennsylvania: Binder content, gradation, in-place roadway density.
- South Carolina: No exceptions.
- Tennessee: Gradations and binder contents that would result in the remove and replace category may alternatively be left in place at 20% liquidated damage at the department's discretion. Any sublot for in-place density that fails to meet the minimum density must be reworked or removed before the lot average is calculated for payment. In-place testing is done during paving, so typically, these areas are rerolled and not replaced, though theoretically, they could be forced to remove and replace them.
- Texas: Acceptance of defective or unauthorized work. When work fails to meet Contract requirements but is adequate to serve the design purpose, the engineer will decide the extent to which the work will be accepted and remain in place. The engineer will document the basis of acceptance by a letter and may adjust the contract price.
- Vermont: In-place roadway density.

- Virginia: We pay based on AC and gradation. If AC and gradation have a large enough penalty, then remove and replace. However, the contractor can opt for a significant pay reduction if not removed and replaced. If you asked about the case not being removed and replaced with bad lab results but good results from the field, also no. However, in many cases, they end up with a pay reduction instead of removal and replacement unless there is a serious field issue related to safety and looks bad.
- Washington: Remove and replace generally stems from a Composite Pay Factor (CPF) of less than 0.75. There are separate CPFs for mixture and density.
- West Virginia: We have a PWL specification for many projects. All specification types have penalty structures in place to address failing materials for smoothness, density, gradation, binder content, and volumetrics (volumetrics only at the plant). The most severe penalties that may require removal/replacement are evaluated project-by-project and are subject to the engineer's evaluation.

***4.*** *How are evaluations typically conducted?*

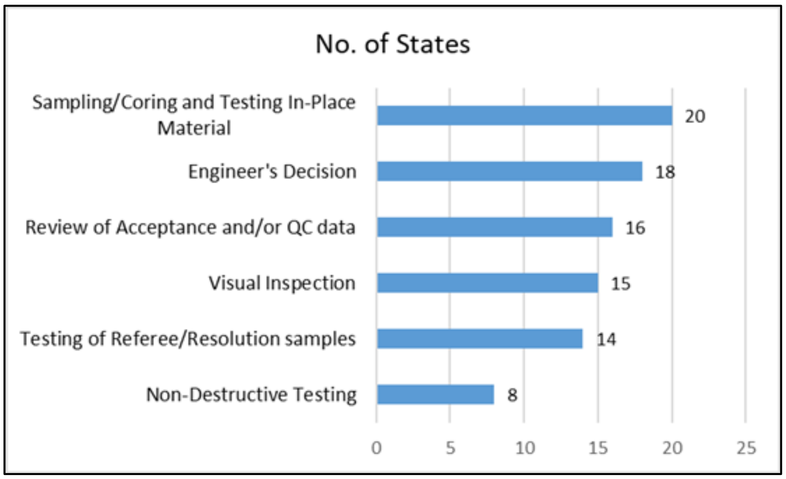



**Figure 10. How In-Place Material Evaluations Are Conducted**

A breakdown of the individual responses follows:

- Alabama: Visual inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material
- Alaska: Engineer’s decision
- Colorado: Engineer’s decision, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material
- Connecticut: Sampling/coring and testing in-place material
- Florida: Visual Inspection of OGFC AC content and gradation failure, Engineer's decision, Sampling/coring and testing in-place material, Non-destructive testing (Rolling Straightedge for smoothness failures tested with the laser profiler), Field permeability on rare occasions for OGFC AC content/gradation failure
- Hawaii: NA

- Indiana: Visual inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material, Non-Destructive testing
- Kansas: Visual Inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material, Non-Destructive testing
- Maine: Sampling/coring and testing in-place material
- Maryland: Visual inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material
- Michigan: Review of Acceptance and/or QC data
- Minnesota: Visual Inspection, Engineer's decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material
- Montana: Visual Inspection, Engineer’s decision, Review of Acceptance and/or QC data, Sampling/coring and testing in-place material.
- Nevada: Visual inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material
- Oregon: Visual Inspection, Engineer's decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material
- Pennsylvania: Visual inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material
- South Carolina: Visual inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material
- Tennessee: Visual inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material, Non-Destructive testing
- Texas: Visual inspection, Engineer’s decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material, Non-Destructive testing
- Vermont: Engineer’s decision, Sampling/coring, and testing in-place material, Non-Destructive testing
- Virginia: Visual Inspection, Engineer's decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material, Non-destructive testing
- Washington: Review of Acceptance and/or QC data. Sampling/coring and testing in-place material.

- West Virginia: Visual inspection, Engineer's decision, Review of Acceptance and/or QC data, Testing of Referee/Resolution samples, Sampling/coring and testing in-place material, Non-Destructive testing.

5. **If sampling/coring and testing in-place materials, what types of samples are taken, and what tests are run?**

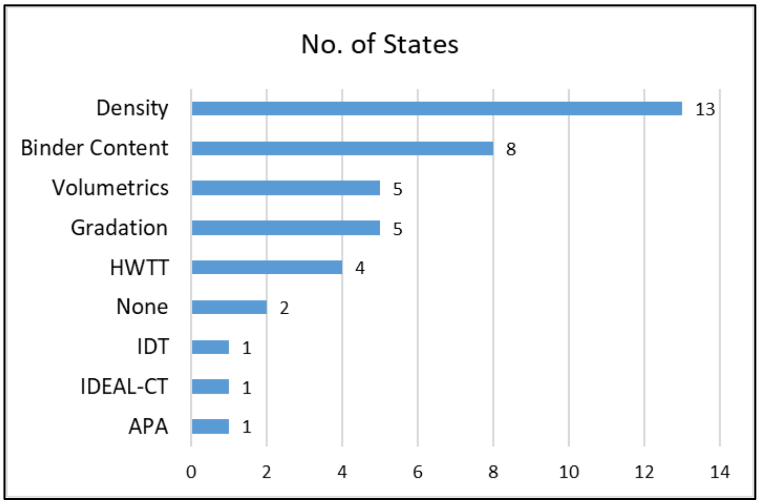



**Figure 11.Tests Typically Performed on In-Place Materials**

A breakdown of the individual responses is as follows:

- Alabama: Field cores, density, ignition oven/gradation.
- Alaska: HMA cores are taken in compacted mat and longitudinal joints to determine the density (i.e., % compaction).
- Colorado: Joint Density - Voids/Density Testing.
- Connecticut: Loose mix – Volumetrics (AASHTO T 269); $P_b$ content (AASHTO T 308); Cores for density (AASHTO T 331).
- Florida: Cores - $G_{mm}$, $G_{mb}$, AC content, gradation, APA (for low $N_{des}$ Air voids)
- Hawaii: Cores and uncompacted samples; testing for $G_{mm}$ (Rice) and $G_{mb}$ (cores) for compaction data.
- Indiana: Plate samples, core samples. volumetric and occasionally performance testing
- Kansas: Determine $G_{mb}$ on cores for in-place density evaluation.
- Maine: If the in-place density for the Lot is < 90 PWL, an additional random core is obtained and tested from each sublot in the Lot.
- Maryland: If both QC and QA do not have enough material to retest, rarely collect in-place cores, and redo the volumetrics for referee testing.
- Michigan: No sampling/coring and testing of in-place materials.
- Minnesota: Volumetrics and Density.
- Montana: In most cases, when we encounter R&R, it's a Hamburg failure, so we will take a 10" core for Hamburg testing. On very rare occasions, we've tested in-situ material to verify a Rice Gravity or dust content.

- Nevada: Density, asphalt content, Rice.
- Oregon: ODOT will use cores to investigate low-density areas and areas of suspected high asphalt content. This is our default for areas with low density from the nuclear gauge.
- Pennsylvania: Cores samples are taken for asphalt content and gradation. Asphalt content and gradation testing are run.
- South Carolina: No sampling/coring and testing of in-place materials.
- Tennessee: This would typically be on a case-by-case basis. The department's project engineer decides whether to force a remove-and-replace. Typically, they will consult with Materials & Tests to review the failed test result, and M&T may perform some further investigation as deemed useful. The contractor has the right per spec to have the split sample of the acceptance test tested by TDOT's Central Lab, though this is quite rare.
- Texas: Core density. Hamburg rutting tests. Asphalt content determination. Shear bond test. (these are the most common)
- Vermont: Cores are sometimes taken to verify low-density results and ensure the removal is warranted with retesting.
- Virginia: Anything can happen based on the case.
- Washington: Depending on the type of failure, 6” cores are taken for forensic testing to confirm $P_b$, Hamburg, IDT, or gradation results. Volumetric or density tests are generally not run on in-place cores.
- West Virginia: We test with nuclear gauges for non-PWL projects, and we pull cores for density, bond strength, and thickness on PWL projects. We also take loose samples in the field for AC and gradation on PWL projects.

6. *Does your agency have experience with running performance tests on field cores to determine the acceptability of the pavement? If so, which tests are typically performed?*

- Alabama: No
- Alaska: No.
- Colorado: No.
- Connecticut: No.
- Florida: Yes. APA on cores where there was a low $N_{des}$ air void failure. Field criteria of 5 mm.
- Indiana: IDEAL-CT, Hamburg
- Kansas: No.
- Maine: No.
- Maryland: No.
- Michigan: No.
- Minnesota: No.
- Montana: Yes. Hamburg.

- Nevada: Yes. It is on a limited basis for special use mix designs, so there is no full acceptance testing. But we run Texas Overlay and 4-point bending beam fatigue.
- Oregon: Yes, but minimal. Minimal experience, so "typical" isn't appropriate. We have extracted field cores and conducted Hamburg WTT to investigate how prone a mix is to rutting with suspected high asphalt content.
- Pennsylvania: No.
- South Carolina: No.
- Tennessee: No.
- Texas: Yes. Hamburg (typically, we run Hamburg on production but will run placement cores when determining whether to leave questionable material in place). Shear bond test.
- Vermont: No.
- Virginia: Yes, for bond strength. Rarely for APA rutting (just for investigation). Probably not for any other performance test for field cores for acceptance. The bond strength test is based on our tack spec. As a referee, however, it rarely happens
- Washington: No.
- West Virginia: Yes. Bond strength, if that is considered a performance test. If not, then our answer is no.

Fourteen of the 23 DOTs responding do not have experience using field cores in mix performance tests. Of the states that do have experience with running performance tests on roadway cores, a follow-up telephone call was made to discuss their experiences.

Florida: In cases where the production air voids are outside of their allowable production range and there is no explainable cause through examination of volumetric production data, FDOT occasionally uses the asphalt pavement analyzer (APA) to test roadway cores to evaluate the potential for rutting. The APA limit is 5.0 mm of rutting when tested at 64°C. FDOT has limited experience with this evaluation method.

Indiana: INDOT has occasionally run performance tests on roadway cores. They typically just use cores to evaluate in-place air voids. For questionable material, they have previously used the HWTT and IDEAL-CT to evaluate in-place material. They don't feel very comfortable using these tests on roadway cores—they were done only as a last option prior to removal and replacement. They made certain to cut the cores from between the wheel paths.

Maryland: In the past, Maryland cut roadway cores, broke down the cores, and then re-compacted the material to determine the compacted air voids. They used those results as a referee when they had a volumetrics failure that was disputed by the contractor. However, they noted that this approach hasn't been used in over five years.

Montana: Montana regularly runs HWTT tests on the production mix following the first 2000-ton start-up and uses the results from this test as a go/no-go. In situations where the HWTT on the production mix fails, they then cut roadway cores and run the HWTT on the cores to evaluate the in-place material (they try to cut 10" diameter cores if possible but also use 6" cores). The criteria they use for the cores is 13 mm of rutting after 10,000 passes. They only core the project if there is a HWTT failure and they typically only run the HWTT test once per project – after the 2000-ton start-up.

Nevada: No response.

Oregon: No response.

Texas: TXDOT will cut cores and run the HWTT on the cores if there is failing material. Generally, their contracting industry does not like TXDOT to do this; however, it is only used when the option is removal and replacement. When they cut cores for HWTT testing, they locate them between the wheel paths to try to get close to 7.0 percent air voids (which is their target density level). The criteria they use is 12.5 mm of rutting on the cores, and the number of passes is a function of the high-temperature binder grade specified in the contract (PG 64 = 10,000; PG 70 = 15,000; PG 76 = 20,000).

Washington: WSDOT will occasionally cut cores and run either HWTT or IDT tests on failing material. It generally is only done once or twice per year. They find the testing cumbersome because they have to use plaster to adjust the thickness of the cores. They will routinely run HWTT on production samples, and if there is a significant delay in getting the test results and the results fail, they use cores to assess the in-place material. Their criteria is ½" of rutting after 15,000 passes. They cut the cores in between the wheel paths. They also occasionally use the IDT test to ensure the mixes are not too stiff from using RAP. They cut roadway cores, run the IDT test at 77°F, and allow a maximum of 175 psi.

### 3.2 Summary of SHA Survey Results

- For the agencies that responded to this survey, the most common types of asphalt testing failures that occur during construction (production and placement) where the specifications require removal and replacement are related to density, binder content, and volumetrics.
- The majority of states (20 of the 23 responses) allow exceptions to removal and replacement.
- In cases where there are exceptions to removal and replacement, the majority of states ultimately use some form of sampling (coring) and testing to evaluate the in-place material.
- Most of the respondents indicated that they primarily use cores to evaluate density and binder content of in-place material that had failing results during production, with a lesser number using cores to evaluate production air voids and gradation failures.
- Concerning running performance tests on roadway cores, four of the 23 responding DOTs use HWTT in some cases. In general, when using the HWTT to evaluate the in-place material, these agencies cut the cores from between the wheel paths to hopefully target 7.0 percent voids. The criteria they use are typically 12.5 mm of rutting after the same number of passes they would use for testing lab-compacted specimens. None of the agencies had a method for addressing situations where the air void levels on the cores were significantly different from 7.0 percent.

# 4. EXPERIMENTAL PLAN

This chapter presents the test plan that was conducted to accomplish the project objectives. The plan was divided into the following three subtasks:

- Subtask 1. Evaluate field performance and construction records for pavement sections with defective materials that were left in place
- Subtask 2. Laboratory testing of lab compacted specimens to determine appropriate performance tests to evaluate dense-graded mixes
- Subtask 3. Laboratory testing to determine appropriate performance tests to evaluate open-graded friction course mixes

Overviews of the objective and approach of each subtask follow in the next sections.

## 4.1 Subtask 1. Evaluate Field Performance and Construction Records for Pavement Sections with Defective Materials that were left in Place

To assess the adequacy of current FDOT practices for evaluating defective materials, the Research Team worked with FDOT to obtain and review project records for pavement sections with defective materials that were left in place. The purpose of these reviews was to identify a suitable cross-section of projects representing the most common material failures and typical levels of evaluation conducted on the defective material (i.e., some failures were simply addressed by a visual review of the pavement and/or a review of the test production data, while other evaluations included comprehensive coring and testing on the in-place material). Based on availability, the projects were selected based on the type of failure and overall quality of the evaluation of the defective material. Twenty-six projects were identified for further assessment in this study. Sixteen projects were dense-graded mixes, and ten projects were OGFC mixes.

The project documents for each section selected for review included available testing records (Process Control (PC), Quality Control (QC), Independent Verification (IV), etc.) and records of the evaluation (Disposition of Defective Material (DDM) report, delineation results, Engineering Analysis Reports, etc.). From this data, the research team provided recommendations for the section of pavements to be evaluated within the project limits. Once the projects were identified, FDOT Pavement Condition Survey (PCS) staff conducted detailed pavement evaluations of the projects. The Research Team and FDOT staff agreed that the performance data of the pavement section portions with defective material would be compared with those of the remaining project for a particular lane that did not experience any issues. It is important to point out that with this approach, the length of the section with non-defective material was typically longer than the length of the remaining section with defective material.

Based on the Research Team's prior experiences with FDOT projects and discussions with FDOT staff, the project focused on three types of failure types FDOT commonly encounters, low air voids in dense-graded mixes (suggesting a potential rutting problem), low binder content in open-graded mixes (suggesting a potential raveling problem), and high binder content in open-graded mixes (suggesting either a potential flushing/bleeding problem or the texture in the mixture "closing up" resulting in insufficient drainage of water from the pavement surface). Table 6 summarizes the characteristics of the projects that were selected for evaluation.

**Table 6. Characteristics of the Projects Selected for Evaluation**

| **Mixture Type** | SP-12.5/FC-12.5/FC-9.5 | FC-5 | FC-5 |
|---|---|---|---|
| **Failure Types** | Low laboratory compacted air voids; low-density | Low binder content | High binder |
| **No. of Projects Evaluated** | 16 | 5 | 5 |

## 4.2 Subtask 2. Laboratory Testing of Lab Compacted Specimens to Determine Appropriate Performance Tests to Evaluate Dense-Graded Mixes

A laboratory evaluation that included five mix designs was performed for this study using different production and construction scenarios that included low lab-compacted air voids (<2.3%) and varying in-place density levels on mixture rutting potential using performance tests. For each of the five designs, rutting tests were conducted at four separate testing conditions as summarized in Table 7. These testing conditions are described in greater detail below. FDOT selected five approved dense-graded designs and shipped the necessary material to NCAT for this evaluation. Rutting for these designs was assessed using the Asphalt Pavement Analyzer (APA, AASHTO T340-23) and the High-Temperature Indirect Tension Test (HT-IDT, ALDOT Method 458, Draft ASTM Standard).

- <u>Testing Condition 1 – Good Production and Good Density</u>
    - This testing condition represents the mix as it is intended to be produced by the job mix formula. This mix is also referred to as the 'original blend' in this report. This mix meets FDOT's master production range (MPR) for air voids at $N_{des}$, total AC content, and dust. This mix was compacted to 7 percent air voids in the lab to represent 93 percent $G_{mm}$ in the field.
- <u>Testing Condition 2 – Poor Production with High Density</u>
    - This testing condition represents a mix that failed FDOT's MPR limits for total AC content (JMF AC + 0.55%) and dust (JMF $P_{200}$ + 1.5%) during production – resulting in low lab-compacted air voids at $N_{design}$ (less than 2.3 percent). This 'poor production' blend may also be referred to as the 'high-dust/high-AC' blend in this report. More details regarding how this blend was simulated in the lab are in the following section of this report. This mix was compacted to 4 percent air voids in the lab (96 percent $G_{mm}$) to represent a mix that was constructed with high in-place density in the field.
- <u>Testing Condition 3 – Poor Production with Good Density</u>
    - This testing condition represents a mix that failed FDOT's MPR limits for total AC content and dust during production – resulting in low lab-compacted air voids at $N_{design}$ (less than 2.3 percent). This mix was compacted to 7 percent air voids in the lab to represent 93 percent $G_{mm}$ in the field. This testing condition represents

a mix that had deficiencies during production but was constructed with acceptable density levels.

- Testing Condition 4 – Poor Production with Low Density
  - This testing condition represents a mix that failed FDOT's MPR limits for total AC content and dust during production – resulting in low lab-compacted air voids at $N_{design}$ (less than 2.3 percent). This mix was compacted to 9.5 percent air voids in the lab to represent 90.5 percent $G_{mm}$ in the field. This effectively represents the worst-case scenario for defective materials, with deficiencies both during plant production and field construction.

**Table 7. Summary of Testing Conditions – Laboratory Rutting Evaluation**

| Testing Condition | Lab Compacted Air Voids at Ndes | Total AC (%) | $P_{200}$ (%) | In-Place Density, Air Voids (%) |
|---|---|---|---|---|
| 1 | Good (4.0%) | JMF | JMF | Good (7.0%) |
| 2 | Low (<2.3%) | JMF + 0.55% | JMF + 1.5% | High (4.0%) |
| 3 | Low (<2.3%) | JMF + 0.55% | JMF + 1.5% | Good (7.0%) |
| 4 | Low (<2.3%) | JMF + 0.55% | JMF + 1.5% | Low (9.5%) |

Table 8 summarizes the five mix designs selected by FDOT for the laboratory rutting evaluation. The table contains the FDOT Design ID (e.g., SP 21-20064A, SP-12.5, TL-C) along with the NCAT ID. For brevity, the NCAT ID will be used throughout this section of the report. Three of the mixes contained Georgia granite (two designs using Junction City granite and one design using Camak granite), one design contained Nova Scotia granite, and one design contained south Florida limestone (Whiterock). The NMAS, virgin binder grade, total AC content, and RAP contents are summarized in Table 8 as well. All of the designs contained a PG 76-22 binder except the Camak 40% RAP design, which used a PG 52-28 binder.

A mix design verification was performed at NCAT using the provided materials for each of the five designs. This was necessary to ensure that the original design (testing condition '1' in Table 7) was starting at 4.0% air voids at $N_{design}$. For each design, a 'high-dust/high-AC' blend was also developed to perform rut testing on testing conditions 2, 3, and 4 in Table 7.

The following steps were taken to verify the original design and to develop the high-dust/high-AC design for each blend:

- Characterize the RAP (ignition and washed gradation) and perform gradations on the aggregate stockpiles.
- Adjust the stockpile percentages (or cold feeds) to obtain the total blend gradation as close as possible to the total blend gradation listed on the FDOT design.
- Compact $N_{des}$ specimens and test $G_{mb}$ and $G_{mm}$ using the modified design.
  - Compare the $G_{mb}$ and $G_{mm}$ values to the JMF values. If $G_{mb}$ and $G_{mm}$ are within AASHTO between lab D2S tolerances, proceed.
- Determine the total AC content that gives 4.0% air voids at $N_{des}$.

- For all but one design, this was within 0.2% AC of the JMF total AC content.

- Develop a high-dust/high-AC blend for the same design by adding 1.5-1.6% baghouse fines to the blend and removing 1.5-1.6% of the fine aggregate stockpile with the highest $P_{200}$ content.
- Mix and compact $N_{design}$ specimens and test $G_{mb}$ and $G_{mm}$ on the high-dust/high-AC blend. These specimens will have an additional +0.55% total AC relative to the verified AC content above.
  - If the lab-compacted air voids are less than 2.3% on the high-dust/high-AC blend, proceed to laboratory rut testing with this blend.
  - If the lab-compacted air voids are greater than 2.3%, a second high-dust/high-AC blend will be developed by coarsening the blend on the #8 sieve to further reduce VMA and air voids.

**Table 8. Summary of Mix Designs – Laboratory Rutting Evaluation**

| FDOT Design ID | NCAT ID | Aggregate Type | NMAS, mm | Binder Grade | Total AC (%) | RAP (%) |
|---|---|---|---|---|---|---|
| SP 21-20064A, SP-12.5, TL-C | Camak 40RAP | Georgia Granite, Camak | 12.5 | PG 52-28 | 5.3 | 40 |
| SPM 19-17098B, FC-12.5, TL-C | Whiterock (WR) | South Florida Limestone | 12.5 | PG 76-22 | 6.1 | 0 |
| SPM 18-16798A, SP-12.5, TL-C | Junction City (JC) – White Sand | Georgia Granite, Junction City | 12.5 | PG 76-22 | 5.1 | 20 |
| SPM 22-21611A, FC-9.5, TL-C | Junction City (JC) – Red Sand | Georgia Granite, Junction City | 9.5 | PG 76-22 | 5.6 | 20 |
| SPM 22-21439A, SP-12.5, TL-C | Duval | Nova Scotia Granite | 12.5 | PG 76-22 | 5.3 | 20 |

Table 9 summarizes the total AC content, dust content, and air voids at $N_{design}$ of the NCAT verified blend and the high-dust/high-AC blend for each of the five mix designs. During the design verification process, there was communication between NCAT and FDOT staff regarding any unexpected occurrences. A summary of these occurrences and their outcomes are summarized as follows:

- The Camak 40% RAP design was the first design tested, and 1.5% baghouse fines (BHF) was added to the design in place of 1.5% of the stockpile with the highest $P_{200}$ content (F20). Due to the loss in fines from the F20, the total dust increase in the blend was a little less than 1.4% total $P_{200}$. For the remaining designs, the percentage of BHF was increased to 1.6% to ensure the total increase in blend $P_{200}$ was closer to 1.5%.
- The Camak 40% RAP design tested with 2.28% air voids at $N_{design}$ on the high-dust/high-AC blend. NCAT was allowed to proceed with this blend after communicating with FDOT staff.
- For the Whiterock design, the NCAT $G_{mb}$ and $G_{mm}$ numbers did not agree well with the JMF despite the blend gradation matching the JMF very closely. FDOT recommended comparing the NCAT verification values to the production values from the Materials

Acceptance and Certification (MAC) system for that particular design. Much better agreement was seen with the NCAT values and the production values, and FDOT recommended proceeding with that blend.

- For the Junction-City-Red-Sand design, the original high-dust/high-AC blend did not have less than 2.3% air voids at $N_{design}$ (2.5%). At the direction of FDOT, this blend was coarsened through the intermediate sieves to lower the VMA and air voids. The coarsened blend had a lab-compacted air void level of 1.6% at $N_{design}$. Notably, this was the only 9.5-mm NMAS design in this portion of the study, and this was the only design where coarsening the high-dust/high-AC blend was necessary to lower the air voids below 2.3%.
- For the Duval design, the $G_{mb}$ and $G_{mm}$ values on the NCAT blend were both approximately 0.04 higher than the $G_{mb}$ and $G_{mm}$ values on the JMF. However, the air voids at $N_{des}$ were very close to 4.0%, while the JMF optimum total AC content was 5.3%. No production data were available for this mix design at the time of testing for reference. Based on a good gradation agreement between the NCAT blend and the JMF and the blend being close to 4.0% air voids, FDOT recommended that NCAT proceed with that blend.

**Table 9. Summary of Design Verification Results – Laboratory Rutting Evaluation**

| NCAT ID | Total AC (%) | | | $P_{200}$ Content (%) | | Air Voids at $N_{design}$ (%) | |
|---|---|---|---|---|---|---|---|
| | JMF Blend | NCAT Blend | High-Dust/High-AC Blend | NCAT Blend | High-Dust/High-AC Blend | NCAT Blend | High-Dust/High-AC Blend |
| Camak 40RAP | 5.3 | 5.45 | 6.00 | 4.74 | 6.09* | 4.0 | 2.3** |
| Whiterock (WR) | 6.1 | 6.52 | 7.07 | 3.31 | 4.85 | 4.0 | 1.8 |
| Junction City (JC) – White Sand | 5.1 | 5.28 | 5.83 | 4.15 | 5.68 | 4.0 | 1.9 |
| Junction City (JC) – Red Sand | 5.6 | 5.78 | 6.33 | 4.29 | 5.76 | 4.0 | 1.6*** |
| Duval | 5.3 | 5.21 | 5.76 | 4.97 | 6.47 | 4.0 | 2.0 |

* 1.5% additional BHF used for high-dust/high-AC blend. 1.6% additional BHF used for other designs.

** 2.28% total air voids. Approved by FDOT to proceed with evaluation.

*** High-Dust/High-AC blend was coarsened on the #8 sieve to reduce air voids.

### APA Testing – Laboratory Rutting Evaluation

The APA (Figure 12) is a wheel-tracking test that measures specimen rut depth as a function of applied loading cycles. The specimens were tested using a test temperature of 64°C with a hose pressure of 100 psi and a wheel load of 100 lbs. For the APA, two specimens are placed in a single-wheel track. Two-wheel tracks, or replicates, were tested for each testing condition in this study. Specimens were compacted in the Superpave Gyratory Compactor (SGC) to a height of 75 mm and to the target density ±0.5 percent for each testing condition. FDOT is currently using 5.0 mm of rutting in the APA as a threshold value for evaluating defective materials on field cores.

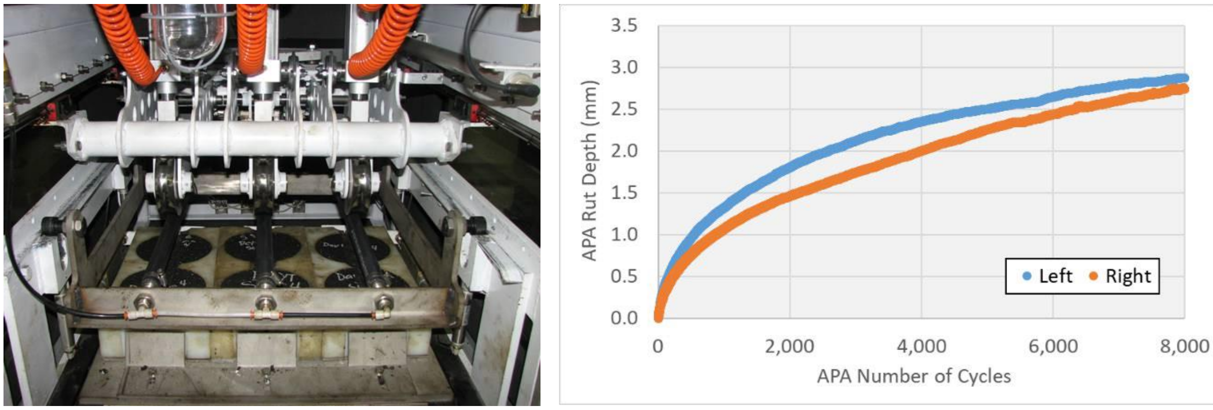



**Figure 12. Asphalt Pavement Analyzer (APA) Machine (left) and Example Data (right)**
**HT-IDT Testing – Laboratory Rutting Evaluation**

### HT-IDT Testing – Laboratory Rutting Evaluation

The HT-IDT test is being evaluated to quickly assess mixture rutting potential in a production setting where a rapid turnaround of results is necessary. The HT-IDT is performed using a standard Lottman breaking head (Figure 13) and any load press capable of loading the specimen at 50 mm/minute and measuring a peak load. A minimum of three specimens for this test were compacted in the SGC to 62 mm tall to the target density +/- 0.5 percent for each testing condition. Specimens were conditioned in a water bath at 50°C for 1 hour before testing. The peak load and specimen dimensions are used to calculate each specimen's indirect tensile strength (ITS). A higher ITS is indicative of a more rutting resistant mixture. The ALDOT BMD Special Provision recommends a minimum ITS of 20 psi for mixtures with good rutting resistance (Yin and West, 2021).

**Figure 13. High-Temperature Indirect Tensile Strength Test (HT-IDT)**

## 4.3 Subtask 3. Laboratory Testing to Determine Appropriate Performance Tests to Evaluate Open-Graded Friction Course Mixes

This laboratory evaluation was performed to evaluate the effect of variability in the gradation and asphalt content on the durability and permeability of FC-5 mixtures. FDOT's master production range (MPR) tolerances for gradation and asphalt content on FC-5 mixtures are summarized in Table 10. The durability of three FC-5 mixtures was assessed using the Cantabro test on gyratory compacted specimens. The permeability of the FC-5 mixes was assessed using the FDOT field permeameter on lab-compacted slab specimens. The FC-5 mixes were tested for durability and permeability at the five testing conditions described in detail as follows:

- Testing Condition 1. As-Designed Mixture (JMF)
  - This testing condition represents an FC-5 mixture that was produced close to the verified mix design for asphalt binder content and gradation.
- Testing Condition 2. High binder content and finer gradation (Fine/High AC or FHAC)
  - This testing condition represents an FC-5 mixture that was produced with a gradation at the extreme fine end of the MPR gradation tolerances with an asphalt content at the high end of the allowable MPR tolerance.
- Testing Condition 3. Low Binder Content and Finer Gradation (Fine/Low AC Or FLAC)
  - This testing condition represents an FC-5 mixture that was produced with a gradation at the extreme fine end of the MPR gradation tolerances with an asphalt content at the low end of the allowable MPR tolerance.
- Testing Condition 4. High Binder Content and Coarser Gradation (Coarse/High AC Or CHAC)
  - This testing condition represents an FC-5 mixture that was produced with a gradation at the extreme coarse end of the MPR gradation tolerances with an asphalt content at the high end of the allowable MPR tolerance.
- Testing Condition 5. Low Binder Content and Coarser Gradation (Coarse/Low AC Or CLAC)
  - This testing condition represents an FC-5 mixture that was produced with a gradation at the extreme coarse end of the MPR gradation tolerances with an asphalt content at the low end of the allowable MPR tolerance.

**Table 10. Summary of FDOT Master Production Range (MPR) Tolerances for FC-5 Mixes**

| Characteristic | Tolerance |
|---|---|
| Asphalt Binder Content (%) | Target ± 0.60 |
| Passing 3/8" Sieve (%) | Target ± 7.50 |
| Passing #4 Sieve (%) | Target ± 6.00 |
| Passing #8 Sieve (%) | Target ± 3.50 |

Table 11 summarizes the mix design gradations and asphalt contents of the three FC-5 mixtures selected for this study. These mixes were designed with the Junction City, Whiterock, and Nova Scotia aggregates and will be referred to by their aggregate type for the remainder of this report. To verify the optimum AC content, aggregate samples of each mixture were batched at NCAT from the provided raw materials and sent to FDOT. FDOT then conducted the pie plate test to determine the optimum AC content of each mix design. Table 11 shows the optimum AC content for each mix design as well as the low and high AC contents, which were 0.6 percent below and 0.6 percent above the provided optimum value. The full FDOT design ID for each FC- 5 mix design is provided in also provided in Table 11.

**Table 11. Summary of JMF Gradations and AC Contents – FC-5 Mixes**

| Sieve (mm) | Sieve (in.) | Junction City (JC) FC-5 | Whiterock (WR) FC-5 | Nova Scotia (NS) FC-5 |
|---|---|---|---|---|
| 19 | 3/4" | 100.0 | 100.0 | 100.0 |
| 12.5 | 1/2" | 96.8 | 94.0 | 95.4 |
| 9.5 | 3/8" | 74.1 | 74.1 | 75.2 |
| 4.75 | #4 | 24.3 | 23.5 | 23.0 |
| 2.36 | #8 | 9.9 | 10.1 | 10.2 |
| 1.18 | #16 | 6.7 | 7.5 | 6.1 |
| 0.6 | #30 | 4.8 | 6.5 | 4.5 |
| 0.3 | #50 | 3.4 | 5.5 | 4.0 |
| 0.15 | #100 | 2.8 | 3.8 | 3.7 |
| 0.075 | #200 | 2.4 | 3.3 | 2.6 |
| | | | | |
| Optimum AC (OAC) (%) | | 6.2 | 6.7 | 6.1 |
| OAC minus 0.6% | | 5.6 | 6.1 | 5.5 |
| OAC plus 0.6% | | 6.8 | 7.3 | 6.7 |
| FDOT Design ID | | SPM 21-19293A | SPM 19-17291A | SPM 22-20361A |

**Cantabro Test for Mixture Durability**

The Cantabro test for FC-5 mixture durability was performed on the three FC-5 mix designs for this study by AASHTO T401-22. Three replicates compacted to $N_{design}$ (50 gyrations) were tested for each gradation and AC combination for the three FC-5 mixtures. Before Cantabro testing, the air void content of each specimen was determined using the vacuum sealing method per AASHTO T331-23. The vacuum sealing apparatus used at NCAT, along with a photo of a specimen after vacuum sealing, are shown in Figure 14. NCHRP Report 877 *Performance-Based Mix Design of Porous Friction Courses* recommended an air void content of 15-20% for OGFC mixes determined with the vacuum sealing method (Watson et al., 2018).

The specimens were conditioned in an environmental chamber for at least four hours at 25°C before Cantabro testing. Subsequently, each specimen was placed inside the Los Angeles Abrasion drum without the charge of steel spheres and subjected to 300 revolutions at a speed of 30 to 33 revolutions per minute. After the test, the largest portion of the remaining specimen was removed from the machine, and the weight was determined (Figure 15). The mass loss is calculated by taking the original mass minus the mass after testing and dividing it by the original mass. A maximum Cantabro mass loss of 20 percent on short-term aged specimens is commonly used for the design of open-graded or porous friction course mixes and is cited in the ASTM D7084 standard for the design of open-graded friction course mixtures.


**Figure 14. Vacuum Sealing Apparatus (left) and Vacuum-Sealed FC-5 Specimen (right)**


**Figure 15. Los Angeles Abrasion Machine Used for Cantabro Testing (left) and FC-5 Specimen after Cantabro Testing (right)**

### FDOT Permeameter Testing

Permeability testing was performed on the three FC-5 mixes for this study using a field permeameter loaned to NCAT by FDOT (Figure 16). Permeability testing was performed on laboratory compacted slab specimens, as shown in Figure 16. For each of the fifteen slabs (three mixes x five testing conditions), a single slab (20-inch x 15-inch) was compacted to a height of 2 inches thick using an automated laboratory slab compactor. The mass of each slab was targeted to match the appropriate density for that testing condition, which was previously determined on gyratory specimens using the vacuum sealing method. Permeability testing was performed by filling the permeameter tube with water and recording the time the water in the tube took to fall between two marks on the permeameter. A minimum of three runs were tested per slab. The permeability of each slab was determined using a spreadsheet provided by FDOT. The coefficient of permeability (k) was calculated as a function of the slab thickness, the distance between the timing marks on the permeameter tube, and the time required for the water to travel between the tube markings.

It should be noted that all of the permeability readings taken using this method were extremely high. The field permeameter is typically used on continuous pavements with confined edges. When testing slabs sitting on top of a concrete pad, the edges of the slab were not confined. Hence, the water had very little distance to travel through the slab before being free to flow out of the slab. These issues were communicated with FDOT during testing, and the decision was made to proceed using this method for this study. However, it is recommended the permeability values in this report only be used as relative rankings within each mix rather than as definitive data regarding the permeability of a given mixture.

**Figure 16. FDOT Permeameter with FC-5 Slab**

# 5. RESULTS AND DISCUSSIONS

## 5.1 Subtask 1 Results and Analysis

For each of the projects under evaluation, a comprehensive review of the project documents was conducted, and key information was summarized. This information included project identification (Florida Project Number [FPN], road, county, county section number), mix type, mix design number, traffic level, date placed, and a description of the project failure type and actions taken. In addition, for each of the projects, the research team provided a recommendation for the test section that needed to be evaluated in terms of PCS within the limits of the projects.

Once the pavement performance data conducted by FDOT PCS staff was received, the research team compared the long-term performance of the material in question with the performance of the non-defective areas of the project to assess whether the correct decision was made when the defective material was left in place and whether improvements can be made to FDOT's current analysis procedures for defective materials. Projects under evaluation were at least 8 years old at the time the surveys were conducted.

Below is an example of the information gathered for one of the projects. Complete project summaries for each project are presented in Appendix A. Table 12 presents a summary of the field performance for one of the projects with a dense-graded mix and low air voids (FPN 201275-2-52-01). This summary included the average, standard deviation, and maximum value for the International Roughness Index (IRI), Laser Crack Measurement System (LCMS) rutting, cracking in the wheel path (CW), cracking outside of the wheel path (CO), and low, medium and severe raveling. Performance data were collected every 0.001 mile (5.28 feet). Although the complete PCS data were summarized to have a good understanding of the overall performance of each project, the analysis focused on the following distresses for each mix and failure type combination:

- Dense-graded mixes with low air voids; rutting
- FC-5 mixes with low binder content-raveling, cracking, and IRI
- FC-5 mixes with high binder content; rutting

**Project 1 – Dense-Graded Mix with Low Air Voids**

*Florida Project Number (FPN):* 201275-2-52-01
*Road:* Sumter Boulevard
*County:* Sarasota
*County Section No.:* 17000
*Mix Type:* SP-12.5
*Mix Design No.*: SPM 13-11624A
*Traffic Level:* C
*Date Placed:* August 6, 2013
*Engineering Analysis Report (EAR) Firm:* Cal-Tech Testing
*Failure Location:* QC failure lot 2, Sublot 1

<u>*Project Description*</u>

Lot 2 Sublot 1 was terminated due to low QC air voids (1.89%). The sample was taken at Load 10 (466.25 tons in lot). The contractor got their results during Load 19 and shut the plant down.

The mix was placed on Lane R2 Sta 19+80 to 43+20; and Lane L1 Sta 43+20 to 19+80. Independent Verification (IV), Verification (V), and process control (PC) samples (Loads 10, 10, & 20, respectively) had air voids of 3.27%, 2.38%, and 2.75%. Load 10 placed was Lane L-1 ~Sta 22+45. Target Sta 22+45 +/- 150 feet.

An EAR was conducted for the project. The analysis included testing core samples for binder content and gradation analysis. The percentage asphalt content vs. the percent passing No. 8 sieve was plotted, and relationships were established between the air voids and the pass/fail line on the percentage asphalt content vs. the percentage passing No. 8 sieve graph. Conclusions were based on whether the core test results were plotted above or below the pass-fail line of the graphs. All the data points fell in the passing zone. The recommendation was to leave the questionable material in place.

Note: The resurfacing consisted of 1.5 in of SP 12.5 (PG 76-22) and 1 in. of FC-9.5 (PG 76-22) placed on top of this layer. The project is an interchange with I-75.

**Research project recommended section for evaluation:** MP 1.933 – 1.990 (Sta 20+95 – 23+95) in Lane L-1.

**Table 12. Example of Field Performance Summary – Dense-Graded Mix-Low Air Voids (FPN 201275-2-52-01)**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 102 | 0.10 | 2.9 | 0.2 | 0 | 0 | 0 |
| | Std. Dev. | 50 | 0.04 | 4.4 | 1.0 | 0 | 0 | 0 |
| | Max. | 271 | 0.20 | 15.2 | 6.5 | 0 | 0 | 0 |
| Non-defective Material | Average | 97 | 0.06 | 0.6 | 0.4 | 0 | 0 | 0 |
| | Std. Dev. | 53 | 0.05 | 2.9 | 1.9 | 5 | 5 | 0 |
| | Max. | 409 | 0.28 | 44.3 | 19.9 | 100 | 100 | 0 |

## Dense-Graded Mixes with Low Air Voids

As indicated previously, 16 projects constructed with dense-graded mixes were included in the evaluation. The QC failures for these projects were low air voids (Va < 2.3%). The QC air voids for these defective materials ranged from 1.67% to 2.23%. Figure 17 summarizes the average rutting of defective and non-defective materials by project. In this figure, the performance of projects 3, 11, and 13 was divided into two different sets of data because 2 lanes within each project failed the QC air voids limit. This resulted in 3 additional data sets under evaluation. As presented in this figure, only Project 9 exceeded an average rutting of 0.2 in (0.21 in) for its corresponding non-defective material. For 7 out of 19 comparisons, the average rutting results of the defective materials were higher than those of the non-defective materials but still relatively low, indicating no significant concern for rutting for any of the projects.

A statistical analysis using a t-test (with a p-value <0.05) was conducted with the test results. The results of this analysis are summarized in Appendix B. Although this analysis indicates that for 15 comparisons, there is a difference in the mean rutting value, because of the overall low rutting results and their relatively high standard deviation, statistical comparisons using a t-test yielded no practical differences in the test results. Based on the results presented in Figure 17, it can be concluded that the decision to leave the defective materials in place for these projects was adequate.

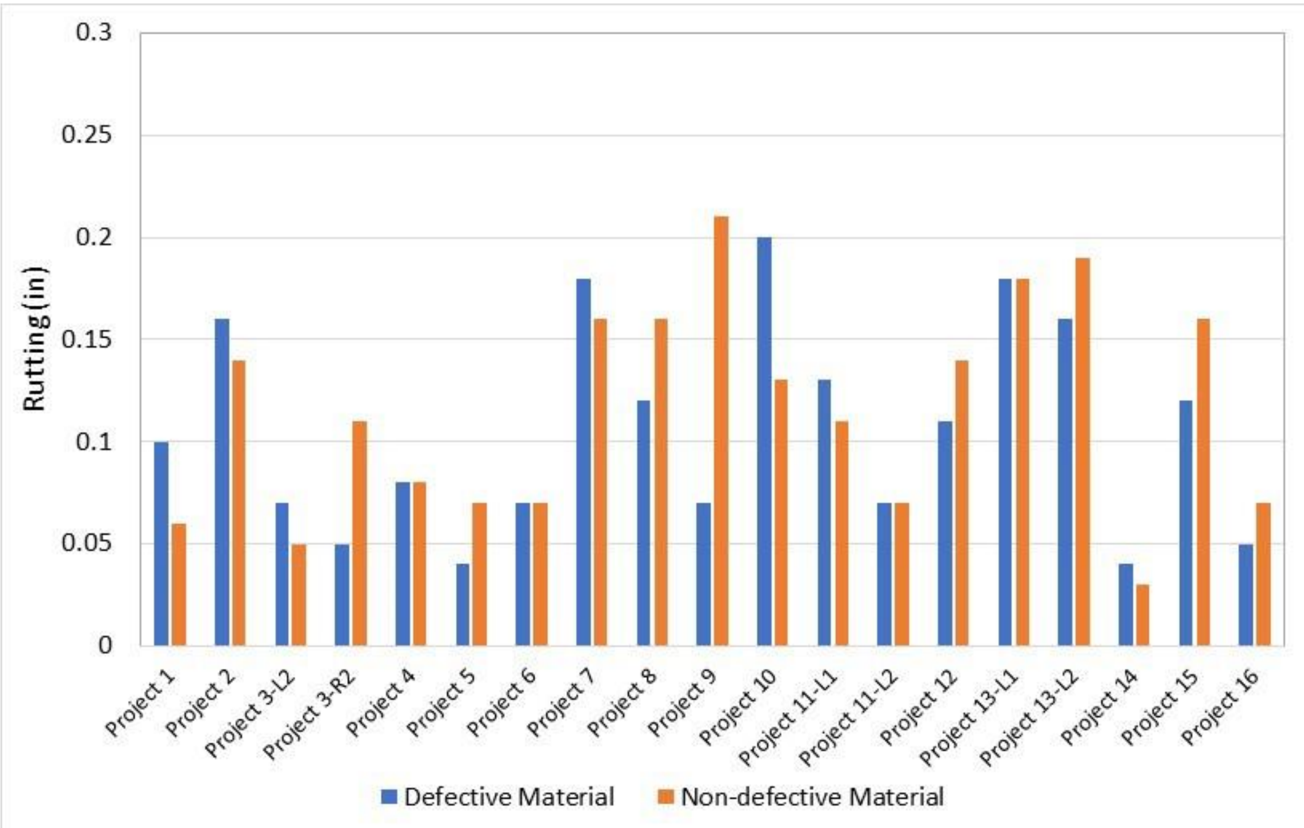



**Figure 17. Summary of Average Rutting of Defective and Non-Defective Materials by Project for Dense-Graded Mixtures with Low Air Voids**

### FC-5 Mixes with Low Binder Content

Five projects constructed with Open-Graded FC-5 mixes with QC failures due to low binder content (AC= target-0.6%) were included in the evaluation. The difference in QC binder content with respect to the target binder content for these defective materials ranged from 0.64% to 1.03%.

Table 13, Table 14, and Table 15 summarize the average percent of raveling (low, medium, and high severity), the average percent of cracking in the wheel path (CW) and outside the wheel path (CO), and the average IRI of defective and non-defective materials by project, respectively. As presented in Table 13, medium or high severity raveling was not a concern for any of the projects. Projects 17, 18, and 21 showed some low raveling, particularly project 18, but for the non-defective material at 56%. For project 21, the raveling percentages for the defective and non- defective materials were almost identical at 15 and 14, respectively. For project 17, the defective materials showed higher low raveling at 15% compared to 7% of the non-defective material. The cracking performance of the projects presented in Table 14 indicates that Projects 18, 19, 20, and 21 had relatively equivalent performance. At the same time, Project 17 showed some separation in the average percentage of CO of the defective material and non-defective materials at 8.0% and 3.7%, respectively. Nevertheless, the average percentage of CW and CO for all the projects did not exceed 8.0%. The average IRI results showed that the defective materials had higher values for all projects than the non-defective materials. However, the IRI did not exceed 77 in/mi. These results suggest that the decision to leave the defective materials in place for these projects was adequate.

**Table 13. Summary of Average Percent Raveling (Low, Medium, and High) of Defective and Non-Defective Materials by Project for FC-5 Mixtures with Low Binder Content**

| Project Number | Raveling Low | | Raveling Med. | | Raveling Sev. | |
|---|---|---|---|---|---|---|
| | Defective Material | Non-Defective Material | Defective Material | Non-Defective Material | Defective Material | Non-Defective Material |
| Project 17 | 15 | 7 | 3 | 1 | 1 | 0 |
| Project 18 | 8 | 56 | 0 | 3 | 0 | 0 |
| Project 19 | 0 | 0 | 0 | 0 | 0 | 0 |
| Project 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| Project 21 | 15 | 14 | 0 | 2 | 0 | 0 |

**Table 14. Summary of Average Percent Wheel Path Cracking (CW) and Outside Wheel Path Cracking (CO) of Defective and Non-Defective Materials by Project for FC-5 Mixtures with Low Binder Content**

| Project Number | Cracking CW (%) | | Cracking CO (%) | |
|---|---|---|---|---|
| | Defective Material | Non-Defective Material | Defective Material | Non-Defective Material |
| Project 17 | 5.1 | 3.3 | 8.0 | 3.7 |
| Project 18 | 1.2 | 2.4 | 5.9 | 7.7 |
| Project 19 | 5.4 | 3.5 | 2.5 | 2.6 |
| Project 20 | 1.5 | 2.1 | 2.8 | 2.6 |
| Project 21 | 2.3 | 3.8 | 1.1 | 1.5 |

**Table 15. Summary of Average IRI of Defective and Non-Defective Materials by Project for FC-5 Mixtures with Low Binder Content**

| Project Number | IRI Avg. (in/mi) | |
|---|---|---|
| | Defective Material | Non-Defective Material |
| Project 17 | 77 | 70 |
| Project 18 | 77 | 69 |
| Project 19 | 46 | 42 |
| Project 20 | 36 | 32 |
| Project 21 | 75 | 63 |

### FC-5 Mixes with High Binder Content

Five additional projects were constructed with FC-5 mixes, and QC failures due to high binder content (AC= target +0.6%) were included in the evaluation. The difference in QC binder content with respect to the target binder content for these defective materials ranged from 0.63% to 0.86%. All the projects used a PG 76-22 binder or higher.

As indicated previously, only rutting data was included in this evaluation. Figure 17 summarizes the average rutting of defective and non-defective materials by project. In this figure, the performance of projects 23 and 26 was divided into two different data sets because 2 lanes within each project failed the QC binder content limit. This resulted in 2 additional data sets under evaluation. As presented in this figure, no project exceeded an average rutting of 0.25 in. For 3 out of 7 comparisons, the rutting of the defective material was higher than the non-defective material but still relatively low. Based on these results and considering that these projects have been in place for 9-12 years and that all used, at a minimum, a PG 76-22 binder, the rutting performance of these projects seems acceptable, and the decision to leave the defective material in place was adequate.

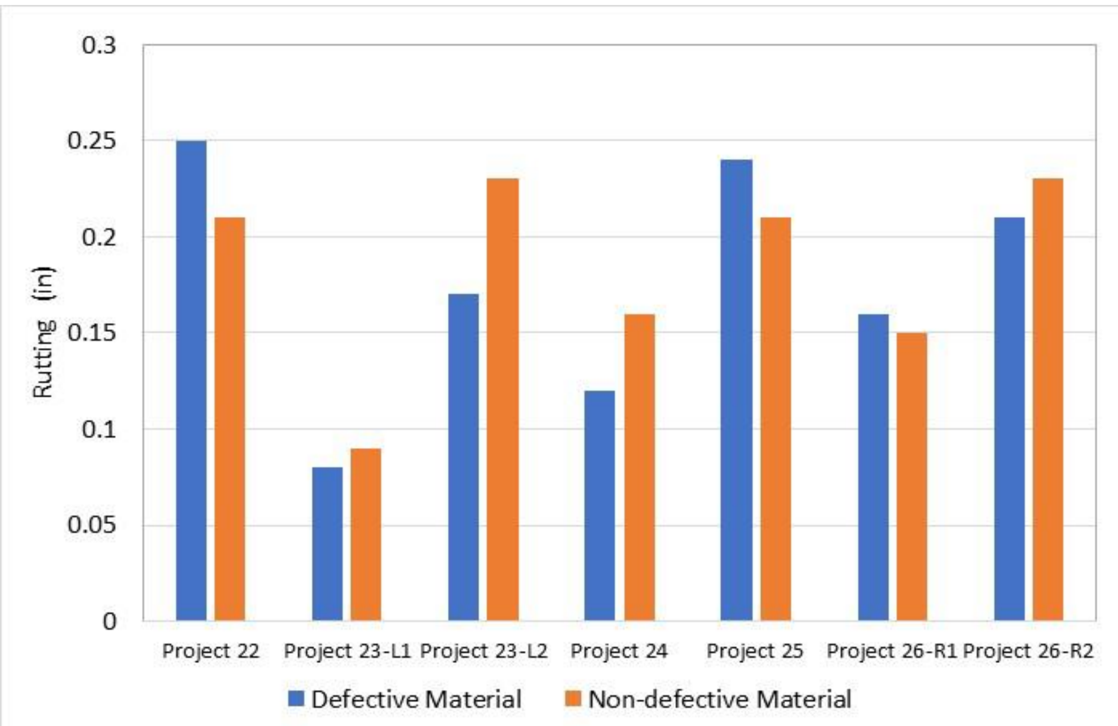



**Figure 18. Summary of Average Rutting of Defective and Non-Defective Materials by Project for FC-5 Mixtures with High Binder Content**

## 5.2 Subtask 2 Laboratory Test Results

### APA Results

The APA test results for this study are summarized in Figure 19, with a more detailed statistical summary presented in Appendix C. For each of the five mixes, an ANOVA ($\alpha = 0.05$) with Games-Howell statistical groupings was performed to evaluate statistical differences between the original blend (normal production and construction) and the high-dust/high-AC blends (poor production) with varying levels of in-place density (high, normal, and poor). These statistical groupings are summarized in Table 16. Note that a lower rut depth indicates better rutting resistance for the APA. Hence, the 'A' statistical groupings represent the mixes with the highest rutting potential (poorest performance) in this evaluation.

For each of the five mixes, the mix with unsatisfactory production (high-dust/high-AC) and poor in-place density (9 to 10% air voids) had the highest rutting and was in the lowest statistical grouping in terms of total APA rutting. This testing condition represented the worst-case scenario and was expected to give the highest laboratory rutting values. In most cases, the original blend with good production and good density (7% air voids) was in the top statistical grouping with the poor production (high-dust/high-AC) mix with high in-place density (4% air voids). It is to be expected that a higher density on a given blend will improve laboratory rutting resistance, given that there is a higher mass of material in the same specimen volume. It is also reasonable that the rutting resistance of a poorly produced mix can be improved with improved compaction in the field. The only exception was the Camak 40% RAP mix with the softer PG 52-28 binder, where the high- dust/high-AC mix with 4% air voids was in the top statistical grouping by itself. The mix with the softer base binder showed greater statistical separation in the APA results because of the higher rut depth magnitudes. When comparing the mixtures with the same density (7% air voids), the original blend always had numerically better (lower) rutting than the high-dust/high-AC blend. However, the only mix with a statistical improvement was the Camak 40% RAP mix. This is also reasonable in that if mixes have comparable density, the mix with higher AC and lower air voids should have higher rut depths. Overall, the relative rankings of the APA data fell in line with expected trends.

This data set was also compared against the FDOT defective material threshold of 5.0-mm used on roadway cores. For the Camak 40% RAP mix, the only mix to pass the 5.0-mm threshold was the high-dust/high-AC blend with high in-place density. Again, the higher rut depths for this set are owed to the use of the softer PG 52-28 binder. None of the sets had an APA rut depth above 5.0-mm for the Whiterock and Duval mixes, including the high-dust/high-AC mix with low in-place density. For the Junction City – White Sand mix, the high-dust/high-AC mix with normal and low in-place density failed the APA criteria. For the Junction City – Red Sand mix, only the high-dust/high-AC mix with low in-place density failed the APA criteria, though the high-dust/high-AC mix with normal density was close with a rut depth of 4.8-mm. In summary, these five mixes showed a wide range of outcomes relative to the 5.0-mm APA threshold.

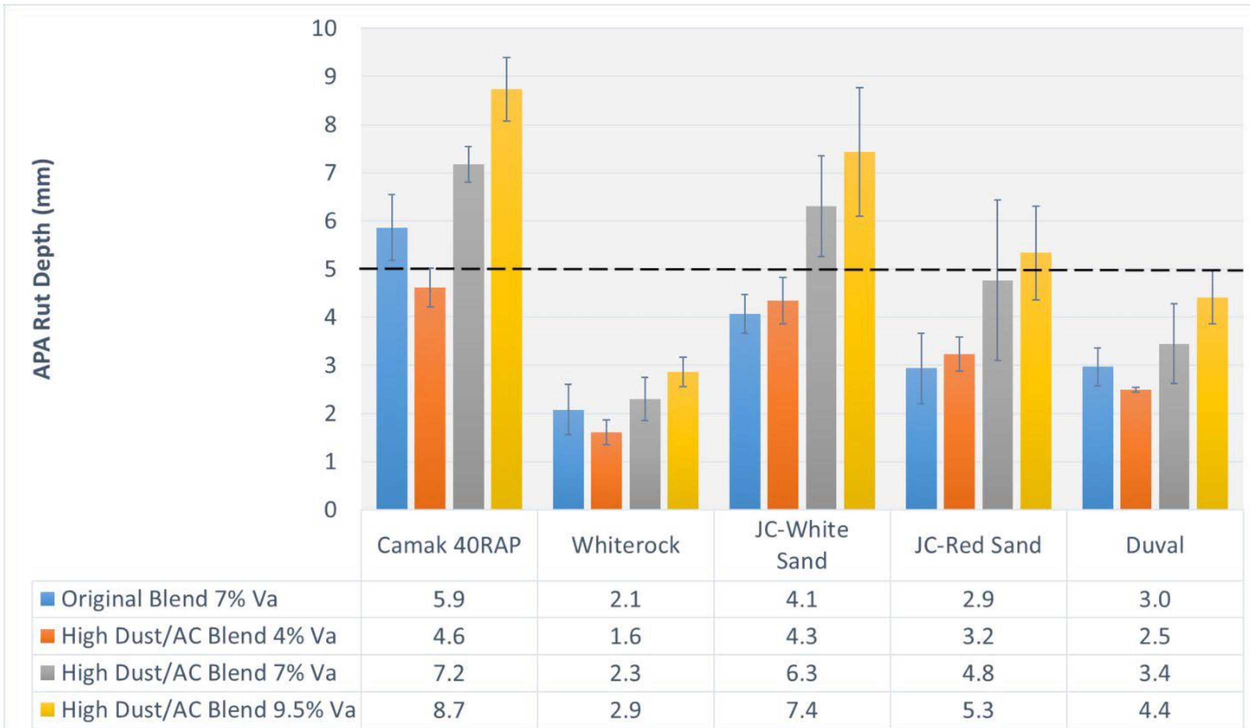



**Figure 19. Summary of APA Results – Laboratory Rutting Evaluation**

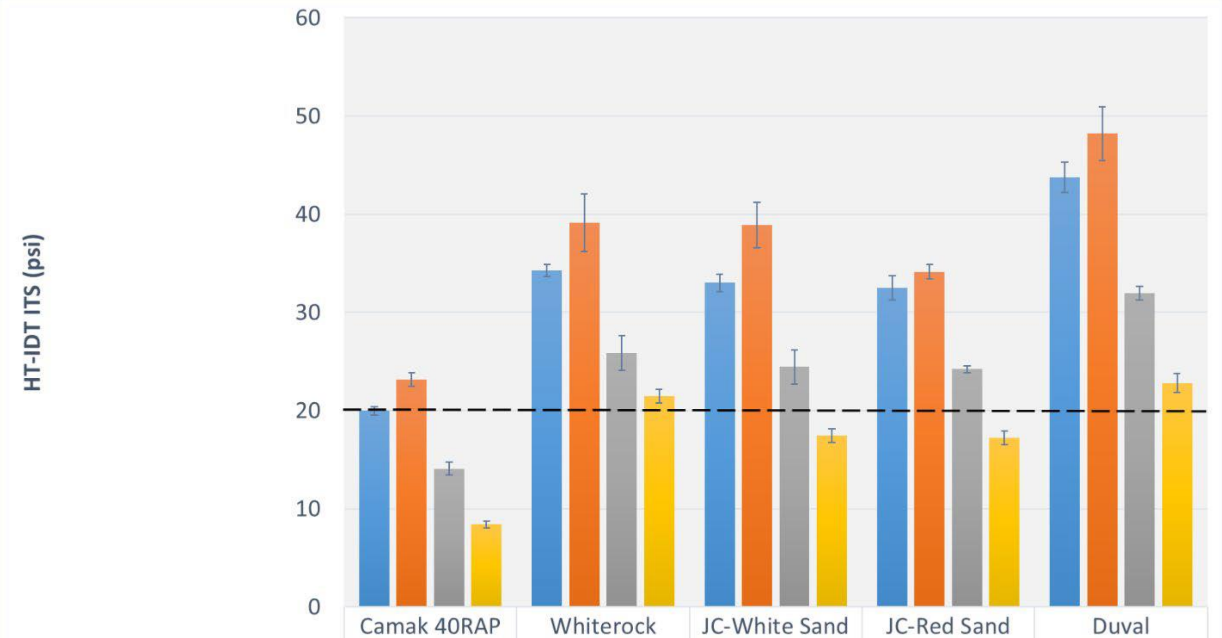
**Table 16. Summary of APA Statistical Groupings – Laboratory Rutting Evaluation**

| AC Content | $P_{200}$ Content | Target Va (%) | Camak 40RAP | Whiterock | JC-White Sand | JC-Red Sand | Duval |
|---|---|---|---|---|---|---|---|
| OAC | Design | 7 | C | B, A | B | B | B |
| OAC + 0.55% | Design + 1.5% | 4 | D | B | B | B, A | B |
| OAC + 0.55% | Design + 1.5% | 7 | B | B, A | A, B | B, A | A, B |
| OAC + 0.55% | Design + 1.5% | 9.5 | A | A | A | A | A |

## HT-IDT Results

The HT-IDT test results for this study are summarized in Figure 20, with a more detailed statistical summary presented in Appendix D. Similar to the APA data, an ANOVA ($\alpha = 0.05$) with Games-Howell statistical groupings was performed to evaluate statistical differences between the original blend (normal production and construction) and the high-dust/high-AC blends (poor production) with varying levels of in-place density. These statistical groupings are summarized in Table 17. Note that for the HT-IDT data, a higher ITS is indicative of better rutting resistance. Hence, a higher letter statistical grouping would indicate higher ITS values and statistically lower rutting resistance (i.e., the letter 'A' would be the top statistical grouping). It is important to note because this is the opposite of the APA data.

Overall, the HT-IDT test results showed the same general trends as the APA results regarding the behavior of the poor production (high-dust/high-AC) mix at varying in-place densities relative to the original blend. The poor production and poor in-place density blend was always in the bottom statistical grouping, and four out of the five mixes (except the Whiterock design) fell below the previously mentioned HT-IDT criterion of 20 psi. The poor production and high in-place density mix (4 percent air voids) always fell in the top statistical grouping, while the original blend was in the top statistical grouping for three of the five mixes. Comparing the original blend with the poor production blend at the same density, the original blend always had statistically better rutting resistance than the poor production blend that was produced with excess AC and dust. Overall, the HT-IDT results showed the same trends as the APA but with greater separation between the statistical groupings.




| | Camak 40RAP | Whiterock | JC-White Sand | JC-Red Sand | Duval |
|---|---|---|---|---|---|
| Original Blend 7% Va | 20.0 | 34.3 | 33.0 | 32.5 | 43.7 |
| High Dust/AC Blend 4% Va | 23.1 | 39.1 | 38.9 | 34.1 | 48.2 |
| High Dust/AC Blend 7% Va | 14.1 | 25.9 | 24.4 | 24.2 | 32.0 |
| High Dust/AC Blend 9.5% Va | 8.4 | 21.5 | 17.4 | 17.2 | 22.8 |

**Figure 20. Summary of HT-IDT Results – Laboratory Rutting Evaluation**

**Table 17. Summary of HT-IDT Statistical Groupings – Laboratory Rutting Evaluation**

| AC Content | $P_{200}$ Content | Target Va (%) | Camak 40RAP | Whiterock | JC-White Sand | JC-Red Sand | Duval |
|---|---|---|---|---|---|---|---|
| OAC | Design | 7 | B | A | B | A | A |
| OAC+0.55% | Design + 1.5% | 4 | A | A | A | A | A |
| OAC+0.55% | Design + 1.5% | 7 | C | B | C | B | B |
| OAC+0.55% | Design + 1.5% | 9.5 | D | C | D | C | C |

Finally, the HT-IDT and APA results from this project were compared to see if they were showing the same general trends. Figure 21 shows the HT-IDT versus the APA results with an individual linear regression for the data from each of the five dense-graded mix designs. Each of these designs showed a strong correlation between the HT-IDT and APA data with a linear regression $R^2$ at or above 0.9 – albeit with only 4 data points per mix. Figure 22 shows all 20 HT-IDT and APA data points plotted against each other in the same relationship. The correlation was still reasonable, although with a bit more scattered (exponential $R^2$ = 0.69). Hence, the HT-IDT and APA tests did show the same general trends in the data for this study.

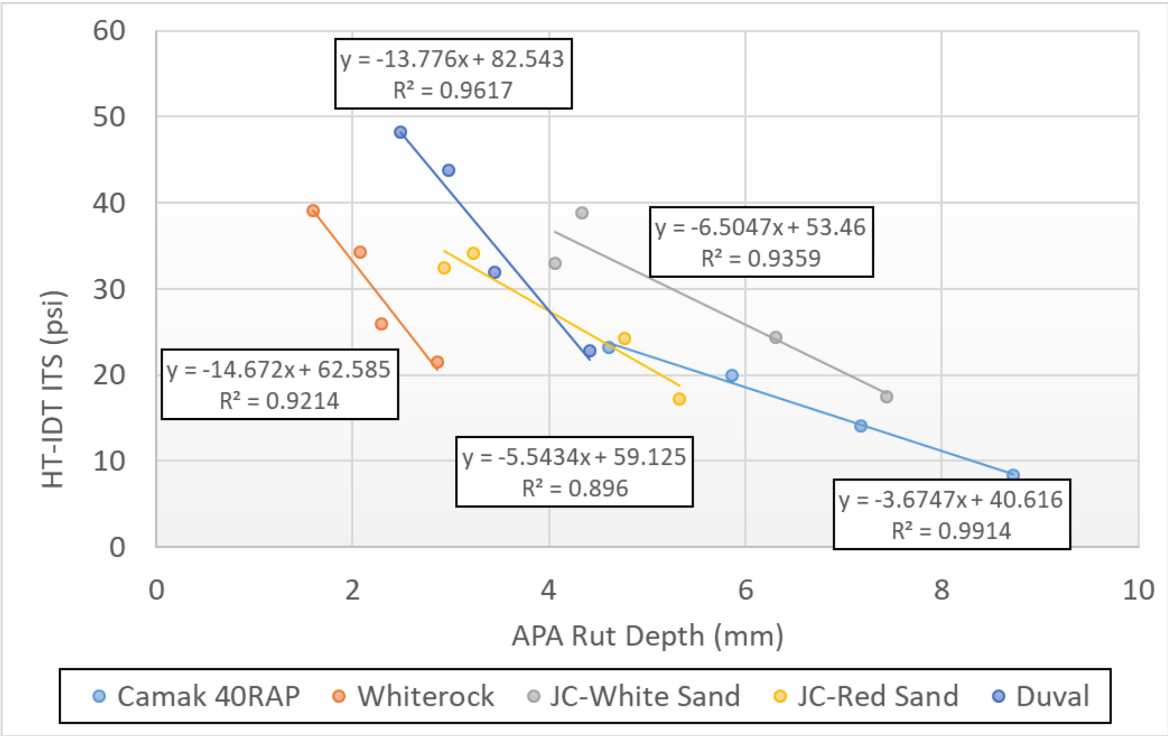


**Figure 21. APA Rut Depth vs. HT-IDT ITS – Individual Projects – Laboratory Rutting Evaluation**

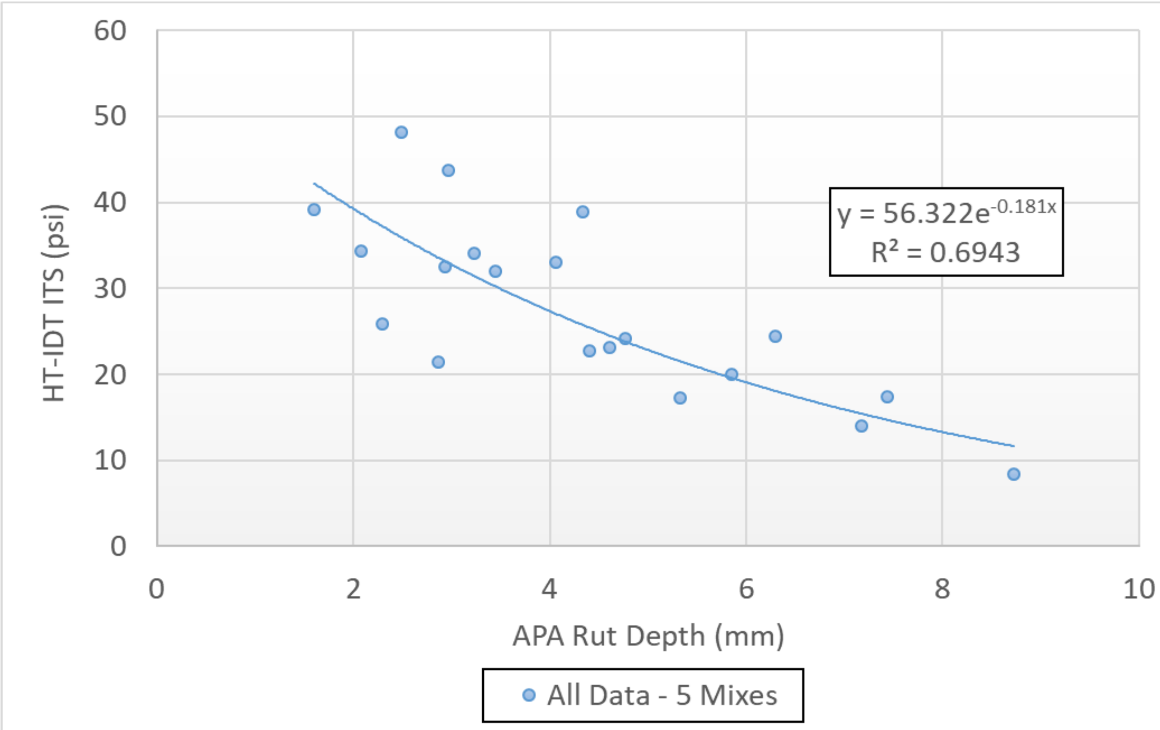



**Figure 22. APA Rut Depth vs. HT-IDT ITS – All Data – Laboratory Rutting Evaluation**

### 5.3 Subtask 3 Laboratory Test Results

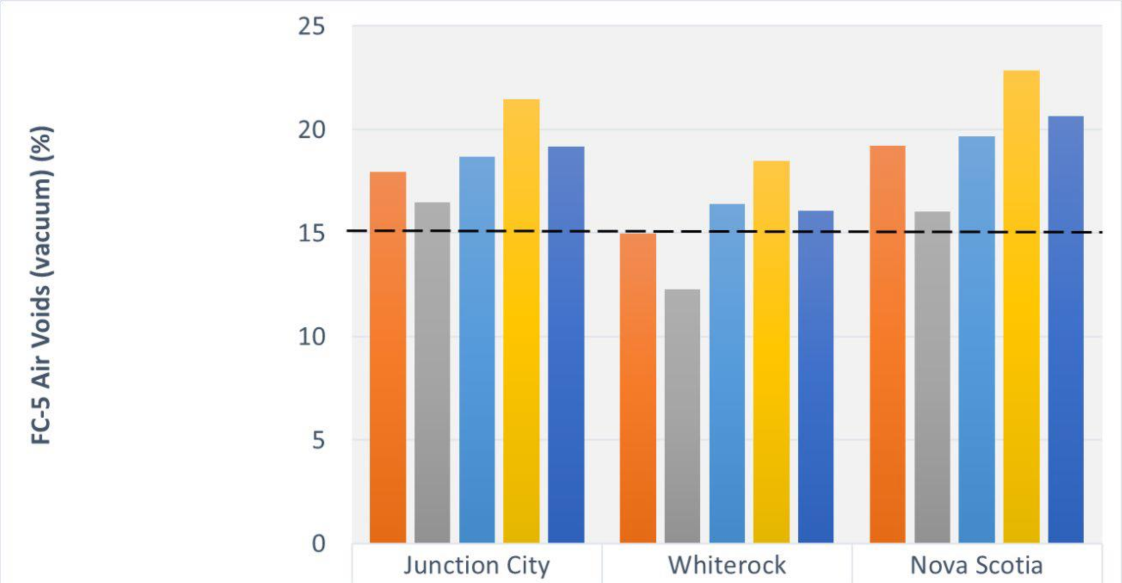
A summary of the FC-5 testing results for all three mixes (gyratory air voids, gyratory Cantabro loss, and slab permeability) is shown in Table 18. It should be noted that data from both gyratory specimens ($N_{des}$ = 50) and slabs are included in this table. Again, the slabs for permeability were compacted to the same target density as determined by the vacuum method for the gyratory specimens.

Graphical summaries of the gyratory air voids and Cantabro loss are shown in Figure 23 and Figure 24, respectively. Finally, a statistical analysis of the Cantabro results (ANOVA ($\alpha$=0.05) with Tukey statistical groupings) is presented in Table 19. The Tukey groupings were used for the Cantabro results since all of the data sets had statistically equal variances.

For the JMF or original blends for the three aggregate sources, two of the blends had average Cantabro loss values above 20 percent. It should be noted that the optimum AC of these blends was selected using the pie plate test and not the Cantabro test. The original blend with the lowest average Cantabro loss (Whiterock) also had the lowest air void content for the three FC-5 designs. For each of the three designs, the original blend fell in the middle statistical grouping with respect to Cantabro loss. The ‘worst case scenario’ from a Cantabro standpoint was the combination of a coarse gradation with low AC content (CLAC). For each of the three FC-5 designs, this blend fell in the statistical grouping with the highest Cantabro loss – over 20% loss for all three mixes and over 40% loss for two of the designs. These CLAC mixtures also had the highest air void content as well among the five testing conditions. The mixtures with the lowest average Cantabro loss always had the combination of finer gradation and high AC content (FHAC). As expected, these FHAC mixes always had the lowest air voids of any testing condition as well. However, for two of the FC-5 designs the FHAC mixes still had air voids above the recommended minimum value of 15%.

**Table 18. Summary of FC-5 Laboratory Mixture Testing Results**

| Aggregate Source | Gradation | Total AC (%) | Gyratory Air Voids (vacuum) (%) | Gyratory Cantabro Mass Loss (%) | Slab Permeability, k ($x10^{-5}$ cm/sec) |
|---|---|---|---|---|---|
| | | | Average | Average | Average |
| Junction City (JC) | Control | 6.2 | 18.7 | 28.1 | 272,977 |
| Junction City (JC) | Fine | 5.6 | 17.9 | 21.0 | 245,917 |
| Junction City (JC) | Fine | 6.8 | 16.5 | 13.6 | 202,381 |
| Junction City (JC) | Coarse | 5.6 | 21.5 | 42.3 | 292,673 |
| Junction City (JC) | Coarse | 6.8 | 19.2 | 21.8 | 295,492 |
| Whiterock (WR) | Control | 6.7 | 16.4 | 18.1 | 247,430 |
| Whiterock (WR) | Fine | 6.1 | 15.0 | 15.2 | 175,236 |
| Whiterock (WR) | Fine | 7.3 | 12.3 | 8.5 | 159,059 |
| Whiterock (WR) | Coarse | 6.1 | 18.5 | 25.1 | 347,381 |
| Whiterock (WR) | Coarse | 7.3 | 16.1 | 13.0 | 296,799 |
| Nova Scotia (NS) | Control | 6.1 | 19.7 | 30.5 | 287,111 |
| Nova Scotia (NS) | Fine | 5.5 | 19.2 | 20.8 | 211,866 |
| Nova Scotia (NS) | Fine | 6.7 | 16.0 | 10.0 | 208,761 |
| Nova Scotia (NS) | Coarse | 5.5 | 22.9 | 51.8 | 401,048 |
| Nova Scotia (NS) | Coarse | 6.7 | 20.7 | 27.8 | 387,662 |




| | Junction City | Whiterock | Nova Scotia |
|---|---|---|---|
| Fine Blend - Low AC | 17.9 | 15.0 | 19.2 |
| Fine Blend - High AC | 16.5 | 12.3 | 16.0 |
| JMF Blend - Optimum AC | 18.7 | 16.4 | 19.7 |
| Coarse Blend - Low AC | 21.5 | 18.5 | 22.9 |
| Coarse Blend - High AC | 19.2 | 16.1 | 20.7 |

**Figure 23. Gyratory Air Voids Summary (vacuum method) – FC-5 Mixes**


| | Junction City FC-5 | Whiterock FC-5 | Nova Scotia FC-5 |
|---|---|---|---|
| Fine Blend - Low AC | 21.0 | 15.2 | 20.8 |
| Fine Blend - High AC | 13.6 | 8.5 | 10.0 |
| JMF Blend - Optimum AC | 28.1 | 18.1 | 30.5 |
| Coarse Blend - Low AC | 42.3 | 25.1 | 51.8 |
| Coarse Blend - High AC | 21.8 | 13.0 | 27.8 |

**Figure 24. Cantabro Mass Loss Summary – FC-5 Mixes**

**Table 19. Statistical Groupings – Cantabro Mass Loss (FC-5)**

| Testing Condition | Junction City (JC) | Whiterock (WR) | Nova Scotia (NS) |
|---|---|---|---|
| JMF Blend - Optimum AC | B | B | B |
| Fine Blend - Low AC | B, C | B | B, C |
| Fine Blend - High AC | C | C | C |
| Coarse Blend - Low AC | A | A | A |
| Coarse Blend - High AC | B, C | B, C | B |

Figure 25 shows the relationship between air voids and Cantabro loss for each of the three FC-5 mixes by aggregate type. Figure 26 shows the relationship between FC-5 slab permeability and gyratory air voids. As expected, based on the previous analysis, a strong relationship between specimen air voids and both Cantabro mass loss and permeability was seen for the data collected from the FC-5 mixes in this study. The effects of these interactions can be seen when looking at how the FC-5 designs for this study perform with varying gradations and asphalt contents. Increasing the AC content will generally lower air voids/permeability and improve Cantabro mass loss, while the opposite was true for lowering the AC content. In general, the coarser FC-5 gradation would increase air voids/permeability but be detrimental to Cantabro mass loss, while the opposite was true for the finer FC-5 gradation. The coarse gradation with low AC was the worst combination in terms of Cantabro mass loss, and the fine gradation with high AC was the worst combination for air voids/permeability.

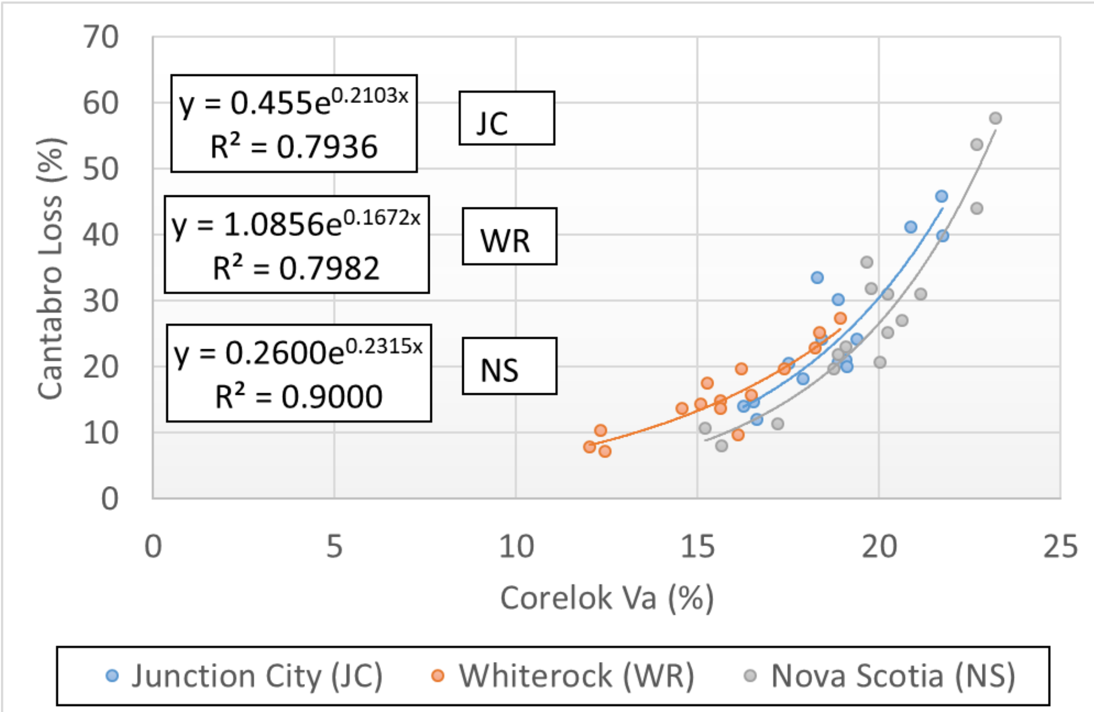



**Figure 25. Cantabro Mass Loss vs. Vacuum Sealer Air Voids – FC-5 Mixes – By Aggregate Type**

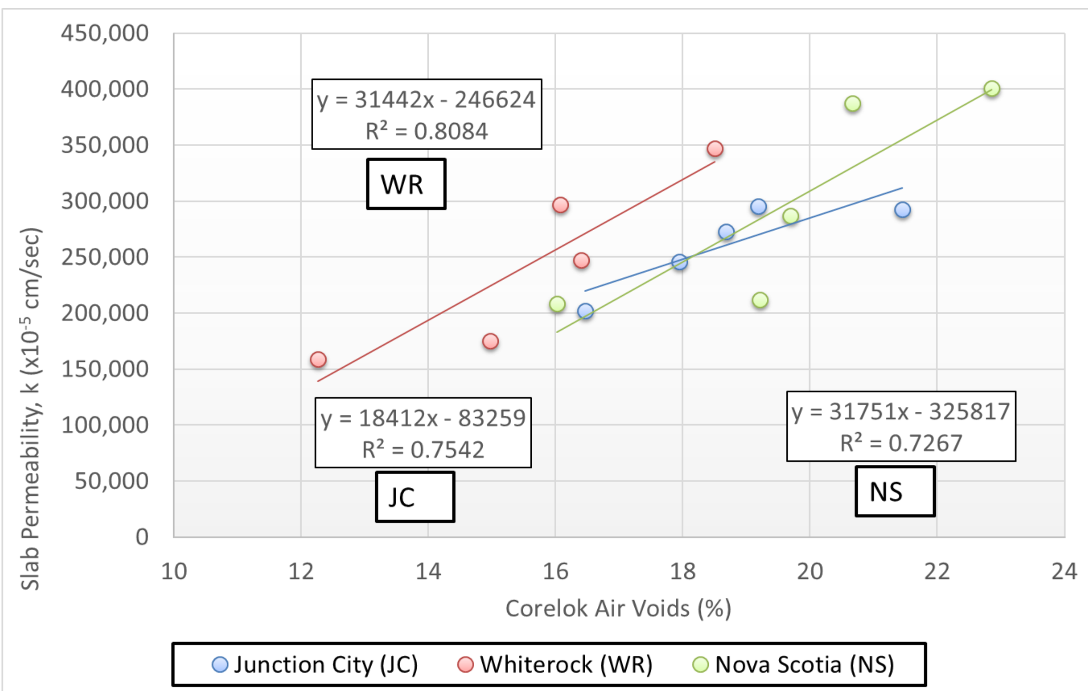



**Figure 26. Slab Permeability (k x $10^{-5}$ cm/sec) vs. Vacuum Sealer Air Voids (%) – FC-5 Mixes**

# 6. FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

## Findings and Conclusions

The major findings and conclusions of the project are summarized below:

*Subtask 1. Evaluate Field Performance and Construction Records for Pavement Sections with Defective Materials that Were Left in Place*

- To assess the adequacy of current FDOT practices for evaluating defective materials, project records for pavement sections with defective materials, as determined by production results, that were left in place were selected, reviewed, and analyzed in conjunction with pavement condition survey results of the projects. The long performance data of the pavement section portions with failing laboratory test results was compared with those of the remaining project that did not experience any issues. Projects under evaluation were at least 8 years old at the time the surveys were conducted. It should be noted the defective areas, as determined by production test results, had been evaluated via an Engineering Analysis Report or delineation and were determined to be acceptable to remain in place without milling and resurfacing the "defective" areas.
- The analysis focused on projects with three mix and failure type combinations. For each combination, specific distresses were considered: dense-graded mixes with low air voids (rutting), FC-5 mixes with low binder content (raveling, cracking, and IRI), and FC-5 with high binder content (rutting).
  - For dense-graded mixes with low air voids, the QC failures corresponded to air voids < 2.3%. The QC air voids for these defective materials ranged from 1.67% to 2.23%. No defective material exceeded an average rutting of 0.2 in. For 7 out of 19 comparisons, the average rutting results of the defective materials were higher than those of the non-defective materials but still relatively low, indicating no significant concern for rutting for any of the projects.
  - For FC-5 mixes with low binder content, the QC failures corresponded to low binder content (AC= target-0.6%). The difference in QC binder content with respect to the target binder content for these defective materials ranged from 0.64% to 1.03%. Medium or high severity raveling was not a concern for any of the projects. Three projects showed some low raveling, but for one project only, the defective material showed higher low raveling compared to the non-defective material (15% vs. 7%). In addition, the average percentage of CW and CO for all the projects did not exceed 8.0%, and the performance of defective and non- defective materials was comparable. Finally, the average IRI results showed that the defective materials had higher values for all projects than the non-defective materials, but the IRI results for all projects did not exceed 77 in/mi.
  - For FC-5 mixes with high binder content, the QC failures corresponded to high binder content (AC= target +0.6%). The difference in QC binder content with respect to the target binder content for these defective materials ranged from 0.63% to 0.86%. All the projects used a PG 76-22 binder or higher. No project exceeded an average rutting of 0.25 in. For 3 out of 7 comparisons, the average rutting results of the defective material were higher than the ones for non-defective material but

still relatively low. Based on these results and considering that these projects have been in place for 9-12 years and that all used, at a minimum, a PG 76-22 binder, the rutting performance of these projects seems adequate.

- For the three mixture/failure type combinations evaluated, it can be concluded that an acceptable decision was made when the defective materials were left in place.

*Subtask 2. Laboratory Evaluation of Lab Compacted Specimens to Determine Appropriate Performance Test to Evaluate Dense-Graded Mixes*

- A laboratory evaluation that included five existing dense-graded mix designs was conducted to assess the impact of different scenarios for low lab-compacted air voids (<2.3%) and varying in-place density levels on mixture rutting potential using the APA and the HT-IDT tests. For each of the mix designs, verifications were performed to ensure that the original designs started at 4.0% air voids at $N_{design}$ before varying in-place density levels. The four production and construction scenarios included (1) good production and good density (original blend), (2) poor production with high density, (3) poor production with good density, and (4) poor production with low density (worst case scenario).
- APA results are summarized as follows:
    - For each of the five mixes, the mix with poor production (high-dust/high-AC), and poor density (9 to 10% air voids) had the highest rutting and lowest statistical grouping. This was expected since this condition represented the worst-case scenario.
    - The original blend or the poor production with good density mix yielded the lowest rutting results and were in the top statistical grouping. This is rational since poorly produced mixes may have improved rutting resistance with better density in the field. The Camak 40% RAP mix with the softer PG 52-28 binder was the only exception, where the high-dust/high-AC mix with 4% air voids was in the top statistical grouping by itself, outperforming the original blend by yielding the lowest rutting.
    - APA test results for each data set were compared to the FDOT defective material threshold of 5.0-mm used on field cores. Three of the five mixes failed the APA criterion for the poor production with low density scenario (Camak 40RAP, JC-White Sand, and JC-Red Sand). Two of the five mixes failed the criterion for the poor production with good density scenario (Camak 40RAP, JC-White Sand). One mix failed the good production with good density scenario (Camak 40RAP) and corresponded to the mix with the softer binder. Finally, no mix for the poor production with high density scenario failed the APA criterion.
- HT-IDT results are summarized as follows:
    - Overall, HT-IDT test results showed a similar trend to the APA results regarding the poor production (high-dust/high-AC) mix performance at different in-place densities relative to the original mix. For each of the five mixes, the mix with poor production and poor density had the lowest ITS results and was at the bottom of the statistical grouping.
    - The poor production mix with good density yielded the highest ITS results for the

five mixes, followed by the poor production mix with good density.

    - HT-IDT test results for each data set were compared to the HT-IDT criterion of 20 psi recommended by ALDOT. Three of the five mixes failed the criterion for the poor production with low density scenarios (Camak 40RAP, JC-White Sand, and JC-Red Sand). One of the five mixes failed the criterion for the poor production with good density (Camak 40RAP). All the mixes with poor production and high density and good production and good density met the HT-IDT criterion.

- The HT-IDT and APA results showed a strong correlation with an $R^2$ at or above 0.9 when the results by mix type were compared. The correlation was still reasonable ($R^2$=0.69) but more scattered when all the data points were included. This suggests that the HT-IDT test has the potential to be considered in lieu of the APA test, but further research is needed to support these results and refine the current threshold recommended by ALDOT.

*Subtask 3. Laboratory Testing to Determine Appropriate Performance Tests to Evaluate Open-Graded Friction Course Mixes*

- A laboratory evaluation that included three FC-5 mixes was conducted to evaluate different scenarios that included the effect of changes in gradation and asphalt content on their durability and permeability using the Cantabro test on gyratory compacted specimens and the FDOT field permeameter on lab-compacted slab specimens, respectively. To verify the optimum AC content, aggregate samples of each mixture were batched at NCAT and sent to FDOT for optimum AC content determination using the pie plate test. The five scenarios included (1) as-designed mixes, (b) high binder content and finer gradation, (3) low binder content and finer gradation, (4) high binder content and coarser gradation, and (5) low binder content and coarser gradation.

- Cantabro results are summarized as follows:
    - Two of the three original blends had average Cantabro loss values above 20 percent.
    - The mixes with the low binder content and coarser gradation scenario yielded the highest Cantabro mass loss for the three mixes. These mixes also had the highest air void content among the five scenarios.
    - The mixes with the high binder content and fine gradation scenario yielded the lowest average Cantabro loss for the three mixes. These mixes also had the lowest air void content among the five scenarios. However, two of these mixes had air voids above the recommended minimum value of 15%.
    - Two of the three mixes with the low binder content and fine gradation scenario had average Cantabro results above 20 percent, but the results were lower than the results of their corresponding original blend. Similarly, two of the three mixes with the high binder content and coarser gradation had average Cantabro results above 20 percent, but the results were lower than the results of their corresponding original blend.
    - A strong correlation between air voids and Cantabro loss was found for each of the three FC-5 mixes. For the combinations evaluated in this study, increasing the

binder content decreased the air voids and improved Cantabro results. In addition, coarser gradation increased air voids but increased Cantabro mass loss.

- Permeability results are summarized as follows:
    - A strong correlation between air voids and permeability results was found for each of the three FC-5 mixes. In general, increasing binder content decreased permeability results. Moreover, coarser gradation increased permeability but also increased Cantabro mass loss.

**Recommendations**

- Based on the findings of the study, the following recommendations are made:
    - The results of Subtask 1 suggested that for the mix and failure type combinations under evaluation, the FDOT's current analysis procedures for defective materials were adequate and that leaving the materials in place did not result in post-construction pavement failure. All the projects were at least 9 years old at the time the pavement condition surveys were conducted.
    - The results of Subtask 2 conducted with dense-graded mixes indicated that the APA and HT-IDT were able to discriminate among different production and construction scenarios and showed a fair correlation with each other. This suggests that these tests could be used to improve current FDOT practices to evaluate defective pavements for dense-graded mixes. The most critical scenario was the mix with unsatisfactory (high dust/ AC) and poor in-place density (9-10% air voids), followed by the mix with poor production (high dust/AC) and good density (7% air voids). For these scenarios, a follow-up evaluation with field performance data is recommended.
    - The results of Subtask 3 conducted with FC-5 mixes indicated that the Cantabro test was able to discriminate among different production scenarios. This suggests that the Cantabro test could be used to improve current FDOT practices to evaluate defective pavements for FC-5 mixes. The most critical scenario was the mix with low binder content and coarser gradation. For this scenario, a follow-up evaluation with field performance data is recommended.

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## APPENDIX A. Summaries of Projects with Defective Materials that Were Left in Place and FDOT Pavement Condition Survey (PCS) Summaries

- Projects with Dense-Graded Mixtures with Low Air Voids
- Projects with Open-Graded Friction Course Mixtures with Low Asphalt Content
- Projects with Open-Graded Friction Course Mixtures with High Asphalt Content

**Projects with Dense-Graded Mixtures with Low Air Voids**

**<u>Project 1:</u>**

**Florida Project Number (FPN):** 201275-2-52-01
**Road:** Sumter Boulevard
**County:** Sarasota
**County Section No.:** 17000
**Mix Type:** SP-12.5
**Mix Design No.** SPM 13-11624A
**Traffic Level:** C
**Date Placed:** August 6, 2013
**Engineering Analysis Report (EAR) Firm:** Cal-Tech Testing
**Description:** QC failure Lot 2, Sublot 1

*Project Description*

Lot 2 Sublot 1 was terminated due to low QC air voids (1.89%). The sample was taken at load 10 (466.25 tons in Lot). The contractor got their results during load 19 and shut the plant down. The mix was placed on Lane R2 Sta 19+80 to 43+20; and Lane L1 Sta 43+20 to 19+80. Independent Verification (IV), Verification (V), and process control (PC) samples (Loads 10, 10, & 20, respectively) had air voids of 3.27%, 2.38%, and 2.75%. Load 10 placed was Lane L-1 ~Sta 22+45. Target Sta 22+45 +/- 150 feet.

An EAR was conducted for the project. The analysis included testing core samples for binder content and gradation analysis. The percentage asphalt content vs. the percent passing No. 8 sieve was plotted, and relationships were established between the air voids and the pass/fail line on the percentage asphalt content vs. the percentage passing No. 8 sieve graph. Conclusions were based on whether the core test results were plotted above or below the pass-fail line of the graphs. The recommendation was to leave the questionable material in place.

Note: Resurfacing consisted of 1.5 in of an SP 12.5 (PG 76-22), and 1 in. of FC-9.5 (PG 76-22) placed on top of this layer. The project is an interchange with I-75.

*Research project recommended section for evaluation:* MP 1.933 – 1.990 (Sta 20+95 – 23+95) in Lane L-1.

**Table A1. PCS Summary Statistics for Defective and Non-Defective Materials – Project 1**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 102 | 0.10 | 2.9 | 0.2 | 0 | 0 | 0 |
| | Std. Dev. | 50 | 0.04 | 4.4 | 1.0 | 0 | 0 | 0 |
| | Max. | 271 | 0.2 | 15.2 | 6.5 | 0 | 0 | 0 |
| Non-defective Material | Average | 97 | 0.06 | 0.6 | 0.4 | 0 | 0 | 0 |
| | Std. Dev. | 53 | 0.05 | 2.9 | 1.9 | 5 | 5 | 0 |
| | Max. | 409 | 0.28 | 44.3 | 19.9 | 100 | 100 | 0 |

**<u>Project 2:</u>**

**FPN:** 207611-3-52-01
**Road:** SR-222
**County:** Alachua
**County Section No.:** 26005
**Mix Type:** FC-12.5
**Mix Design No.** SPM 08-4852D
**Date Placed:** 7/20/2009
**EAR Firm:** Asphalt Technologies, Inc.
**Description:** IV failure Lot 13, Sublot 3.

*<u>Project Description</u>*

Lot 13, Sublot 3 failed due to low IV air voids (1.36%). The failure appeared to be due to a high asphalt content. The sample was taken on Load 2. The QC split from this sample had an air void content of 1.60%. Load 2 was placed at Sta 606+49 – 605+15 in L-1.
Questionable material was placed at the following locations:

- L-2 Sta 394+78 – 386+75, and Sta 606+00 – 598+40
- L-1 Sta 585+74 – 558+30, and Sta 607+83 – 608+48
- R-1 Sta 350+91 – 394+80

An EAR was conducted for this project. EAR was on all material produced in Lot 13, Sub 2 (the last passing test was on Load 36), the first passing test was on 7/20/09, Lot 13, sublot 3, Load 9, and the last passing test was on Load 36. The testing plan included testing cores taken from questionable areas. Tests included bulk specific gravity ($G_{mb}$), maximum specific gravity ($G_{mm}$), determination of asphalt binder content ($P_b$), and gradation analysis. The recommendation was to remove and replace the material from Sta 607+83– 604+48 (L-1), Sta 388+78 – 386+75 (L-2), and Sta 606+00 – 604+10 (L-2). All the other materials in Lot 13, and Sublot 3 were deemed acceptable and allowed to remain in place.

Note: Resurfacing consisted of 1.5in of an SP 12.5 (PG 76-22) and 1.5 in of an FC 12.5 (PG 76-22).

*<u>Research project recommended section(s) for evaluation:</u>* MP 10.729–9.73 (Sta 611+00 – 558+29) in Lanes L-1 and L-2.

**Table A2. PCS Summary Statistics for Defective and Non-Defective Materials – Project 2**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 78 | 0.16 | 4.1 | 7.8 | 0 | 0 | 0 |
| | Std. Dev. | 46 | 0.12 | 6.5 | 10.2 | 0 | 0 | 0 |
| | Max. | 484 | 0.75 | 40.0 | 58.7 | 0 | 0 | 0 |
| Non-defective Material | Average | 84 | 0.14 | 3.9 | 2.2 | 0 | 0 | 0 |
| | Std. Dev. | 60 | 0.07 | 7.6 | 5.7 | 0 | 0 | 0 |
| | Max. | 700 | 0.58 | 56.2 | 57.4 | 0 | 0 | 0 |

**<u>Project 3:</u>**

**FPN:** 207700-2-52-01
**Road:** SR-120
**County:** Alachua
**County Section No.:** 26003
**Mix Type:** SP-12.5
**Mix Design No.** SP 10-8447A
**Date Placed:** 10/3/2010
**EAR Firm:** Bechtol Engineering and Testing
**Description:** IV failure Lot 1 Sub 1

*<u>Project Description</u>*

Lot 1 Sublot 1 had an IV low air void failure for sample 2C001I (2.04%). The IV sample came from Load 11. The material was placed in R-1, R-2, and L-1. The questionable material was placed at the following locations:

- L-2 Sta 25+89 – 13+71
- R-2 Sta 13+71 – 35+70
- L-1 Sta 35+70 – 13+71
- R-1 Sta 13+71 – 35+70

An EAR was conducted for this project. The test plan included cores taken from the questionable areas. The analysis focused on asphalt content, % passing 200 sieve material, and in-place air voids. The evaluation concluded that the material was acceptable to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP 12.5 and 1.5 in of an FC 12.5.

*<u>Research project recommended section (s) for evaluation:</u>* L-2 from MP 0.07 to 0.165 (Sta 13+71 – 18+71) and R-2 from MP 0.07 to 0.165 13+71 – 18+71 (same limits – different lane).

**Table A3. PCS Summary Statistics for Defective and Non-Defective Materials – Project 3**

| Section | | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|---|
| L2 | Defective Material | Average | 90 | 0.07 | 4.1 | 0.6 | 0 | 0 | 0 |
| | | Std. Dev. | 55 | 0.05 | 9.1 | 1.8 | 0 | 0 | 0 |
| | | Max. | 293 | 0.19 | 65.7 | 10.7 | 0 | 0 | 0 |
| | Non-defective Material | Average | 94 | 0.08 | 6.4 | 1.6 | 0 | 0 | 0 |
| | | Std. Dev. | 65 | 0.08 | 9.4 | 5.2 | 0 | 0 | 0 |
| | | Max | 637 | 0.52 | 45.9 | 85.3 | 0 | 0 | 0 |
| R2 | Defective Material | Average | 81 | 0.05 | 2.7 | 1.1 | 0 | 0 | 0 |
| | | Std. Dev. | 61 | 0.04 | 6.6 | 3.0 | 0 | 0 | 0 |
| | | Max. | 350 | 0.21 | 32.8 | 15.4 | 0 | 0 | 0 |
| | Non-defective Material | Average | 93 | 0.11 | 5.8 | 1.7 | 0 | 0 | 0 |
| | | Std. Dev. | 68 | 0.11 | 8.3 | 5.6 | 0 | 0 | 0 |
| | | Max. | 648 | 0.74 | 48.5 | 92.0 | 0 | 0 | 0 |

**<u>Project 4:</u>**

**FPN:** 207700-2-52-01
**Road:** SR-120
**County:** Alachua
**County Section No.:** 26003
**Mix Type:** SP-12.5
**Mix Design No.** SP 09-7671E
**Date Placed:** 10/4, & 10/5/2010
**EAR Firm:** Bechtol Engineering and Testing
**Description:** IV failure Lots 2 Sublots 1 & 3

*<u>Project Description</u>*

Lot 1 Sublot 1 had an IV low air void failure for samples No. 2C002F, and 2C003I (2.23, and 2.03 %). The questionable material was placed at the following locations on 10/04/2010:

- L-2 Sta 56+25 – 37+44
- R-2 Sta 37+44 – 41+42

Questionable material was placed at the following location on 10/05/2010

- L-2 Sta 91+68 – 74+44

An EAR was conducted for this project. The test plan included cores taken from the questionable areas. The analysis focused on asphalt content, % passing 200 sieve material, and in-place air voids. The results indicate that the in-place air voids, asphalt content, and percentage passion 200 sieve were within the allowable tolerances established by FDOT and that the material was acceptable to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP 12.5 and 1.5 in of an FC 12.5.

*<u>Research project recommended section for evaluation:</u>* L-2 from MP 1.383 to 1.478 (Sta 83+00 to 88+00).

**Table A4. PCS Summary Statistics for Defective and Non-Defective Materials – Project 4**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 81 | 0.08 | 2.3 | 0.3 | 0 | 0 | 0 |
| | Std. Dev. | 58 | 0.05 | 8.4 | 1.2 | 0 | 0 | 0 |
| | Max. | 293 | 0.19 | 65.7 | 7.6 | 0 | 0 | 0 |
| Non-defective Material | Average | 94 | 0.08 | 6.4 | 1.6 | 0 | 0 | 0 |
| | Std. Dev. | 65 | 0.08 | 9.4 | 5.2 | 0 | 0 | 0 |
| | Max. | 637 | 0.52 | 45.9 | 85.3 | 0 | 0 | 0 |

**Project 5:**

**FPN:** 210687-3-52-01
**Road:** SR-200
**County:** Nassau
**County Section No.:** 74040
**Mix Type:** SP-12.5
**Mix Design No.** SPM 10-8451A
**Date Placed:** 5/25/2011
**EAR Firm:** Asphalt Technologies, Inc.
**Description:** IV failure Lot 19, Sublot 1

*Project Description*
Lot 19, Sublot 1 had an IV low air voids failure (1.95%). The questionable material was placed at the following locations:

- R1 Sta 83+13 to 109+90
- R2 76+10 to 84+57

An EAR was conducted for this project. The department decided to evaluate the mix from the passing QC test on load 6 to the passing QC on load 35. The testing plan included testing cores taken from questionable areas. Tests included $G_{mb}$, $G_{mm}$, determination of $P_b$, and gradation analysis. The evaluation concluded that the gradation, AC content, and in-place air voids were within the master production range at all locations. The percentage passing #8 sieve material was on the course side of the target but within an acceptable range. At two of the locations the in-place avoids were lower than usual for a pavement that had not been subjected to a significant amount of traffic, but likely the result of the low-end P8 material. Finally, it was indicated that since the mix contained a polymer-modified binder, and would be overlaid with a polymer-modified friction course, the performance of the mix should be good, and therefore the recommendation was to allow the questionable mix in lot 19 to remain in place.

Note: Resurfacing consisted of 3 in of a Superpave mix traffic C (PG 76-22) mix and 3/4 in of an FC-5 (PG 76-22).

*Research project recommended section for evaluation:* R-1 from MP 17.087 to 17.144 (Sta 96+50 to 99+50).

**Table A5. PCS Summary Statistics for Defective and Non-Defective Materials – Project 5**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 41 | 0.04 | 0.0 | 0.0 | 0 | 0 | 0 |
| | Std. Dev. | 21 | 0.01 | 0.0 | 0.0 | 0 | 0 | 0 |
| | Max. | 117 | 0.05 | 0.0 | 0.0 | 0 | 0 | 0 |
| Non-defective Material | Average | 51 | 0.07 | 0.5 | 0.6 | 3 | 1 | 0 |
| | Std. Dev. | 34 | 0.04 | 1.7 | 2.6 | 16 | 9 | 0 |
| | Max. | 415 | 0.69 | 44.7 | 47.3 | 100 | 100 | 0 |

**Project 6:**

**FPN:** 220412-5-52-01
**Road:** SR-281
**County:** Santa Rosa County
**County Section No.:** 58005
**Mix Type:** FC-12.5
**Mix Design No.** SPM 10-8467A
**Date Placed:** 12/12/2012
**EAR Firm:** NOVA Engineering and Environmental, LLC
**Description:** IV failure on Lot 24, Sublot 2.

*Project Description*
Load 18 had an IV low air voids failure (2.24%). The questionable material was placed at the following location:

- L2 Sta 1327+50 and 1296+18

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas and a site visit for visual observation to determine if any deformation existed along the alignment in question. The cores were used to determine $G_{mm}$ and Gmb for in-place air voids determination and gradation analysis. The in-place air voids of the EAR cores met the production ranges. A review of test records and interviews with staff members indicated that the failed sample was obtained when QC laboratory tests showed a downward trend in air voids due to a slightly elevated asphalt and material passing the 200 sieve. This was corrected once detected. The recommendation was to leave the questionable material in place.

Note: The resurfacing consisted of 2 in of a Superpave mix traffic C (PG 76-22) mix and 1.5 in of an FC-12.5 (PG 76-22) mix.

*Research project recommended section for evaluation:* MP 4.533 to 4.590 (Sta 1317+80 – 1320+80).

**Table A6. PCS Summary Statistics for Defective and Non-Defective Materials – Project 6**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 93 | 0.07 | 5.9 | 0.5 | 0 | 0 | 0 |
| | Std. Dev. | 45 | 0.02 | 7.8 | 1.0 | 0 | 0 | 0 |
| | Max. | 226 | 0.1 | 31.7 | 3.9 | 0 | 0 | 0 |
| Non-defective Material | Average | 93 | 0.07 | 3.9 | 0.9 | 0 | 0 | 0 |
| | Std. Dev. | 48 | 0.03 | 6.1 | 2.9 | 0 | 0 | 0 |
| | Max. | 445 | 0.23 | 33.4 | 31.0 | 0 | 0 | 0 |

**<u>Project 7:</u>**

**FPN:** 413048-1-52-01
**Road:** I-95
**County:** Indian River
**County Section No.:** 88081
**Mix Type:** SP-12.5
**Mix Design No.** SPM 12-10185A
**Date Placed:** 2/24/2014
**EAR Firm:** Construction Testing and Inspection, Inc.
**Description:** IV Failure Lot 31 Sublot 2

*<u>Project Description</u>*

Load 35 had an IV low air voids failure (1.98%). The questionable material was placed at the following location:

- R-1 Sta 451+25 – 472+07
- R-2 Sta 451+20 – 469+57
- R-3 Sta 435+98 – 449+10

An EAR was conducted for this project on Loads 29-63. The QC for sub-lot 2 taken on load 28 had passing air voids of 3.21%. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$ and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The EAR indicated that the average in-place density of the EAR cores was within 90-95% of $G_{mm}$ at each location and that asphalt content and percentage passing 200 sieve values were within acceptable limits. It was recommended that the material within the area of concern be allowed to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP structural course traffic D (PG 76-22) and 0.75 in of an FC-5 (PG 76-22).

*<u>Research project recommended section for evaluation:</u>* Lane R-3 MP 5.909 – 6.103 (Sta 438+90 – 449+10).

**Table A7. PCS Summary Statistics for Defective and Non-Defective Materials – Project 7**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 43 | 0.18 | 0.1 | 0.2 | 0 | 0 | 0 |
| | Std. Dev. | 27 | 0.03 | 0.4 | 1.2 | 0 | 0 | 0 |
| | Max. | 242 | 0.26 | 2.6 | 12.1 | 0 | 0 | 0 |
| Non-defective Material | Average | 47 | 0.16 | 0.6 | 2.5 | 0 | 0 | 0 |
| | Std. Dev. | 32 | 0.05 | 2.1 | 6.5 | 3 | 0 | 0 |
| | Max. | 542 | 0.43 | 33.8 | 36.2 | 100 | 0 | 0 |

**Project 8:**

**FPN:** 423028-2-52-01
**Road:** SR-26
**County:** Alachua
**County Section No.:** 26130
**Mix Type:** FC-12.5
**Mix Design No.** SPM 11-9677B
**Date Placed:** 4/13/2012
**EAR Firm:** Bechtol Engineering and Testing
**Description:** IV Failure Lot 3, Sublot 2

*Project Description*

Load 22 had an IV low air voids failure (2.16%). The questionable material was placed at the following location:

- R-1 Sta 252+08 to 278+00 (lift 1/1)

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$, and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The analysis indicated no excessive consolidation when comparing production cores vs. EAR cores and between wheel paths vs. within the wheel path. The asphalt content of the in-place materials was lower than the failing IV sample, the percentage passing 200 sieve results did not indicate excessive fine material, and aggregate gradations were within acceptable limits when compared to the JMF. It was recommended that the material was acceptable to remain in place.

Note: Resurfacing consisted of an SP structural course traffic C (PG 76-22) of various thicknesses and 1.5 in of an FC-12.5 (PG 76-22).

*Research project recommended section for evaluation:* Lane R-1 from MP 12.086 to 12.238 (Sta 269+00 – 277+00).

**Table A8. PCS Summary Statistics for Defective and Non-Defective Materials – Project 8**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 81 | 0.12 | 0.8 | 1.8 | 0 | 0 | 0 |
| | Std. Dev. | 35 | 0.06 | 2.4 | 4.8 | 0 | 0 | 0 |
| | Max. | 266 | 0.31 | 15.2 | 28.9 | 0 | 0 | 0 |
| Non-defective Material | Average | 81 | 0.16 | 0.8 | 0.5 | 0 | 0 | 0 |
| | Std. Dev. | 48 | 0.09 | 3.1 | 2.4 | 0 | 0 | 0 |
| | Max. | 442 | 0.59 | 47.9 | 30.3 | 0 | 0 | 0 |

**Project 9:**

**FPN:** 424473-1-52-01
**Road:** SR-20
**County:** Alachua
**County Section No.:** 26080
**Mix Type:** FC-12.5
**Mix Design No.** SP 11-9678B
**Date Placed:** 5/7/2012
**EAR Firm:** Bechtol Engineering and Testing
**Description:** IV Failure Lot 6 Sublot 1

*Project Description*

Load 20 had an IV low air voids failure (2.09%). The questionable material was placed at the following location:

- R-1 Sta 1271+90 to 1295+70 (Lift 1 of 1)

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$, and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The analysis indicated that no excessive consolidation when comparing production cores vs. EAR cores and between wheel paths vs. within the wheel path. The asphalt content of the in-place materials was lower than the failing IV sample, the percentage passing 200 sieve results did not indicate excessive fine material, and aggregate gradations were within acceptable limits when compared to the JMF. It was recommended that the material was acceptable to remain in place.

Note: Resurfacing consisted of 2 in of a friction course FC-12.5 traffic level C.

*Research project recommended section for evaluation:* Lane R-1 from 1284+20 to 1287+70.

**Table A9. PCS Summary Statistics for Defective and Non-Defective Materials – Project 9**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 54 | 0.07 | 0.7 | 0.4 | 0 | 0 | 0 |
| | Std. Dev. | 42 | 0.01 | 4.8 | 2.9 | 0 | 0 | 0 |
| | Max. | 322 | 0.09 | 39.2 | 23.4 | 0 | 0 | 0 |
| Non-defective Material | Average | 53 | 0.21 | 0.8 | 0.4 | 0 | 0 | 0 |
| | Std. Dev. | 37 | 0.10 | 2.8 | 2.0 | 0 | 0 | 0 |
| | Max. | 397 | 0.52 | 27.2 | 26.3 | 0 | 0 | 0 |

**Project 10:**

**FPN:** 424619-1-52-01
**Road:** SR-8 (I-10)
**County:** Gadsden
**County Section No.:** 50001
**Mix Type:** SP-12.5
**Mix Design No.** SPM 10-8847A
**Date Placed:** 3/6/2012
**EAR Firm:** Cal-Tech Testing, Inc.
**Description:** IV failure Lot 1 Sublot 2

*Project Description*

Load 10 had an IV low air voids failure (2.23%). The questionable material was placed at the following location:

- L-2, Sta 580+00 to 542+80

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$, and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The core test results indicated that the samples had in-place air voids ranging from 4.43% to 8.78%, asphalt content ranging from 4.79%to 5.32%, and passing the No. 200 sieve ranging from 5.42 to 6.10%. The evaluation concluded that the in-place air voids, the asphalt content, and the passing No. 200 sieve material were within the master production range and that the material was acceptable to remain in place.

Note: Resurfacing consisted of 2 in of an SP structural course traffic D (PG 76-22) and 0.75 in of an FC-5 (PG 76-22).

*Research project recommended section for evaluation:* L-2 from MP 9.442 – 10.147 (Sta 580+00 to 542+80).

**Table A10. PCS Summary Statistics for Defective and Non-Defective Materials – Project 10**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 38 | 0.20 | 2.7 | 1.8 | 29 | 0 | 0 |
| | Std. Dev. | 17 | 0.05 | 4.2 | 4.4 | 44 | 0 | 0 |
| | Max. | 165 | 0.35 | 30.1 | 29.9 | 100 | 0 | 0 |
| Non-defective Material | Average | 38 | 0.13 | 2.7 | 3.2 | 4 | 0 | 0 |
| | Std. Dev. | 26 | 0.05 | 4.5 | 6.3 | 19 | 2 | 0 |
| | Max | 668 | 0.53 | 42.9 | 59.5 | 100 | 100 | 0 |

**Project 11:**

**FPN:** 425211-2-52-01
**Road:** SR-25
**County:** Miami-Dade
**County Section No.:** 87090
**Mix Type:** SP-12.5 (TL-D)
**Mix Design No.**: SP 12-10474A
**Date Placed:** 2/12/2013
**EAR Firm:** Asphalt Technologies, Inc.
**Description:** IV failure Lot 19 Sublot 3

*Project Description*

Load 4 had an IV low air voids failure (2.19%) and a high asphalt content (6.52% with a target of 5.9%). The questionable material was placed at the following location:

- L-1 & L-2 from Sta 13+00 – 17+50 and in the intersection from Sta 17+50 – 19+00.

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$ and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The analysis focused primarily on asphalt content, P-200, and in-place air voids. The EAR concluded that the gradation, AC content, and in-place air voids were within an acceptable range, and the mix was recommended to remain in place.

Note: Resurfacing consisted of two lifts 2.5 in and 1.5 in of an SP structural course traffic D (PG 76-22), and 0.75in of friction course FC-5 traffic D (PG 76-22).

*Research project recommended section for evaluation:* L-1 & L-2 from MP 5.080 to MP 5.194 (Sta 13+00 – 19+00).

**Table A11. PCS Summary Statistics for Defective and Non-Defective Materials – Project 11**

| Section | | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|---|
| L1 | Defective Material | Average | 186 | 0.13 | 6.1 | 5.1 | 0 | 0 | 0 |
| | | Std. Dev. | 135 | 0.08 | 8.4 | 10.3 | 0 | 0 | 0 |
| | | Max. | 668 | 0.36 | 36.0 | 60.2 | 0 | 0 | 0 |
| | Non-defective Material | Average | 146 | 0.11 | 6.1 | 4.1 | 0 | 0 | 0 |
| | | Std. Dev. | 85 | 0.05 | 8.4 | 7.2 | 0 | 0 | 0 |
| | | Max | 680 | 0.29 | 31.5 | 29.5 | 0 | 0 | 0 |
| L2 | Defective Material | Average | 122 | 0.07 | 2.7 | 1.1 | 0 | 0 | 0 |
| | | Std. Dev. | 84 | 0.06 | 5.9 | 3.2 | 0 | 0 | 0 |
| | | Max. | 666 | 0.25 | 37.0 | 22.0 | 0 | 0 | 0 |
| | Non-defective Material | Average | 84 | 0.07 | 1.6 | 2.8 | 0 | 0 | 0 |
| | | Std. Dev. | 61 | 0.05 | 3.9 | 5.7 | 0 | 0 | 0 |
| | | Max | 519 | 0.20 | 20.1 | 24.8 | 0 | 0 | 0 |

**<u>Project 12:</u>**

**FPN:** 427165-1-52.01
**Road:** SR-35/700 (US-301)
**County:** Pasco
**County Section No.:** 14050
**Mix Type:** SP-12.5
**Mix Design No.**: SP 13-11446A
**Date Placed:** 6/14/13
**EAR Firm:** Construction Testing and Inspection, Inc.
**Description:** QC Air Void Failure Lot 4 Sublot 1

*<u>Project Description</u>*

Load 3 had an IV low air voids failure (1.85%). A review of QC data indicated high asphalt content and percentage passing 200 sieve were likely the cause of the high air voids. The questionable material was placed at the following location:

- Location R-1, Sta 924+00 – 962+27.

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The analysis focused on asphalt content and gradation analysis. The EAR concluded that the gradation and asphalt content were within an acceptable range, and the mix was recommended to remain in place.

Note: Note: Resurfacing consisted of 1.5 in of an SP structural course traffic C, and 0.75 in of an FC-5.

*<u>Research project recommended section for evaluation:</u>* R-1 from MP 16.461 – 17.185 (Sta 924+00 – 962+27).

**Table A12. PCS Summary Statistics for Defective and Non-Defective Materials – Project 12**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 51 | 0.11 | 0.37 | 1.78 | 0 | 0 | 0 |
| | Std. Dev. | 29 | 0.05 | 0.91 | 4.45 | 0 | 0 | 0 |
| | Max. | 255 | 0.27 | 8.19 | 40.21 | 0 | 0 | 0 |
| Non-defective Material | Average | 49 | 0.14 | 3.55 | 3.12 | 9 | 2 | 0 |
| | Std. Dev. | 34 | 0.05 | 6.83 | 6.78 | 28 | 12 | 0 |
| | Max. | 551 | 0.60 | 54.47 | 86.31 | 100 | 100 | 0 |

**Project 13:**

**FPN:** 428690-1-52-01
**Road:** SR-20/25 (US-441)
**County:** Alachua
**County Section No.:** 26020
**Mix Type:** SP-12.5
**Mix Design No.**: SPM 13-11009C
**Date Placed:** 4/22/2014
**EAR Firm:** Construction Testing and Inspection, Inc.
**Description:** QC Air Void Failure Lot 3 Sublot 4

*Project Description*

Load 22 had an IV low air voids failure (1.67%). A review of QC data indicated that the probable cause for the low air voids was the high asphalt content and course gradation of the mix sampled. The questionable material was placed at the following location:

- L-1 Sta 882+81 to 847+67 and R-2 Sta 871+45 to 882+50

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$ and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The EAR concluded that the gradation, AC content, and in-place air voids were within an acceptable range, and the mix was recommended to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP structural course traffic C (PG 76-22) and 1.5 in of an FC-12.5 (PG 76-22).

*Research project recommended section for evaluation:* R-2 from MP 16.585 – 16.808 (Sta 871+45 – 882+81) and L-1 from MP 16.808 – 16.134 (Sta 882+81 – 847+67)

**Table A13. PCS Summary Statistics for Defective and Non-Defective Materials – Project 13**

| Section | | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med. (%) | Raveling Sev. (%) |
|---|---|---|---|---|---|---|---|---|---|
| L1 | Defective Material | Average | 52 | 0.18 | 0.3 | 0.7 | 4 | 1 | 0 |
| | | Std. Dev. | 32 | 0.04 | 1.3 | 3.0 | 19 | 10 | 0 |
| | | Max. | 439 | 0.32 | 12.0 | 26.5 | 100 | 100 | 0 |
| | Non-defective Material | Average | 45 | 0.18 | 0.4 | 1.4 | 5 | 1 | 0 |
| | | Std. Dev. | 33 | 0.07 | 1.9 | 4.4 | 22 | 9 | 0 |
| | | Max | 667 | 0.73 | 30.4 | 48.7 | 100 | 100 | 0 |
| R2 | Defective Material | Average | 54 | 0.16 | 5.6 | 0.9 | 0 | 0 | 0 |
| | | Std. Dev. | 25 | 0.03 | 7.4 | 3.1 | 0 | 0 | 0 |
| | | Max. | 145 | 0.21 | 30.6 | 24.9 | 0 | 0 | 0 |
| | Non-defective Material | Average | 41 | 0.19 | 1.4 | 1.9 | 0 | 0 | 0 |
| | | Std. Dev. | 25 | 0.08 | 4.2 | 5.4 | 0 | 0 | 0 |
| | | Max | 668 | 0.74 | 84.7 | 85.8 | 0 | 0 | 0 |

**Project 14:**
**FPN:** 430659-1-52-01
**Road:** SR-500 (US-192)
**County:** Brevard
**County Section No.:** 70050
**Mix Type:** SP-12.5
**Mix Design No.** SPM 13-11185A
**Date Placed:** 12/12/2014
**EAR Firm:** Bechtol Engineering and Testing
**Description:** IV Failure Lot 1 Sublot 1

*Project Description*

Load 3 had an IV low air voids failure (1.94%). The questionable material was placed at the following location:

- R-1 Sta 110+12 – 119+55 (Lift 1/1)

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$ and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The EAR concluded that the average density of the cores was greater than 90% and that aggregate gradations and AC contents were within acceptable limits. The high AC content of the failed sample was not supported by the core test values. The recommendation was to leave the questionable material in place.

Note: The resurfacing consisted of 1.5 in of SP mix traffic C (PG 76-22) and 0.75 in of FC-5 (PG 76-22).

*Research project recommended section for evaluation:* Lane R-1 from MP 4.100 – 4.278 (Sta 110+12 – 119+55).

**Table A14. PCS Summary Statistics for Defective and Non-Defective Materials – Project 14**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 54 | 0.04 | 0.2 | 2.0 | 0 | 0 | 0 |
| | Std. Dev. | 34 | 0.01 | 0.6 | 3.6 | 0 | 0 | 0 |
| | Max. | 224 | 0.1 | 3.9 | 21.1 | 0 | 0 | 0 |
| Non-defective Material | Average | 50 | 0.03 | 0.2 | 1.6 | 0 | 0 | 0 |
| | Std. Dev. | 27 | 0.02 | 0.9 | 3.5 | 0 | 0 | 0 |
| | Max. | 216 | 0.1 | 9.0 | 21.9 | 0 | 0 | 0 |

**Project 15:**

**FPN:** 431079-1-52-01
**Road:** SR-91
**County:** Palm Beach
**County Section No.:** 93470
**Mix Type:** SP-12.5
**Mix Design No.**: SPM 12-10846A
**Date Placed:** 11/05/2013
**EAR Firm:** Cal-Tech Testing, Inc.
**Description:** IV Failure Lot 6 Sublot 3

*Project Description*

Load 3 had an IV low air voids failure (2.04%). The questionable material was placed at the following location:

- L-2 1762+66 – 1717+00

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$ and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The EAR concluded that the percentage of effective asphalt content ($P_{be}$) was acceptable. However, the core test results from station 1759+00 indicated in-place air voids below 4% (3.56% and 3.64%). The EAR recommended removing the material placed between stations 1762+66 and 17+54+00 since air voids below 4% would likely result in rutting of the pavement section. Still, the remaining material was acceptable to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP structural course traffic D (PG 76-22), and 0.75 in of an FC-5 (PG 76-22).

*Research project recommended section for evaluation:* L-2 from MP 80.940 – 80.239 (Sta 1754+00 – 1717+00).

**Table A15. PCS Summary Statistics for Defective and Non-Defective Materials – Project 15**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 48 | 0.12 | 1.9 | 2.7 | 0 | 0 | 0 |
| | Std. Dev. | 20 | 0.03 | 3.3 | 4.7 | 0 | 0 | 0 |
| | Max | 151 | 0.22 | 17.4 | 23.0 | 0 | 0 | 0 |
| Non-defective Material | Average | 47 | 0.16 | 2.6 | 3.2 | 1 | 0 | 0 |
| | Std. Dev. | 30 | 0.05 | 4.1 | 5.5 | 8 | 0 | 0 |
| | Max | 411 | 0.53 | 41.7 | 60.3 | 100 | 0 | 0 |

**Project 16:**

**FPN:** 430548-1-52-01
**Road:** SR-24
**County:** Levy
**County Section No.:** 34070
**Mix Type:** FC-12.5
**Mix Design No.**: SPM 15-13359A
**Date Placed:** 2/18/2015
**EAR Firm:** Bechtol Engineering and Testing
**Description:** IV Failure Lot 17 Sublot 2

*Project Description*

Load 17 had an IV low air voids failure (1.82%). The questionable material was placed at the following location:

- L-1 Sta 1275+95 – 1243+80

An EAR was conducted for this project on Loads 10-33. The testing plan included testing cores taken from the questionable areas. The cores were used to determine $G_{mm}$, and $G_{mb}$ for in-place air voids determination, asphalt content, and gradation analysis. The EAR indicated that the average in-place density of the EAR cores was greater than 90%, one core location yielded an average density of 89.2%. The aggregate gradations and AC contents were within acceptable limits. The low air voids results of the failed sample were not supported by the EAR core test values. The EAR recommended to allow the questionable material to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP structural course traffic B (PG 76-22), and 1.5 in of an FC-12.5 (PG 76-22).

*Research project recommended section for evaluation:* L-1 Sta 1275+95 – 1243+80.

**Table A16. PCS Summary Statistics for Defective and Non-Defective Materials – Project 16**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 96 | 0.05 | 3.7 | 0.6 | 0 | 0 | 0 |
| | Std. Dev. | 49 | 0.03 | 5.5 | 2.7 | 0 | 0 | 0 |
| | Max | 293 | 0.21 | 27.2 | 28.4 | 0 | 0 | 0 |
| Non-defective Material | Average | 115 | 0.07 | 4.1 | 0.6 | 0 | 0 | 0 |
| | Std. Dev. | 59 | 0.03 | 7.2 | 2.3 | 0 | 0 | 0 |
| | Max | 573 | 0.23 | 47.7 | 32.3 | 0 | 0 | 0 |

**Projects with Open-Graded Friction Course Mixtures with Low Asphalt Content**

**Project 17:**

**FPN:** 209566-2-52-01
**Road:** SR-228
**County:** Duval
**County Section No.:** 72120
**Mix Type:** FC-5
**Mix Design No.** SPM 11-9657A
**Date Placed:** 2/24/2012
**EAR Firm:** EAR not required, Delineation
**Description:** Lot 16 Sublot 2 (Low QC Binder content)

*Project Description*

The target binder content was 5.40%, and the QC result was 4.72%. The failing load was Load 43. The load was discarded along with the next seven loads (Loads 43-50). It was determined that the failing asphalt binder content was caused by a faulty asphalt pump. The questionable material was placed at the following location:

- L-1 Sta 1504+27 to 1442+65

Delineation included loads 23 (the last acceptable PC result) through load 42. The delineation cores indicated that the AC content was within the acceptable range; therefore, the material should remain in place.

Note: Resurfacing consisted of 2 in of an SP structural course traffic C (PG 76-22) and 0.75 in of an FC-5 (PG 76-22).

**Research project recommended section for evaluation:** L-1 MP 10.724 – 11.891 (Sta 1442+65 to 1504+27).

**Table A17. PCS Summary Statistics for Defective and Non-Defective Materials – Project 17**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 77 | 0.20 | 5.1 | 8.0 | 15 | 3 | 1 |
| | Std. Dev. | 44 | 0.06 | 7.3 | 10.0 | 34 | 15 | 9 |
| | Max | 645 | 0.60 | 43.7 | 98.1 | 100 | 100 | 100 |
| Non-defective Material | Average | 70 | 0.19 | 3.3 | 3.7 | 7 | 1 | 0 |
| | Std. Dev. | 39 | 0.08 | 6.2 | 6.6 | 25 | 9 | 6 |
| | Max | 561 | 0.77 | 64.5 | 50.2 | 100 | 100 | 100 |

**Project 18:**

**FPN:** 220231-1-52-01
**Road:** SR-85
**County:** Okaloosa
**County Section No.:** 57040
**Mix Type:** FC-5
**Mix Design No.** SPM 10-8890A
**Date Placed:** 11/5/2012
**EAR Firm:** EAR not required, Delineation
**Description:** Lot 27 Sublot 3 (Low QC binder Content)

*Project Description*

The target binder content was 5.7%, and the QC result was 5.06%. PC test on Load 5 (106 tons) at the start of production AC was 5.46%. When a QC test was conducted on Load 12 the lot was terminated. Questionable material was placed on:

- R-2 Sta 197+19 – 232+75
- L-2 Sta 218+92 – 197+19.

Delineation was conducted, and two samples exceeded the MPR, and L-2 was removed and replaced from Sta 209+42 to 197+19. The remaining questionable material remained in place.

Note: Resurfacing consisted of 2.5 in of an SP structural course traffic C (PG 76-22) and 0.75 in of an FC-5 (PG 76-22).

*Research project recommended section for evaluation:* R-2 MP 9.208 – 9.882 (Sta 197+19 – 232+75) and L-2 MP 9.620 – 9.440 (Sta 218+92 – 209+42).

**Table A18. PCS Summary Statistics for Defective and Non-Defective Materials – Project 18**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 77 | 0.19 | 1.2 | 5.9 | 8 | 0 | 0 |
| | Std. Dev. | 57 | 0.04 | 3.9 | 9.5 | 27 | 0 | 0 |
| | Max | 393 | 0.29 | 32.1 | 30.2 | 100 | 0 | 0 |
| Non-defective Material | Average | 69 | 0.09 | 2.4 | 7.7 | 56 | 3 | 0 |
| | Std. Dev. | 51 | 0.04 | 4.8 | 10.7 | 49 | 16 | 0 |
| | Max | 694 | 0.41 | 39.2 | 56.1 | 100 | 100 | 0 |

**Project 19:**

**FPN:** 423432-1-52-01
**Road:** SR-93 (I-75)
**County:** Hamilton
**County Section No.:** 32100
**Mix Type:** FC-5
**Mix Design No.** SPM 10-8213A
**Date Placed:** 9/29/2011
**EAR Firm:** EAR not required, Delineation
**Description:** Lot 27 Sublot 4 (Low QC Binder Content)

*Project Description*

The target binder content was 5.20%, and the QC result was 4.14%. The attributable cause for the asphalt content failure was, in part, the coarse gradation on the 3/8" and #4 sieves, which was out of the MPR. Loads 3 to 14 were delineated for low binder content. The sublot was verified, and the results showed that the gradation and asphalt content were within the MPR. The questionable material was allowed to remain in place.

Note: Resurfacing consisted of 2 in of an SP structural course traffic E (PG 76-22) and 0.75 in of an FC-5 (PG 76-22).

*Research project recommended section for evaluation:* R-3 MP 14.702- 15.640 (Sta 2620+55 to 2670+07).

**Table A19. PCS Summary Statistics for Defective and Non-Defective Materials – Project 19**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 46 | 0.15 | 5.4 | 2.5 | 0 | 0 | 0 |
| | Std. Dev. | 25 | 0.04 | 7.3 | 5.3 | 0 | 0 | 0 |
| | Max | 236 | 0.34 | 43.2 | 38.0 | 0 | 0 | 0 |
| Non-defective Material | Average | 42 | 0.21 | 3.5 | 2.6 | 0 | 0 | 0 |
| | Std. Dev. | 32 | 0.06 | 6.1 | 5.9 | 0 | 0 | 0 |
| | Max | 579 | 1.39 | 97.5 | 61.9 | 0 | 0 | 0 |

**Project 20:**

**FPN:** 428809-1-52-01
**Road:** SR-9 (I-95)
**County:** Nassau
**County Section No.:** 74160
**Mix Type:** FC-5
**Mix Design No.** SPM 14-12565A
**Date Placed:** 5/31/2014
**EAR Firm:** EAR not required, Delineation
**Description:** Lot 47 Sublot 4 (Low QC Binder Content)

*Project Description*

The target binder content was 6.10%, and the QC result was 5.36%. The loads in question were Loads 33-55 placed in L-3, and the delineation testing was done from Sta 144+50 to 62+03. The sublot was verified, and the results showed that asphalt content was within the MPR. The questionable material was allowed to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP structural course traffic C (PG 76-22) and 1.5 in of an FC-12.5 (PG 76-22).

*Research project recommended section for evaluation:* L-3 from MP 0.818 – 2.381 (Sta 62+00 – 144+50).

**Table A20. PCS Summary Statistics for Defective and Non-Defective Materials – Project 20**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 36 | 0.15 | 1.5 | 2.8 | 0 | 0 | 0 |
| | Std. Dev. | 21 | 0.04 | 3.1 | 5.6 | 0 | 0 | 0 |
| | Max | 268 | 0.28 | 24.9 | 41.5 | 0 | 0 | 0 |
| Non-defective Material | Average | 41 | 0.22 | 2.1 | 2.6 | 0.04 | 0.04 | 0 |
| | Std. Dev. | 32 | 0.07 | 5.4 | 6.2 | 1.8 | 1.8 | 0 |
| | Max | 626 | 1.24 | 106.8 | 72.3 | 100 | 100 | 0 |

**Project 21:**

**FPN:** 429023-1-52-01
**Road: SR-416**
**County:** Seminole
**County Section No.:** 77470
**Mix Type:** FC-5
**Mix Design No.** SPM 14-10489A
**Date Placed:** 12/4/2014
**EAR Firm:** EAR not required, Delineation
**Description:** Lot 21 Sublot 4 (Low QC Binder Content)

The target binder content was 5.7%, and the QC result was 5.02%. The material was placed in R-2 from Sta 1972+80 – 2076+75. The failed sample came from Load 29, located at approximately 2075+00. One delineation location failed to meet the MPR. The DDM recommendation was to remove the material represented by the failing delineation. This included the removal of Lane R-2 from Sta 2015+00 – 2031+54 and 2032+99 – 2035+00 Lane R-2; everything else was allowed to stay in place.

*Research project recommended section for evaluation:* MP 13.326 – 14.128 and from 14.507 – 15.298 in R-2.

**Table A21. PCS Summary Statistics for Defective and Non-Defective Materials – Project 21**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 75 | 0.14 | 2.3 | 1.1 | 15 | 0.2 | 0 |
| | Std. Dev. | 64 | 0.05 | 5.6 | 3.3 | 35 | 4.6 | 0 |
| | Max | 671 | 0.52 | 77.5 | 26.1 | 100 | 100 | 0 |
| Non-defective Material | Average | 63 | 0.12 | 3.8 | 1.5 | 14 | 2 | 0 |
| | Std. Dev. | 48 | 0.06 | 9.9 | 4.4 | 34 | 14 | 3 |
| | Max | 699 | 0.74 | 109.1 | 60.2 | 100 | 100 | 100 |

**Projects with Open-Graded Friction Course Mixtures with High Asphalt Content**

**Project 22:**

**FPN:** 428809-1-52-01
**Road:** SR-9
**County:** Nassau
**County Section No.:** 74160
**Mix Type:** FC-5
**Mix Design No.** SPM 14-12565A
**Date Placed:** 5/27/14
**EAR Firm:** EAR not required, Delineation
**Description:** QC Failure Lot 46 Sublot 3

*Project Description*

The target binder content was 6.10%, and the QC result was 6.73%. The material in question was placed in L-3, and the delineation testing was from Sta 346+50 – 438+50. The sublot was verified with cores. The results showed that only two areas out of 20 (6.73% and 7.09%) had asphalt content above the MPR. The questionable material was allowed to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP structural course traffic C (PG 76-22) and 1.5 in of an FC-12.5 (PG 76-22).

*Research project recommended section for evaluation:* L-3 from MP 6.898 – 7.497 (Sta 383+00 – 414+60).

**Table A22. PCS Summary Statistics for Defective and Non-Defective Materials – Project 22**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 34 | 0.25 | 1.3 | 2.2 | 0 | 0 | 0 |
| | Std. Dev. | 14 | 0.06 | 3.3 | 5.3 | 0 | 0 | 0 |
| | Max | 107 | 0.39 | 16.7 | 40.0 | 0 | 0 | 0 |
| Non-defective Material | Average | 41 | 0.21 | 2.1 | 2.7 | 0 | 0 | 0 |
| | Std. Dev. | 32 | 0.07 | 5.3 | 6.1 | 2 | 2 | 0 |
| | Max | 791 | 1.24 | 106.8 | 72.3 | 100 | 100 | 0 |

**Project 23:**

**FPN:** 428809-1-52-01
**Road:** SR-9
**County:** Nassau
**County Section No.:** 74160
**Mix Type:** FC-5
**Mix Design No.** SPM 11-9373A
**Date Placed:** 5/4/14
**EAR Firm:** EAR not required, Delineation
**Description:** IV Failure, Lot 39 Sublot 1

The target binder content was 5.9 %, and the QC result was 6.56%. The material in question was placed in R1 and R2 load 11-15, and the delineation testing was from Sta 540+00-560+00 for R1 and Sta 534+00-552+00 for R2. The sublot was verified with cores. The test results showed that no asphalt content was higher than 6.78%, and considering that the upper limit for the MPR was 6.5%, it was concluded that the highest limit should not be detrimental to pavement performance. The questionable material was allowed to remain in place.

Note: Resurfacing consisted of 1.5 in of an SP structural course traffic C (PG 76-22) and 1.5 in of an FC-12.5 (PG 76-22).

*Research project recommended section for evaluation:* R-1 Sta 530+80 – 562+65 and R-2 Sta 523+40 – 546+40.

**Table A23. PCS Summary Statistics for Defective and Non-Defective Materials – Project 23**

| Section | | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|---|
| R1 | Defective Material | Average | 38 | 0.08 | 0.5 | 3.0 | 6 | 0 | 0 |
| | | Std. Dev. | 17 | 0.02 | 1.6 | 6.3 | 23 | 0 | 0 |
| | | Max. | 136 | 0.14 | 15.7 | 29.0 | 100 | 0 | 0 |
| | Non-defective Material | Average | 40 | 0.09 | 1.1 | 1.6 | 2 | 0 | 0 |
| | | Std. Dev. | 24 | 0.03 | 2.9 | 4.7 | 13 | 0 | 0 |
| | | Max | 640 | 0.31 | 32.5 | 58.2 | 100 | 0 | 0 |
| R2 | Defective Material | Average | 44 | 0.17 | 0.6 | 0.9 | 0 | 0 | 0 |
| | | Std. Dev. | 31 | 0.02 | 1.6 | 3.4 | 0 | 0 | 0 |
| | | Max. | 248 | 0.25 | 13.5 | 37.9 | 0 | 0 | 0 |
| | Non-defective Material | Average | 46 | 0.23 | 1.8 | 1.9 | 0 | 0 | 0 |
| | | Std. Dev. | 27 | 0.05 | 3.9 | 5.0 | 5 | 0 | 0 |
| | | Max | 464 | 0.44 | 57.5 | 49.8 | 100 | 0 | 0 |

**Project 24:**

**FPN:** 431079-1-52-01
**Road:** SR-91
**County:** Palm Beach
**County Section No.:** 93470
**Mix Type:** FC-5
**Mix Design No.**: SPM 13-11643A
**Date Placed:** ~ 5/2014
**EAR Firm:** EAR not required
**Description:** QC Failure Lot 24 Sublot 1

The AC content failed the MPR for being on the high side. The report provided by FDOT does not provide the actual AC content. The questionable mix was placed in R1 Sta 1502+73 to 1540+80 and L1 station 1618+50 to 1592+00. The decision was to observe the material for bleeding for 15 days. No bleeding was present. The material was allowed to stay in place.

*Research project recommended section for evaluation:* R-1 1502+73 – 1540+00; L-1 1618+50 – 1592+00.

**Table A24. PCS Summary Statistics for Defective and Non-Defective Materials – Project 24**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 56 | 0.12 | 0.5 | 1.7 | 0 | 0 | 0 |
| | Std. Dev. | 42 | 0.02 | 1.5 | 4.6 | 0 | 0 | 0 |
| | Max | 430 | 0.18 | 12.3 | 30.0 | 0 | 0 | 0 |
| Non-defective Material | Average | 44 | 0.16 | 1.1 | 0.9 | 7 | 1 | 0 |
| | Std. Dev. | 25 | 0.03 | 2.8 | 3.1 | 24 | 7 | 0 |
| | Max | 375 | 0.35 | 27.3 | 28.5 | 100 | 100 | 0 |

**Project 25:**

**FPN:** 432532-1-52-01
**Road:** SR-75 (US-231)
**County:** Jackson
**County Section No.:** 53050
**Mix Type:** FC-5
**Mix Design No.**: SPM 11-13188A
**Date Placed:** 7/22/2015
**EAR Firm:** Left in Place – no analysis
**Description:** QC Failure Lot 9 Sublot 3

The target binder content was 6.10 %, and the QC result was 6.96%. The material in question was placed in Lane R-2, Sta 557+26 – 576+80. Because of the type of mix and binder used (FC-5 with PG 82-22), it was concluded that the AC content would not cause any type of premature failure. The mix was allowed to stay in place.

Note: Resurfacing in outside lanes consisted of 3 in of an SP structural course C (PG 82-22) and 0.75 in of an FC-5 (PG 82-22).

*Research project recommended section for evaluation:* Lane R-2, Sta 557+26 – 576+80 (MP 13-104 – 13.474).

**Table A25. PCS Summary Statistics for Defective and Non-Defective Materials – Project 25**

| Section | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|
| Defective Material | Average | 39 | 0.24 | 3.3 | 0.7 | 0 | 0 | 0 |
| | Std. Dev. | 21 | 0.02 | 4.2 | 3.2 | 0 | 0 | 0 |
| | Max | 200 | 0.32 | 16.9 | 27.4 | 0 | 0 | 0 |
| Non-defective Material | Average | 42 | 0.21 | 2.2 | 0.3 | 12 | 0 | 0 |
| | Std. Dev. | 20 | 0.06 | 3.8 | 1.7 | 32 | 7 | 0 |
| | Max | 191 | 0.55 | 28.7 | 26.9 | 100 | 100 | 0 |

**Project 26:**

**FPN:** 424630-1-52-01
**Road:** SR-9A (I-295)
**County:** Duval
**County Section No.:** 72002
**Mix Type:** FC-5
**Mix Design No.**: SPM 10- 8012B
**Date Placed:** 8/13/12 & 9/5/12
**EAR Firm:** Asphalt Technologies
**Description:** QC Failure Lot 12

The target binder content was 5.7 %, and the QC result was 6.42%. In addition, gradations in the 3/8 sieve, the #4 sieve, and the #8 sieve did not meet the MPR. Mix was placed in the following locations: R-1 Sta 774+23 – 857+00; L-2 Sta 296+00 – 305+01 & Sta 762+78 – 857+00; and R-2 Sta 297+26 – 305+01 & Sta 762+78 – 834+37.

An EAR was conducted for this project. The testing plan included testing cores taken from the questionable areas. The AC content was out of the MPR at station 301+13 in R-2. The AC content was also out of the MPR on the low side at four locations at the sour hen of L-2. The gradation was slightly out of the MPR on the fine side at numerous locations through the questionable areas. Visual evaluations were also made in all areas. This visual evaluation did not identify any problematic areas. Based on the results indicating the gradation was slightly out of the MPR and the good appearance of the pavement, it was recommended that the material remain in place.

Note: Resurfacing consisted of 2 in of an SP structural course traffic D (PG 76-22) and 0.75 in of an FC-5 (PG 76-22).

*Research project recommended section for evaluation:* R-1 MP 12.975 – 11.351 (Sta 774+23 – 860+00); L-2 MP 13.382 – 11.351 (Sta 295+00 – 860+00), and R-2 MP 13.382 – 11.836(Sta 297+26 – 305+01 & Sta 762+78 – 834+37). However, no “good areas were available in L2, so it was omitted from the evaluation.

**Table A26. PCS Summary Statistics for Defective and Non-Defective Materials – Project 26**

| Section | | Statistical Parameter | IRI Avg (in/mi) | LCMS Rut Avg. (in) | Cracking CW (%) | Cracking CO (%) | Raveling Low (%) | Raveling Med (%) | Raveling Sev (%) |
|---|---|---|---|---|---|---|---|---|---|
| R1 | Defective Material | Average | 39 | 0.16 | 1.8 | 2.3 | 3 | 0 | 0 |
| | | Std. Dev. | 23 | 0.03 | 6.0 | 5.4 | 18 | 0 | 0 |
| | | Max. | 370 | 0.28 | 70.2 | 44.4 | 100 | 0 | 0 |
| | Non-defective Material | Average | 36 | 0.15 | 0.7 | 1.2 | 0 | 0 | 0 |
| | | Std. Dev. | 17 | 0.02 | 1.9 | 3.2 | 0 | 0 | 0 |
| | | Max | 122 | 0.20 | 15.7 | 20.4 | 0 | 0 | 0 |
| R2 | Defective Material | Average | 43 | 0.21 | 3.7 | 1.9 | 15 | 0 | 0 |
| | | Std.Dev. | 33 | 0.05 | 7.0 | 4.5 | 35 | 0 | 0 |
| | | Max. | 583 | 0.50 | 45.1 | 28.3 | 100 | 0 | 0 |
| | Non-defective Material | Average | 46 | 0.23 | 4.8 | 1.0 | 4 | 0 | 0 |
| | | Std.Dev. | 39 | 0.06 | 5.8 | 2.6 | 19 | 0 | 0 |
| | | Max. | 560 | 0.39 | 35.4 | 21.4 | 100 | 0 | 0 |

## APPENDIX B. Dense-Graded Mixes with Low Air Voids-Statistical Analysis

| Project # | Material Type | Mean rutting | Std. Dev. | t-test (P-value) |
|---|---|---|---|---|
| Project 1 | Defective | 0.10 | 0.04 | 0.000 |
| | Good | 0.06 | 0.05 | |
| Project 2 | Defective | 0.16 | 0.12 | 0.000 |
| | Good | 0.14 | 0.07 | |
| Project 3-L2 | Defective | 0.07 | 0.05 | 0.000 |
| | Good | 0.05 | 0.08 | |
| Project 3-R2 | Defective | 0.05 | 0.04 | 0.000 |
| | Good | 0.11 | 0.11 | |
| Project 4 | Defective | 0.08 | 0.05 | 0.550 |
| | Good | 0.08 | 0.08 | |
| Project 5 | Defective | 0.04 | 0.01 | 0.000 |
| | Good | 0.07 | 0.04 | |
| Project 6 | Defective | 0.07 | 0.02 | 0.873 |
| | Good | 0.07 | 0.03 | |
| Project 7 | Defective | 0.18 | 0.03 | 0.000 |
| | Good | 0.16 | 0.05 | |
| Project 8 | Defective | 0.12 | 0.06 | 0.000 |
| | Good | 0.16 | 0.09 | |
| Project 9 | Defective | 0.07 | 0.01 | 0.000 |
| | Good | 0.21 | 0.10 | |
| Project 10 | Defective | 0.20 | 0.05 | 0.000 |
| | Good | 0.13 | 0.05 | |
| Project 11-L1 | Defective | 0.11 | 0.143 | 0.662 |
| | Good | 0.105 | 0.045 | |
| Project 11-L2 | Defective | 0.07 | 0.06 | 0.528 |
| | Good | 0.07 | 0.05 | |
| Project 12 | Defective | 0.11 | 0.050 | 0.000 |
| | Good | 0.14 | 0.053 | |
| Project 13-L1 | Defective | 0.18 | 0.043 | 0.000 |
| | Good | 0.18 | 0.072 | |
| Project 13-L2 | Defective | 0.16 | 0.028 | 0.000 |
| | Good | 0.19 | 0.077 | |
| Project 14 | Defective | 0.04 | 0.014 | 0.000 |
| | Good | 0.03 | 0.015 | |
| Project 15 | Defective | 0.12 | 0.03 | 0.000 |
| | Good | 0.16 | 0.05 | |
| Project 16 | Defective | 0.05 | 0.03 | 0.000 |
| | Good | 0.07 | 0.03 | |

## APPENDIX C. Summary of APA Results-Laboratory Rutting Evaluation

| NCAT Mix ID | AC Content | P200 Content | N | Air Voids (%) | APA Rut Depth (mm) | | |
|---|---|---|---|---|---|---|---|
| | | | | Avg. | Avg. | St. Dev | CV (%) |
| Camak 40RAP | OAC | Design | 6 | 7.0 | 5.9 | 0.7 | 11.7 |
| | OAC + 0.55% | Design + 1.5% | 4 | 3.9 | 4.6 | 0.4 | 8.7 |
| | OAC + 0.55% | Design + 1.5% | 4 | 7.0 | 7.2 | 0.4 | 5.2 |
| | OAC + 0.55% | Design + 1.5% | 4 | 9.3 | 8.7 | 0.7 | 7.5 |
| Whiterock | OAC | Design | 4 | 7.2 | 2.1 | 0.5 | 25.0 |
| | OAC + 0.55% | Design + 1.5% | 4 | 4.0 | 1.6 | 0.3 | 16.1 |
| | OAC + 0.55% | Design + 1.5% | 4 | 7.1 | 2.3 | 0.4 | 19.6 |
| | OAC + 0.55% | Design + 1.5% | 4 | 9.9 | 2.9 | 0.3 | 10.6 |
| JC-White Sand | OAC | Design | 4 | 6.9 | 4.1 | 0.4 | 9.8 |
| | OAC + 0.55% | Design + 1.5% | 4 | 4.0 | 4.3 | 0.5 | 11.2 |
| | OAC + 0.55% | Design + 1.5% | 4 | 7.0 | 6.3 | 1.1 | 16.7 |
| | OAC + 0.55% | Design + 1.5% | 4 | 9.3 | 7.4 | 1.3 | 17.9 |
| JC-Red Sand | OAC | Design | 4 | 6.9 | 2.9 | 0.7 | 25.0 |
| | OAC + 0.55% | Design + 1.5% | 4 | 4.3 | 3.2 | 0.4 | 11.0 |
| | OAC + 0.55% | Design + 1.5% | 4 | 6.9 | 4.8 | 1.7 | 35.0 |
| | OAC + 0.55% | Design + 1.5% | 4 | 10.0 | 5.3 | 1.0 | 18.2 |
| Duval | OAC | Design | 4 | 7.0 | 3.0 | 0.4 | 13.3 |
| | OAC + 0.55% | Design + 1.5% | 4 | 4.2 | 2.5 | 0.0 | 2.0 |
| | OAC + 0.55% | Design + 1.5% | 4 | 7.3 | 3.4 | 0.8 | 24.2 |
| | OAC + 0.55% | Design + 1.5% | 4 | 9.4 | 4.4 | 0.6 | 12.6 |

## APPENDIX D. Summary of HT-IDT Results – Laboratory Rutting Evaluation

| NCAT Mix ID | AC Content | $P_{200}$ Content | N | Air Voids (%) | HT-IDT Indirect Tensile Strength (psi) | | |
|---|---|---|---|---|---|---|---|
| | | | | Avg. | Avg. | St. Dev | CV (%) |
| Camak 40RAP | OAC | Design | 4 | 6.9 | 20.0 | 0.4 | 2.0 |
| | OAC + 0.55% | Design + 1.5% | 4 | 4.2 | 23.1 | 0.7 | 2.9 |
| | OAC + 0.55% | Design + 1.5% | 4 | 6.9 | 14.1 | 0.7 | 4.7 |
| | OAC + 0.55% | Design + 1.5% | 4 | 9.7 | 8.4 | 0.3 | 4.0 |
| Whiterock | OAC | Design | 4 | 7.1 | 34.3 | 0.6 | 1.8 |
| | OAC + 0.55% | Design + 1.5% | 4 | 3.9 | 39.1 | 2.9 | 7.5 |
| | OAC + 0.55% | Design + 1.5% | 4 | 7.2 | 25.9 | 1.8 | 6.9 |
| | OAC + 0.55% | Design + 1.5% | 3 | 9.6 | 21.5 | 0.7 | 3.1 |
| JC-White Sand | OAC | Design | 4 | 7.1 | 33.0 | 0.9 | 2.7 |
| | OAC + 0.55% | Design + 1.5% | 4 | 4.2 | 38.9 | 2.3 | 6.0 |
| | OAC + 0.55% | Design + 1.5% | 4 | 7.0 | 24.4 | 1.7 | 7.0 |
| | OAC + 0.55% | Design + 1.5% | 4 | 9.4 | 17.4 | 0.7 | 3.8 |
| JC-Red Sand | OAC | Design | 4 | 7.0 | 32.5 | 1.3 | 3.9 |
| | OAC + 0.55% | Design + 1.5% | 4 | 4.2 | 34.1 | 0.7 | 2.2 |
| | OAC + 0.55% | Design + 1.5% | 4 | 6.9 | 24.2 | 0.3 | 1.4 |
| | OAC + 0.55% | Design + 1.5% | 4 | 9.6 | 17.2 | 0.7 | 4.1 |
| Duval | OAC | Design | 4 | 7.1 | 43.7 | 1.5 | 3.5 |
| | OAC + 0.55% | Design + 1.5% | 4 | 3.9 | 48.2 | 2.7 | 5.7 |
| | OAC + 0.55% | Design + 1.5% | 4 | 7.1 | 32.0 | 0.7 | 2.2 |
| | OAC + 0.55% | Design + 1.5% | 4 | 9.7 | 22.8 | 1.0 | 4.3 |