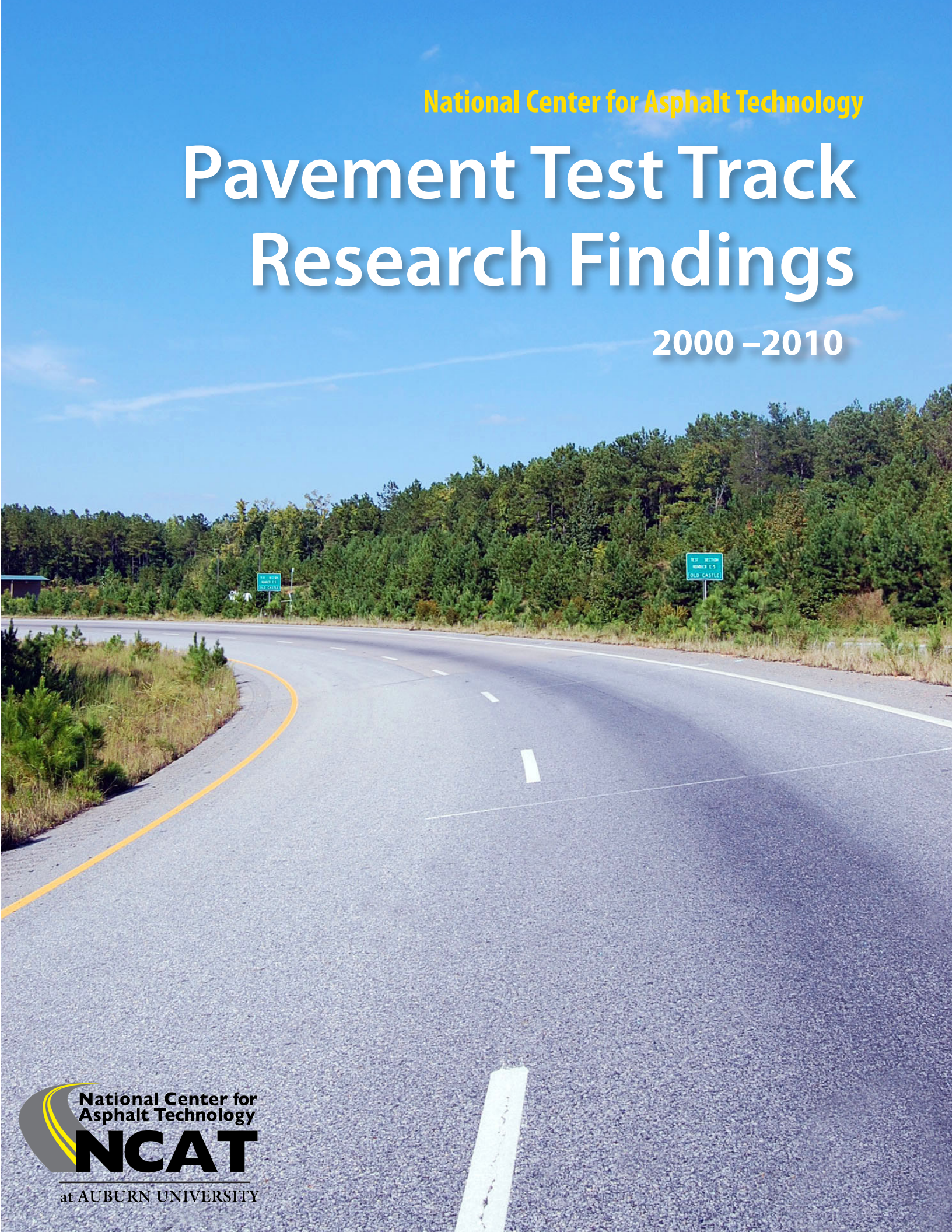
National Center for Asphalt Technology

Pavement Test Track Research Findings

2000 –2010



National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

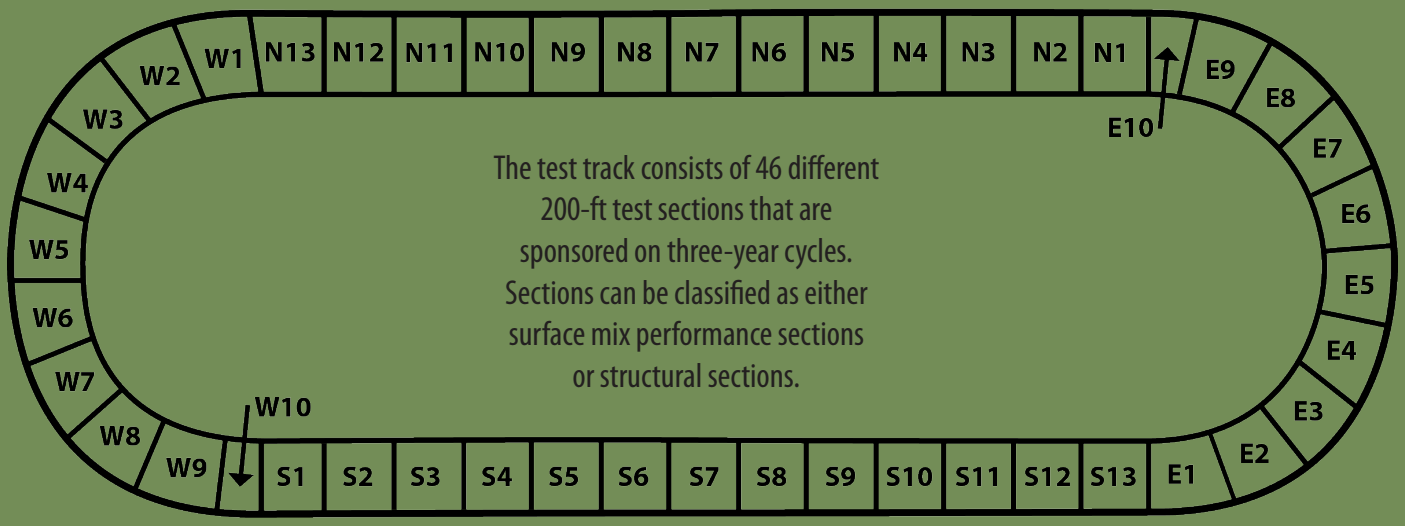
Overview

The NCAT Pavement Test Track, a world-renowned accelerated pavement-testing facility, has been operating for 10 years. It is a cooperative project with individual test sections sponsored by highway agencies and commercial interest groups. This special report highlights key findings since the first heavily loaded tractor-trailer made the inaugural 1.7-mile journey around the track a decade ago.

Test track findings have already resulted in numerous improvements in current asphalt pavement specifications, and the research will continue to pay dividends for years to come.

Findings span the industry areas of mix design, aggregate and binder characteristics related to performance, structural design and tire-pavement interaction.

By the Numbers



The test track consists of 46 different 200-ft test sections that are sponsored on three-year cycles. Sections can be classified as either surface mix performance sections or structural sections.

National Center for Asphalt Technology Pavement Test Track Research Findings Cycles 1–4, 2000-2010

Introduction

The NCAT Pavement Test Track is a unique accelerated pavement-testing facility that unites real-world pavement construction with live heavy trafficking for rapid testing and analysis of asphalt pavements. It is funded and managed as a cooperative project among highway agencies and industry sponsors.

Figure 1. NCAT Pavement Test Track.

The track is a 1.7-mile oval with 46 different 200-ft test sections that are sponsored on three-year cycles. Each sponsor has specific research objectives for their section(s) and shared objectives for the track as a whole. Three cycles have been completed since the test track opened in 2000, and a fourth cycle will end in 2011.

The track sections are exposed to a fleet of heavily loaded tractor-trailers that circle the track five days per week for 16 hours per day, applying 10 million equivalent single-axle loads (ESALs) to the pavements during each three-year research cycle. Pavement performance within each section is continuously monitored to evaluate rutting, fatigue cracking, roughness, texture, friction and noise. At the end of each cycle, test sections either remain in place for additional evaluation during the next cycle or are replaced, as determined by the section sponsor.

Test sections can be classified as either surface mix performance sections, which are built on a robust cross-section that limits distresses to the experimental surface layers, or as structural sections of different thicknesses that more closely resemble real-world pavements. Structural pavement sections have embedded strain and pressure sensors to analyze pavement response to loads for validation of mechanistic-empirical pavement design procedures. All sections are also equipped with temperature sensors throughout the pavement depth. Construction materials are often long-hauled from other states as required by sponsors in order to build 200-ft test sections that are truly representative of sponsors' roadways.

Test Track Background

The first cycle began in 2000 with the loading of 46 test sections. The only variable among the sections in the first cycle of tests was the properties of the mixtures in the top four inches. This cycle was completed in 2002 after 10 million ESALs had been applied to the sections. This traffic level is representative of up to 20 years of traffic on typical rural interstate highways.

The second cycle of tests began in 2003 when parts of the test track were reconstructed. Eight sections were completely removed down to the subgrade and reconstructed to evaluate different thicknesses of hot-mix asphalt (HMA). Some of these structural sections used modified asphalt, and others used neat asphalt in adjacent sections. The structural section experiments marked the beginning of using the test track to examine issues relating to mechanistic pavement design. Each of these structural sections was

built with embedded stress and strain gauges to measure the section's response to traffic throughout the cycle. Fourteen other sections from the original construction were milled and overlaid with a new surface mix to be evaluated. The remaining sections were left in place to evaluate the effects of two more years of traffic (another ten million ESALs) and environmental exposure on durability.

The third research cycle began in 2006, with a combination of new and old sections in service. Eight original sections built in 2000 (all surface mix performance sections) remained in place and accumulated 30 million ESALs by the end of the third cycle in 2008. Sixteen sections (12 mix performance and four structural) from the second cycle also remained in place and had accumulated 20 million ESALs at the end of the third cycle. Twenty-two new sections (15 mix performance and seven structural) were built in 2006.

The fourth cycle began in 2009 and will be completed in late 2011. Three of the original surface mix performance sections built in 2000 remain in place and will have accumulated 40 million ESALs by the end of the fourth cycle. Eleven sections from the 2003 track (nine mix performance and two structural) remain in place and will have accumulated 30 million ESALs. Nine sections from the 2006 track (eight mix performance and one structural) remain in place and will have accumulated 20 million ESALs. Twenty-three new sections (nine mix performance and 14 structural) were built in the current research cycle.

Research Findings

A number of findings from the test track have been used by the various sponsors to improve their materials specifications and pavement design policies. The majority of the research findings can be categorized into one of the following areas: (1) mix design, (2) aggregate characteristics related to performance, (3) binder characteristics related to performance, (4) structural design and (5) tire-pavement interaction. This report is a summary of findings related to each of these five areas.

1. Mix Design

1.1 High RAP Mixtures

Six test sections in the third cycle were devoted to evaluating the performance of pavements with both moderate (20 percent) and high (45 percent) reclaimed asphalt pavement (RAP) contents. Results indicate that high RAP content mixes can provide excellent rutting performance and durability. Field performance through four years does not indicate that using a softer virgin binder grade improves performance for high RAP content mixes.

Figure 2. Reclaimed asphalt pavement (RAP).

In the current cycle, sections were built with 50 percent RAP in the surface, intermediate and base layers to further assess the cracking resistance of high RAP mixes. In one section, the virgin binder is a regular PG 67-22 binder, and in the other section the same binder was foamed. Both mixes were produced as warm mix at lower temperatures. Another surface mix performance section was milled and inlaid with gravel containing 45 percent RAP and PG 67-22 binder. Porous friction course (PFC) surfaces in three other sections were placed with 15 percent RAP.

1.2 Warm-Mix Asphalt

MeadWestvaco donated materials to produce and construct an early version of its Evotherm warm-mix asphalt (WMA). These two WMA test sections opened to heavy traffic immediately after construction, near

the end of the 2003 research cycle, and this new technology proved to be very resistant to rutting.

Both sections remained in service throughout the 2006 track, exhibiting durability and rutting performance comparable to HMA for 10.5 million ESALs. One section remains in service on the 2009 track. Durability of WMA has been found to be comparable to HMA through five years and more than 16 million ESALs.

In the current cycle, data shows that WMA sections built with both foamed asphalt technology and an additive technology have the same structural response to heavy loads and environmental effects as HMA. These sections were also opened up to heavy traffic after construction in August 2009 and have proven to be resistant to rutting.

Figure 3. Warm-mix asphalt temperature.

1.3 Stone-Matrix Asphalt (SMA) Mixtures

Through the first four cycles of the NCAT Pavement Test Track, 21 SMA sections have been put to the test (eight on the 2000 track, eight on the 2003 track, three on the 2006 track and two on the 2009 track). Excellent performance of the SMA test sections in the first cycle prompted several states to use this premium mix type to extend pavement life for heavy traffic highways. Specific test sections using crushed gravel aggregate in an SMA performed as well as other SMA sections, allowing states with limited native quarried stone to implement SMA at a much lower cost. Other test sections were built to compare SMA and Superpave mixes on a life-cycle cost basis. After five years and 10 million ESALs, both sections had less than 2 mm of wheel-path deformation, but the Superpave section was showing an increasing trend of macrotexture—an indicator of weathering—and some cracking at the longitudinal joint. In contrast, the higher binder content SMA section exhibited only a slight change in macrotexture with no cracking.

1.4 Open-Graded Friction Course Mixtures

After four years the twin-layer OGFC surface continues to be the smoothest, quietest and most effective section at eliminating water spray on the track.

Several highway agencies have sponsored test sections to evaluate the performance of open-graded friction course (OGFC) mixes with different aggregates and construction techniques. The Georgia DOT sponsored two test sections to assess how aggregates with different percentages of flat and elongated particles would affect performance. Results showed that more cubical aggregate reduced the permeability and capacity to eliminate water spray compared to less cubical and lower cost aggregate. The Tennessee DOT sponsored an OGFC mixture using a hard limestone that had great performance, including excellent friction results, prompting TDOT to begin putting OGFC on some routes for the first time in 2005. The Mississippi DOT continues to assess an all-gravel OGFC placed in 2006, which has already endured over 16 million ESALs. Florida DOT is currently evaluating an OGFC mixture containing 15 percent RAP.

One of the most interesting test sections on the track has been the twin-layer OGFC placed in 2006. This section has a 9.5 mm nominal maximum aggregate size (NMAS) OGFC surface layer on top of a 12.5 mm NMAS OGFC layer. Both OGFC layers were placed with a special (and very large) paver built specifically to simultaneously place two HMA layers (see Fig. 4). After four years the twin-layer OGFC surface continues to be the smoothest, quietest and most effective section at eliminating water spray on the track.

Figure 4. Twin-layer paver.

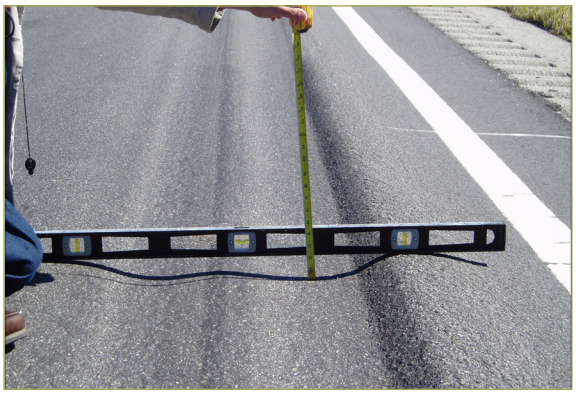


Figure 5. Two-inch rutting shown in Indiana low-air voids experiment.

Although the enhanced safety and reduced-noise benefits of OGFC mixtures are well documented, test track research is currently assessing the structural contribution of the OGFC surface layer and how OGFC may be able to minimize top-down cracking when a heavy tack coat is used.

1.5 Critical Air Voids Level for Acceptance

The Indiana Department of Transportation sponsored test track research to identify the lowest limit for air voids, one of the most used pay-factors for pavement quality. A series of short sections constructed with surface layers having low QC air voids were subjected to the test track's heavy trafficking. The surface mixes were intentionally produced to have QC air voids between 1.0 and 3.5 percent by adjusting the mix gradation and increasing the asphalt content. Results showed that the rate of rutting significantly increased when QC air voids were less than 2.75 percent, indicating that removal and replacement of surface layers is appropriate below that level. It is important to note that the Indiana DOT experiment used only mixes with neat asphalt binder. Other sections on the track with surface mixes containing modified binders with air voids less than 2.5 percent have held up very well under the extreme traffic on the track.

1.6 Comparison of Mix Design Methods

In the first cycle, the Oklahoma DOT built two test sections to compare the performance of mixes designed by the Superpave system to mixes designed by OKDOT's standard Hveem-based mix design. Although both sections exhibited good performance on the track, less rutting was observed in the Superpave section. This test track study gave OKDOT the confidence to move forward with implementing Superpave.

1.7 Fine-Graded vs. Coarse-Graded Mixtures

During the early years of Superpave implementation, there was a strong push toward coarse-graded mixtures for improving rutting resistance. However, that notion was called into question when the results of Westrack showed that a coarse-graded gravel mix was less resistant to rutting and fatigue cracking than a fine-graded mix with the same aggregates. In the first cycle of the NCAT Pavement Test Track, the issue was examined more completely. Twenty-seven sections were built with a wide range of aggregate types comparing coarse-, intermediate- and fine-graded mixtures. NCAT test track results showed that fine-graded Superpave mixes perform as well as coarse-graded and intermediate-graded mixes under heavy traffic and tend to be easier to compact, less prone to segregation and less permeable. Based on these findings, many state highway agencies revised their specifications to allow the use of more fine-graded mix designs.

Figure 6. Crack mapping on the test track.

1.8 Increased Durability

Test track research has shown that higher asphalt contents improve mix durability, leading to longer pavement life. More asphalt can be incorporated into the mixture by reducing the compactive effort required during mix design. Several states placed mixes on the test track that were designed with 50 to 70 percent gyrations in the Superpave gyratory compactor (SGC) that have withstood the heavy loading on the track with great performance.

1.9 Top-Down Cracking

Florida's pavement management system has shown that top-down cracking is the state's most prevalent form of pavement distress. University of Florida research has indicated that the best method for predicting resistance to top-down cracking is the energy ratio, which is determined from properties of the surface mixture and stress conditions in the pavement structure. Florida DOT has sponsored test track sections in past and current cycles to validate the energy ratio concept and to determine ways to mitigate this mode of distress. Test sections have shown that using a polymer-modified binder in dense-graded surface layers increases a mixture's energy ratio and improves the pavement's resistance to top-down cracking. The current cycle is assessing how a heavy tack coat applied with a spray-paver during construction of an OGFC layer may provide added resistance to the start or severity of top-down cracking.

1.10 Thin Overlay Using a 4.75 mm NMAS Mix

Thin HMA overlays (less than 1¼-inch thick) are a common treatment for pavement preservation. Currently, about half of U.S. states utilize 4.75 mm Nominal Maximum Aggregate Size (NMAS) mixtures in thin overlay applications. An advantage of the 4.75 mm mixtures is that they can be placed as thin as ½ inch, allowing the mix to cover a much larger area than thicker overlays. In the second test track cycle, the Mississippi DOT sponsored a test section of 4.75 mm surface mix containing limestone screenings, fine crushed gravel and a native sand. The section has been in place for nearly seven years and carried more than 25 million ESALs with only seven millimeters of rutting and no cracking. This section is proof that well-designed 4.75 mm mixes are a tough and durable option for pavement preservation.

2. Aggregate Characteristics

2.1 Effect of Aggregate Toughness on Performance

The South Carolina DOT used the test track to evaluate how an aggregate with an excessive LA abrasion loss would hold up through plant production, construction and performance in a real pavement. Although the aggregate did break down more than other aggregates through the plant, the resulting asphalt mixture performed well on the track. Rutting performance on the track was similar to that of other sections, and there were no signs of raveling, as indicated by texture changes. Based on these results, South Carolina changed its specifications to allow the use of this aggregate source with higher LA abrasion loss.

In another test section, South Carolina was interested in assessing the polishing behavior of a different aggregate material. A surface mixture with the aggregate was designed, produced and placed on the track. Friction tests conducted at regular intervals of traffic applications showed a sharp decline in skid resistance, indicating that the aggregate was not suitable for use in surface mixes. The test track enabled South Carolina to make this assessment in less than two years without putting the driving public at risk. Mississippi and Tennessee DOTs constructed sections to observe how blending limestone into gravel mixes effects pavement performance and friction test results. Both states concluded that mixes containing all local crushed gravel will provide satisfactory performance.

Figure 7. Chert gravel.

Missouri DOT constructed three test sections on the 2003 track to determine the possibility of adjusting the quality requirements for SMA aggregates without compromising performance. Before that time, only one in-state source of material could be used. As a result of this experiment, Missouri was able to revise the specification and reap the benefits of lower-cost SMA mixes through increased competition and reduced haul cost.

2.2 Elimination of the Restricted Zone

Part of the original Superpave mix design procedure included a restricted zone within the gradation band for each nominal aggregate size. Test track sections with a variety of aggregate types proved that mixtures with gradations through the restricted zone could have excellent rutting resistance. The restricted zone was subsequently removed from the Superpave specifications.

3. Binder Characteristics

Figure 7. Taking rut measurements on the test track.

3.1 Effect of Binder Grade on Rutting

Superpave guidelines recommend using a higher PG grade for high traffic-volume roadways to minimize rutting. Results from the first cycle of testing indicated that, on average, permanent deformation was reduced by more than 50 percent when the high-temperature grade was increased from PG 64 to PG 76. This two-grade bump is typical of many projects on high traffic-volume roadways. This information validated one of the key benefits of modified asphalt binders. The Florida DOT had conducted accelerated testing of its own using a Heavy Vehicle Simulator (HVS) to determine at what depth it would be possible to discontinue the use of modified binders without sacrificing improved rutting performance. Two sections of the 2003 track were subsequently used to validate these findings by comparing their performance with those used in the HVS experiment. Results on the NCAT Pavement Test Track were comparable to results in the HVS, giving Florida confidence to implement its previous findings.

3.2 Increasing the Binder Content in Mixtures Containing Modified Binders

In the first cycle, the Alabama Department of Transportation also sponsored test sections to evaluate mix designs with an extra 0.5 percent asphalt content. Performance of those sections on the track showed that increasing the asphalt content of mixes produced with modified binders did not affect rutting resistance; however, mixes produced with neat binders were more sensitive to changes in asphalt content. Furthermore, the performance of test sections containing neat asphalt were consistent with the finding described in Section 1.5. For mixtures with modified binders, low lab-compacted air voids are not a good indicator of rutting.

3.3 Comparison of Different Types of Binder Modification

The effect of binder modifiers on the performance of dense SMA and PFC mixes was a major focus on the 2000 track. Excellent performance was observed in all mixes produced with modified binders, regardless of the type of modifier used.

In the current cycle, Missouri DOT sponsored two sections to compare the performance of a surface mix containing an SBS-modified binder and a ground tire rubber-modified binder. Both binders graded as PG 76-22. To date, comparisons of the two sections show that both binders provide excellent and essentially equivalent performance.

Figure 8. Falling-weight deflectometer testing on the track.

4. Structural Design

4.1 Engineering Response of Pavement Structures to Load and Environment

Over the past three cycles, 18 test sections have been instrumented with stress and stain gauges to measure actual responses of pavement structures to loading and environmental conditions. The stress and strain measurements at the bottom of asphalt layers have correlated well with predicted values, using layered-elastic models for a wide range of pavement materials and thicknesses at high speeds. This important finding validates the use of such models in mechanistic-based pavement structural design methods, including PerRoad and the Mechanistic-Empirical Pavement Design Guide (MEPDG).

4.2 Revision of the Asphalt Layer Coefficient for Pavement

Although many highway agencies are preparing for implementation of the MEPDG, thousands of projects continue to be designed using the pavement design method developed more than 50 years ago that was based on the AASHO Road Test. In simplified terms, the current method relates the expected decrease in pavement serviceability to the design traffic divided by the structural capacity of the pavement structure. The pavement's structural capacity is calculated by summing the products of the thickness of each layer multiplied by an assigned layer coefficient that represents the relative structural contribution of that layer.

ALDOT implemented the new layer coefficient in its pavement design practice in 2010 and estimates this change will save $25 million per year in construction costs.

The Alabama DOT funded a study to examine the layer coefficient for structural asphalt layers. The performance and loading history of all 14 structural sections built on the NCAT test track in the second and third cycles were analyzed. These test sections represented a broad range in asphalt thicknesses, mix types, bases and subgrades. The analysis indicated that the asphalt layer coefficient should be increased from 0.44 to 0.54. This 18 percent increase in the layer coefficient translates directly to an 18 percent reduction in the design thickness for new pavements and overlays. ALDOT implemented the new layer coefficient in its pavement design practice in 2010 and estimates this change will save $25 million per year in construction costs.

4.3 Strain Threshold for Perpetual Pavements

Analysis of data from in-situ pavement instrumentation from three cycles of the test track indicates that these pavements can withstand higher levels of strain than suggested by lab tests without accumulating fatigue damage. This may allow pavement engineers to design perpetual pavements with thinner cross-sections and, thus, make HMA more competitive against other pavement types in life-cycle cost comparisons.

5. Tire-Pavement Interaction

5.1 New Generation Open-Graded Friction Course Mixes

Each cycle of the test track has featured sections with new-generation open-graded friction course (OGFC) mixtures using a variety of aggregate types. Testing has shown that OGFC surfaces, also known as porous friction courses, eliminate water spray, improve skid resistance and significantly reduce tire-pavement noise.

5.2 Friction Performance

Several agencies have sponsored test sections to evaluate the performance of OGFC mixtures with a range of aggregate types.

Figure 9. OGFC on the test track.

Examples of aggregates used in OGFC surfaces on the test track include granites, limestone, slags and gravels. Ongoing research is explaining the correlation between friction results on the test track with laboratory conditioning and friction testing. This work will reduce the cost, time and risks associated with field evaluation of new pavement surfaces and could provide new opportunities for research on building safer roads.

5.3 Tire-Pavement Noise and Pavement Surface Characteristics

The noise generated from tire-pavement interaction is substantially influenced by the macrotexture and porosity of the surface layer. Tire-pavement noise testing on the track indicates that the degree to which these factors influence noise levels is related to the weight of the vehicle and tire pressures. For lighter passenger vehicles, the porosity of the surface, which relates to the degree of noise attenuation, is the dominant factor. For heavier vehicles (with higher tire pressures), the macrotexture of the surface and the positive texture presented at the tire-pavement interface has a greater influence.

5.4 High-Precision Diamond Grinding to Remove Bumps for Smoother Roads

A good way to level high areas in the pavement surface that can occur in the construction and maintenance of HMA is through high-precision diamond grinding. When performed on transverse joints at the test track, this grinding process resulted in a very smooth and tight surface. None of the numerous joints leveled with the grinding equipment during each research cycle have exhibited any performance issues. Some of the leveled areas have been in service for up to 10 years with no performance problems. No sealing was applied to these treated surfaces.

6. Prediction Testing

6.1 Performance Tests to Predict Rutting

The pavement engineering field is interested in identifying a reliable test that can predict rutting performance. Through each cycle, NCAT has conducted several performance tests on the mixtures placed at the track, including dynamic modulus, repeated load tests and wheel-tracking tests. Although the amount of rutting for most of the test sections at the track has been low, sufficient rutting was observed to determine if trends exist between the performance tests and actual rutting measured on the track. The results have shown that the dynamic modulus has no correlation with rutting. The Asphalt Pavement Analyzer (APA) is a popular test for assessing rutting potential and has consistently provided reasonable correlations with test track performance. As a result of this testing at the track, the Oklahoma DOT implemented a specification requiring the use of the APA on new mix designs. Based on a correlation between APA results and rutting on the track in the third cycle, an APA criteria of 5.5 mm was established for heavy-traffic pavements.

As a result of testing at the track, the Oklahoma DOT implemented a specification requiring the use of the Asphalt Pavement Analyzer (APA) on new mix designs.

In the last few years, several researchers have recommended a repeated-load axial deformation test known as the Flow Number (FN) test for predicting rutting. Although no consensus has been reached regarding several variations of the test method, NCAT has used a confined test with 10 psi and a repeated axial stress of 70 psi. A strong correlation was found between the results of the FN test using these conditions and rutting on the track. A minimum FN criterion of 800 cycles was recommended for heavy traffic pavements.

6.2 Using Energy Ratio to Predict Top-Down Cracking

As described in Section 1.9, the University of Florida and Florida DOT have developed a promising method for predicting the susceptibility of surface layers to top-down, load-related cracking. This method was validated on the test track in the third cycle. Two test sections were built with identical structures, except for the surface layers. One surface mix was designed with a low energy ratio, and the other was designed with a high energy ratio. As expected, the section with the low energy ratio exhibited top-down cracking

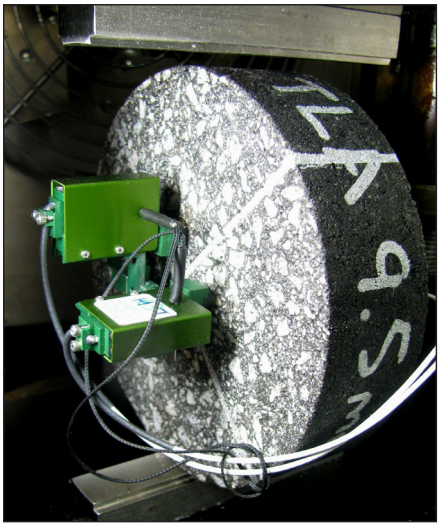


Figure 10. Testing the Indirect Tensile Creep Compliance as part of energy ratio.

first, with cracks appearing after 1.9 million ESALS. The section with the higher energy ratio surface layer carried 50 percent more traffic before cracks appeared. This research demonstrated that top-down cracking is a phenomenon that can be replicated in experimental pavements and that the energy ratio method can correctly assess the relative performance of surface mixes to this mode of distress.

6.3 Dynamic Modulus Prediction

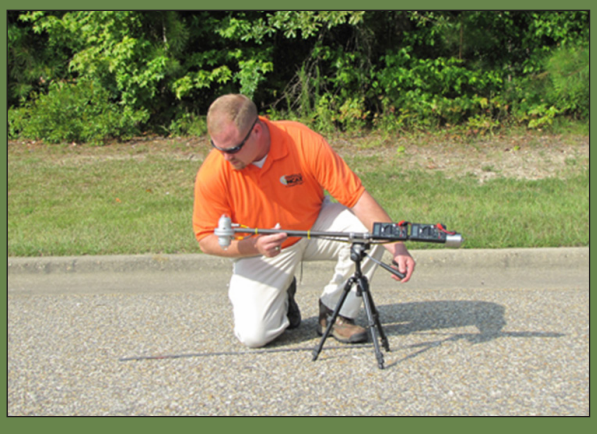
In mechanistic-based pavement design methods, the dynamic modulus (E*) is a basic input for HMA, since this property characterizes the rate of loading and temperature dependency of HMA. Three predictive dynamic modulus models and laboratory-measured E* values were compared to determine which model most accurately reflected E* values determined in laboratory testing. The Hirsch model proved to be the most reliable E* model for predicting the dynamic modulus of an HMA mixture.

Test Track Field Equipment

Top left: The Automatic Road Analyzer (ARAN) van is used for high-speed profiling and continuous rut-depth measurement using full lane scanning lasers.

Bottom left: Solar reflectance is measured with a pyrometer according to ASTM E 1918.

Bottom right: The close-proximity noise (CPX) trailer uses two free field microphones to isolate the tire/pavement noise.



Acknowledgements and Disclaimer

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