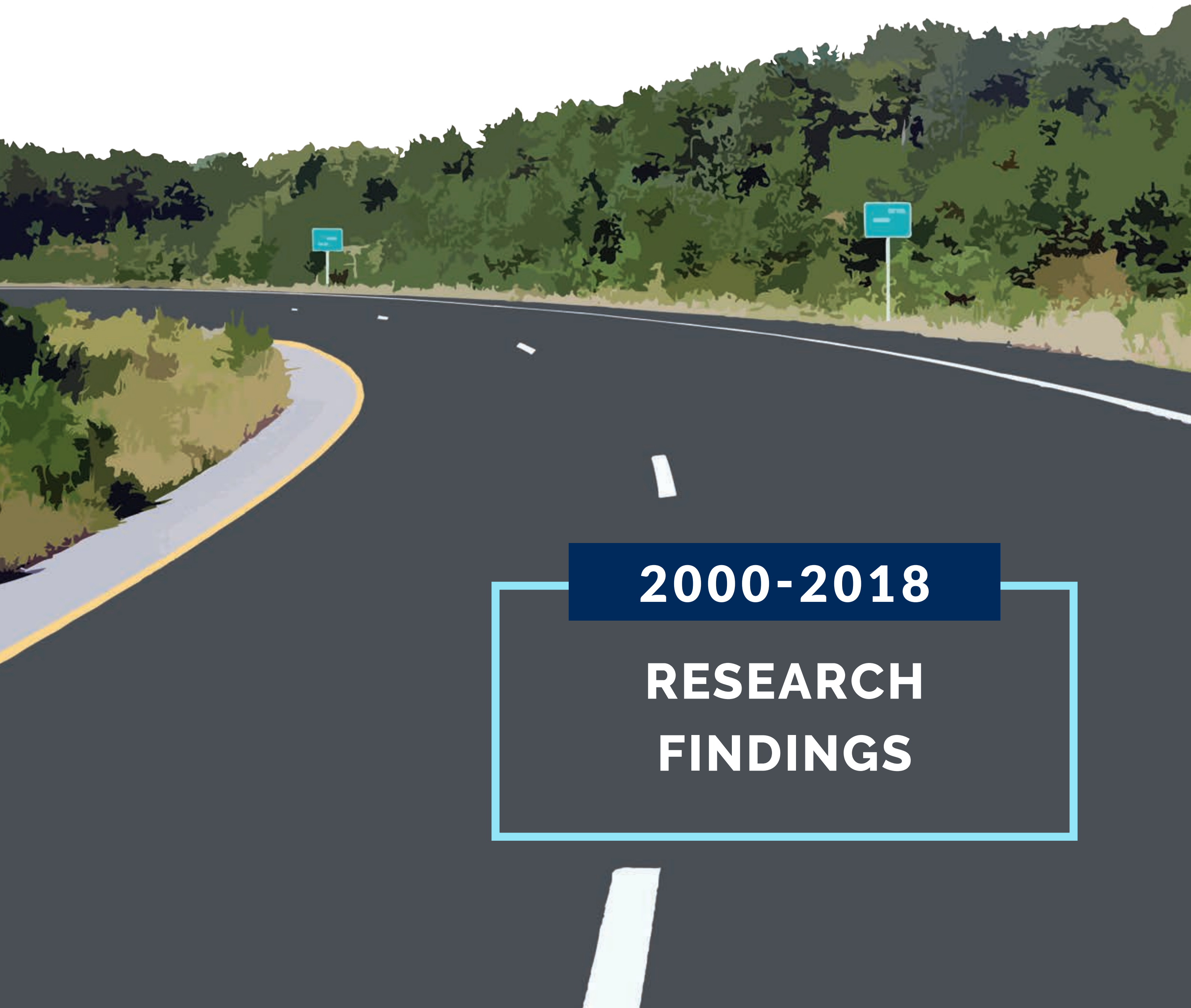
NCAT TEST TRACK



2000-2018

RESEARCH FINDINGS

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CAPABILITIES

The NCAT Test Track is a national research proving ground for asphalt pavements. This real-world laboratory allows for cutting-edge pavement experimentation while avoiding the risk of failure on actual roadways.

The National Center for Asphalt Technology (NCAT) Pavement Test Track is a world-renowned accelerated pavement testing facility that combines full-scale pavement construction with live, heavy truck trafficking for rapid testing and analysis of asphalt pavements. It is the only facility that simultaneously tests dozens of instrumented pavements under real environmental conditions with accelerated loading.

Since its original construction in 2000, findings from this unique facility have helped improve specifications for aggregate, binder and mix design as well as more cost-effective asphalt pavement design methods. The research will continue to pay dividends for years to come.

OVERVIEW

Located on a 309-acre site, NCAT's Test Track is a 1.7-mile oval comprised of 46 200-foot test sections sponsored on three-year research cycles. The track is funded as a cooperative project among highway agencies and industry sponsors with specific research objectives for their sections and shared objectives for the track as a whole. Sections can be classified as structural experiments, surface mix experiments or pavement preservation studies. At the end of each research cycle, test sections either remain in place for additional evaluation in the next cycle or are replaced.

Structural pavement sections have varying thicknesses that closely resemble real-world highway pavements. They have embedded strain and pressure sensors to evaluate pavement response to loads for validation of mechanistic-empirical pavement design models. Surface mix performance sections are built on a robust cross-section that limits distresses to the experimental surface layers. Pavement preservation treatments are applied on structural and surface mix performance sections when testing on these sections has been completed to determine the life extending benefits of these treatments.

In 2015, a partnership was established with the Minnesota Department of Transportation's Road Research facility (MnROAD) to address asphalt pavement research needs in both northern and southern climates. Through the partnership, similar structural pavement sections were built at MnROAD and at the Test Track to evaluate asphalt mixture cracking tests. The partnership also includes pavement preservation experiments to quantify the life extending benefits of pavement preservation on both low-volume and high-volume roadways. Findings from the NCAT-MnROAD pavement preservation experiments are summarized in another report.

This document provides a summary of key findings from NCAT's Test Track at the end of the sixth research cycle in 2018 and their implementation. Findings from the pavement preservation experiments are reported in other documents.

RESEARCH CYCLES

Each research cycle on the track consists of three phases. The first phase begins with building or replacing test sections. The second phase involves trafficking, data collection and laboratory testing. The third phase of the cycle involves forensic evaluations of test sections as needed.

PHASE ONE

Test sections are built and/or replaced, which normally takes about six months. Mixture samples from construction are obtained for laboratory testing.

PHASE TWO

Each section is subjected to 10 million equivalent single-axle loads (ESALs) of heavy truck traffic applied over a period of two years. Performance of the test sections is monitored throughout the second phase.

PHASE THREE

Forensic analyses are conducted on damaged sections to determine the contributing factors to pavement distresses. This can include destructive evaluation such as trenching and coring.

HIGHWAY AGENCIES USE TEST TRACK RESEARCH TO IMPROVE MATERIALS SPECIFICATIONS, CONSTRUCTION PRACTICES AND PAVEMENT DESIGN PROCEDURES.

FIRST CYCLE (2000-2003)

The first cycle began with the loading of 46 newly constructed test sections. The only variables were the properties of the mixtures in the top four inches. This cycle was completed after 10 million ESALs had been applied to the test sections, which is two to four times the loading most interstate highways carry in a two-year period.

SECOND CYCLE (2003-2006)

Structural experiments were first conducted on the Test Track in the second cycle to examine issues relating to mechanistic pavement design. Eight sections from the first cycle were completely removed down to the subgrade and reconstructed to evaluate different thicknesses of asphalt. Some of these structural sections used modified asphalt binder, and others used neat asphalt. Each structural section was built with embedded stress and strain gauges to continually measure the pavement response to traffic. In addition, 14 other sections from the original track construction were milled and overlaid with new surface mixes, and the remaining 24 sections were left in place to evaluate the effects of additional traffic and environmental exposure on durability.

THIRD CYCLE (2006-2009)

Twenty-two new sections (15 mix performance and seven structural evaluation) were built for the third cycle. Eight original surface mix performance sections from the first cycle remained in place and accumulated a total of 30 million ESALs by the end of the third cycle. Sixteen sections from the second cycle (12 mix performance and four structural) remained in place and accumulated a total of 20 million ESALs.

FOURTH CYCLE (2009-2012)

Twenty-five new sections were built for the fourth research cycle. By the end of the fourth cycle, three of the original surface mix performance sections remaining from the first cycle had accumulated a total of 40 million ESALs, nine sections remaining from the second cycle accumulated a total of 30 million ESALs, and nine sections remaining from the third cycle accumulated a total of 20 million ESALs. Six agencies worked together to establish the Group Experiment, a collection of test sections with a common cross-section to assess the performance and structural response of pavements constructed with warm-mix asphalt (WMA) technologies, high reclaimed asphalt pavement (RAP) contents, a combination of high RAP content and WMA, and a porous friction course containing 15% RAP.

FIFTH CYCLE (2012-2015)

The 2012 track featured a more complex range of experiments than any of the previous cycles. Of the 46 total sections, 22 were new, 14 were left in place from the fourth cycle (including all of the Group Experiment sections), six were left in place from the third cycle, three remained from 2003, and two remained from the original track construction. The Green Group Experiment began in the fifth cycle to evaluate the performance and structural responses of test sections optimizing the use of WMA and recycled materials. Other major focuses of the fifth cycle were on porous friction courses (PFCs) and cold central plant recycling (CCPR) mixes. Eight new PFC test sections and one previously built PFC section were tested. Three new structural sections were constructed to evaluate the CCPR mix in the base layer.

SIXTH CYCLE (2015-2018)

The 2015 research cycle consisted of two sections from 2000, one surface mix performance section from 2003, three sections from the 2006 high RAP experiment, three sections from 2009 with crack seals and high friction surfaces, 18 sections remaining in place from the 2012 research cycle for additional evaluation and 19 new sections. Of the 19 new sections, nine sections were removed to the aggregate base layer and replaced with new asphalt structures. Seven of these sections were instrumented for the Cracking Group Experiment to identify which laboratory tests best correlate with the field cracking performance. The remaining 10 new sections included four surface mix performance sections, four pavement preservation sections with thinlay and chip seals, and two sections with high friction thinlay and microsurfacing.

PERFORMANCE TESTING

NCAT is accredited by AASHTO for adherence to published standards and compliance to requirements in asphalt binder and mixture testing. NCAT results are recognized as credible and statistically verifiable.

LABORATORY TESTING

Hamburg Wheel-Track Testing

Asphalt Pavement Analyzer (APA)

Flow Number (Fn)

Dynamic Modulus (E*)

Resilient Modulus (Mr)

Overlay Test

Illinois Flexibility Index Test (I-FIT)

Semi Circular Bend Test (SCB)

Indirect Tensile Creep Compliance

Disk-Shaped Compact Tension Test (DCT)

Bending Beam Fatigue (BBF)

Bond Strength

Tensile Strength Ratio (TSR)

Simplified Visco-Elastic Continuum Damage (S-VECD) Fatigue Test (a.k.a. Cyclic Fatigue)

FIELD TESTING

Close-Proximity Noise Trailer

Mobile Laboratory

Falling Weight Deflectometer

Albedometer

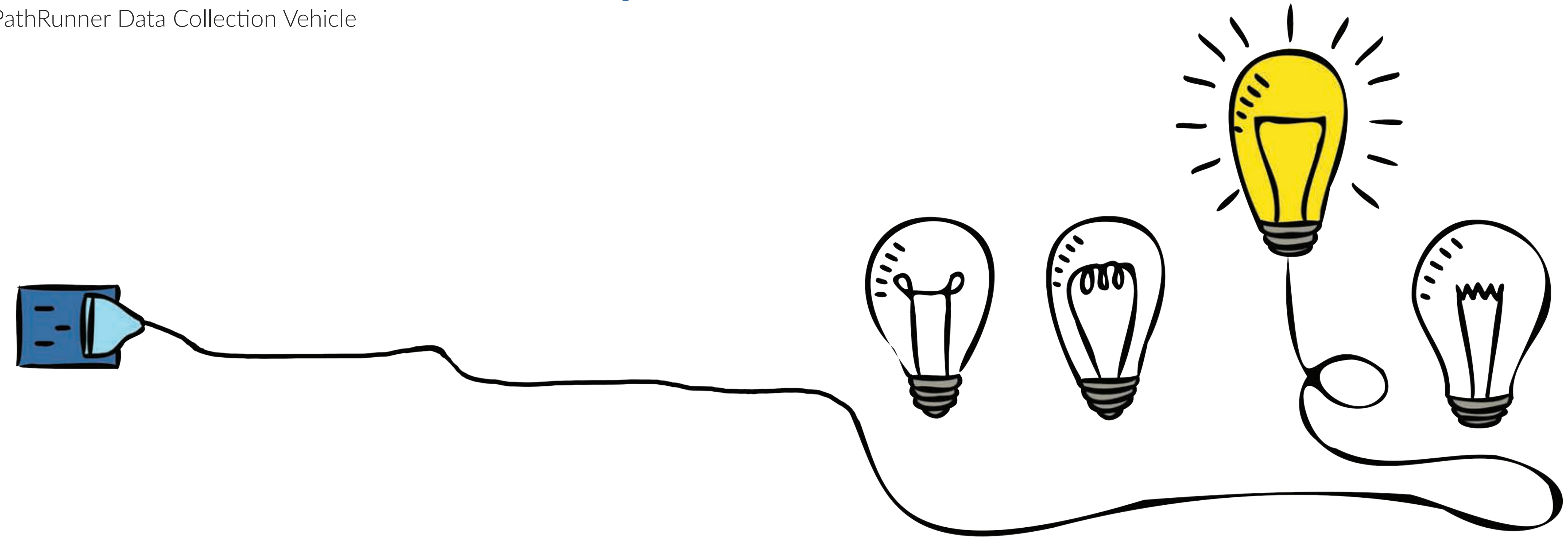
Dynamic Friction Tester

PathRunner Data Collection Vehicle

KEY FINDINGS

The focus of the Test Track is on practical research and the application of findings that lead to specification improvements agencies can put into contracts. These key findings can be categorized into the following areas:

1. MIX DESIGN
2. AGGREGATE PROPERTIES
3. BINDER CHARACTERISTICS
4. STRUCTURAL PAVEMENT DESIGN AND ANALYSIS
5. TACK COAT APPLICATIONS
6. RELATIONSHIPS BETWEEN LABORATORY RESULTS AND FIELD PERFORMANCE
7. INTERLAYERS
8. FOUNDATION SUPPORT
9. TIRE-PAVEMENT INTERACTION



MIX DESIGN

FINE GRADED VS. COARSE-GRADED

In the early years of Superpave implementation, there was an emphasis on coarse-graded mixtures to improve 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 aggregate. In the first cycle of the Test Track, the issue was examined more completely. Twenty-seven sections were built with a wide range of aggregate types to compare coarse-, intermediate-, and fine-graded mixtures. Results demonstrated 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.

WARM-MIX ASPHALT (WMA)

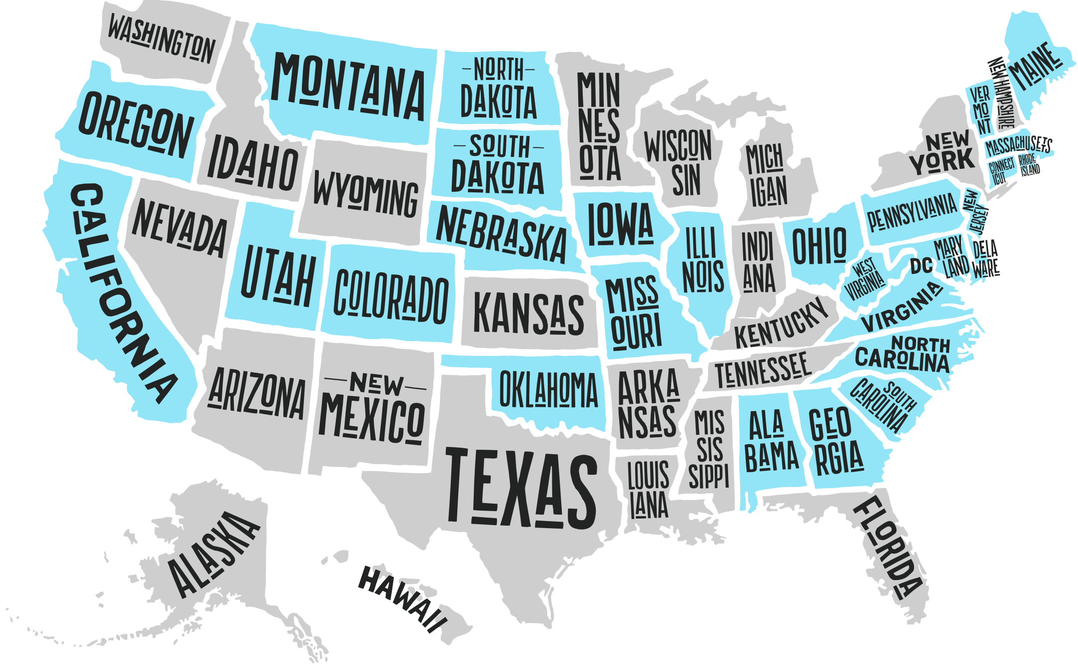
An early version of MeadWestvaco's Evotherm® WMA technology was used in overlays to repair two test sections with extensive damage near the end of the 2003 research cycle. These two sections were opened to heavy traffic immediately after construction and remained in service throughout the 2006 cycle with rutting performance comparable to HMA for 10.5 million ESALs and no cracking. One section was left in place at the start of the 2009 cycle and endured more than 16 million ESALs before the test section was used for a different experiment. The performance of those sections was early evidence that WMA could hold up to extremely heavy traffic. Additional WMA test sections built in 2009 also performed very well and helped agencies gain confidence to implement WMA despite concerns of rutting raised by laboratory tests.

HIGH RECLAIMED ASPHALT PAVEMENT (RAP) CONTENT

Six test sections built in the third cycle and trafficked through the fourth cycle were devoted to evaluating the performance of pavements containing moderate (20%) to high (45%) RAP contents. After approximately 20 million ESALs, the sections had practically no rutting, very little raveling and small amounts of low severity surface cracking. The use of a softer virgin binder was shown to provide better resistance to raveling and cracking of the 45% RAP mixes. No rutting or cracking benefit was observed for using polymer-modified virgin binder in the mixes with 20% or 45% RAP. Additional test sections built in 2009 with 50% RAP in each pavement layer performed better than a companion virgin test section in all performance measures including fatigue cracking. The improved fatigue cracking is partly attributed to a higher stiffness of the 50% RAP mixes, which resulted in substantially lower tensile strains at the bottom of the test sections compared to sections with all virgin mixtures.

DESIGN GYRATIONS

The Test Track, along with data from field projects across the U.S. collected as part of NCHRP project 9-29, showed that the gyratory compaction effort specified in AASHTO standards was too high. The lab compaction effort was not representative of what actually occurs in pavements since high N_{design} numbers tend to grind aggregate particles and break them down much more than what occurs during construction or under traffic. Mix designers were typically using coarse-graded mixes to meet the volumetric mix design criteria, but those mixes are more challenging to compact in the field and tend to be more permeable, making pavements less durable. Numerous mixes on the Test Track designed with 50 to 70 gyrations in the Superpave gyratory compactor held up to the heavy loading with great performance. As a result, many states (shown below in blue) significantly reduced their N_{design} levels.



The durability of longitudinal joints in asphalt pavements is a major concern of the Kentucky Transportation Cabinet (KYTC) and many other state DOTs. While poor compaction of the mix at a longitudinal joint is often considered the main cause leading to its deterioration, coarse-graded asphalt mixtures can also make compaction more challenging at the joint. For this reason, KYTC evaluated a fine-graded mixture designed with an N_{design} of 65 gyrations against a KYTC-approved coarse-graded mixture designed with an N_{design} of 100 gyrations in two adjacent sections following standard practices for constructing the longitudinal joints. Field permeability tests on the longitudinal joints showed that the fine-graded mixture was 20% less permeable, making the joint less susceptible to freeze-thaw damage.

STONE-MATRIX ASPHALT (SMA)

Through the first three cycles of the track, 19 SMA sections (eight on the 2000 track, eight on the 2003 track and three on the 2006 track) were put to the test. Excellent performance of these sections in the first cycle prompted several states to adopt this premium mix type for heavy traffic highways. Mississippi, Missouri and Georgia then used the Test Track to evaluate lower-cost aggregates in SMA, which have helped make this mix type more economical. An SMA mixture containing 12% ground tire rubber by weight of binder and an SMA with 5% recycled shingles was successfully used in the 2012 Group Experiment. These two mixes did not contain added fibers as typically used with SMA but had no issues with binder draindown.

THIN LIFT OVERLAY

Thin HMA overlays (less than 1¼-inch thick) are a common treatment for pavement preservation; about half of U.S. states currently utilize 4.75 mm NMAS mixtures in thin overlay applications. An advantage of these mixtures is that they can be placed as thin as ½ inch, covering a much larger area than thicker overlays.

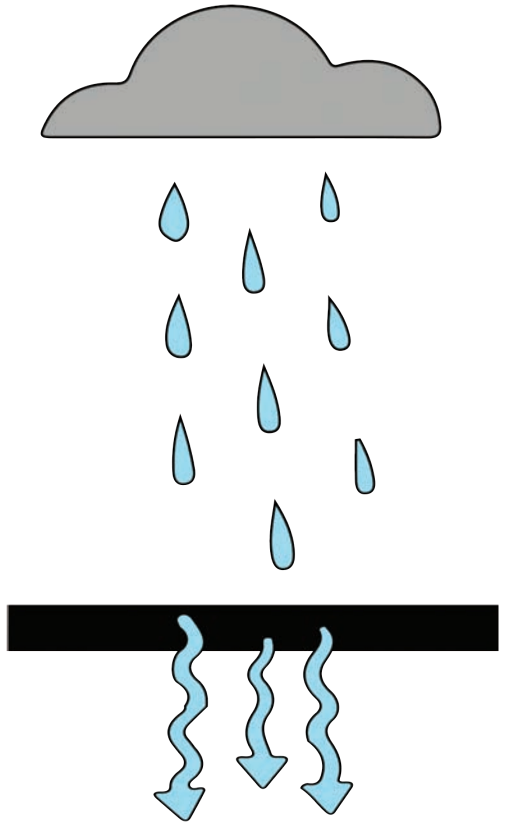
In 2003, the Mississippi DOT sponsored a test section with a 4.75 mm surface mix containing limestone screenings, fine crushed gravel and a native sand with a polymer-modified asphalt. That section has carried more than 50 million ESALs with only 7 mm of rutting and no cracking. This section is proof that well-designed 4.75 mm mixes are a durable option for pavement preservation. In 2012, the 4.75 mm NMAS mix was redesigned by adding RAP, changing from polymer-modified to neat asphalt, eliminating imported stone screenings and relying completely on locally available surplus sand stockpiles in Mississippi. After 20 million ESALs, no cracking, rutting, roughness, raveling or friction deficiencies were noted for the redesigned mix. A low cost per mile can be achieved as a result of the use of all local materials, RAP, and neat asphalt binder in a thin surface layer.

The Tennessee DOT (TDOT) has used 5/8-inch NMAS mixes for thin-lift surfaces for many years. TDOT wanted to evaluate 4.75-mm mixes in thicker lifts (e.g. 1.25 inches) to achieve better in-place density but wanted to make sure this would not lead to a rutting problem. In 2015, TDOT evaluated a 4.75-mm mix placed in a 1.5-inch lift to assess its rutting resistance. The mix was designed with 16% fine RAP and a total binder content of 6.8% that included 0.13 RAP binder ratio and PG 64-22 virgin binder. The mixture showed excellent performance with no cracking, less than 2.0 mm rutting, and good smoothness. The mixture also maintained a stable friction value and had a slight increase in macrotexture under traffic.

NEW GENERATION OPEN-GRADED FRICTION COURSE (OGFC)

OGFC mixtures have been used in the southern states for many years as a method for reducing wet-weather accidents on the highway. However, its use has declined in recent years due to premature raveling issues occurring after approximately six or seven years in service.

In 2012, the Alabama DOT sponsored three test sections to evaluate potential changes in its mix design procedure to improve the durability of OGFC mixtures. The first potential change is the use of a finer gradation of 9.5 mm NMAS, the second is the utilization of synthetic fiber instead of cellulose fiber, and the final change considered is to use ground tire rubber-modified binder to replace polymer-modified binder and cellulose fiber. These changes were incorporated in three OGFC mix designs. The three mixtures had no cracking or raveling, and rutting was about 0.05 inches after 20 million ESALs were applied over two research cycles. These proposed changes are being considered in an updated OGFC mix design procedure.



AGGREGATE PROPERTIES

FLAT AND ELONGATED

The Georgia DOT led the way in using SMA in the early 1990s and soon after began to modify their OGFC mixes toward a coarser and thicker porous European mix. Georgia established strict aggregate shape limits for these premium mixes based on European experience; however, these strict specifications limited the available aggregate sources in Georgia and resulted in prices that were more than four times the price of conventional coarse aggregates. Georgia DOT used the track to evaluate the effect of using aggregates with a less strict flat and elongated requirement for their OGFC mixes. Test Track performance showed that the lower cost aggregates actually improved drainage characteristics.

TOUGHNESS

The South Carolina DOT used the track to evaluate an aggregate with an LA abrasion loss that exceeded their specification limit. Aggregate degradation was assessed through plant production, construction, and under traffic. Although the aggregate did break down more than other aggregates through the plant, the test section performed very well. Rutting performance on the track was similar to other sections, and there were no signs of raveling as indicated by texture measurements. Based on these results, the agency revised its specifications to allow the aggregate source.

POLISHING AND FRICTION

In 2003, the South Carolina DOT evaluated a surface mix containing a new aggregate source on the track to assess polishing characteristics. Friction tests conducted at regular intervals showed a sharp decline in results, indicating that the aggregate was not suitable for use in surface mixes. This enabled South Carolina to make an assessment in less than two years without putting the driving public at risk. Mississippi and Tennessee DOTs followed with similar experiments to assess blends of limestone and gravel on mix performance and friction. Both states concluded that mixes containing crushed gravel provided satisfactory performance and revised their specifications to allow more gravel in their surface mixes. Test sections sponsored by the Florida DOT used a limestone aggregate source that was known to polish. When the sections became unsafe for the NCAT fleet, a high friction surface treatment containing an epoxy binder and calcined bauxite aggregate was evaluated. The treatment provided excellent friction results for over 30 million ESALs.

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. In the first cycle of the Test Track, sections with a variety of aggregate types proved that mixtures with gradations through the restricted zone were not necessarily susceptible to rutting. The restricted zone was subsequently removed from Superpave specifications.

BINDER CHARACTERISTICS

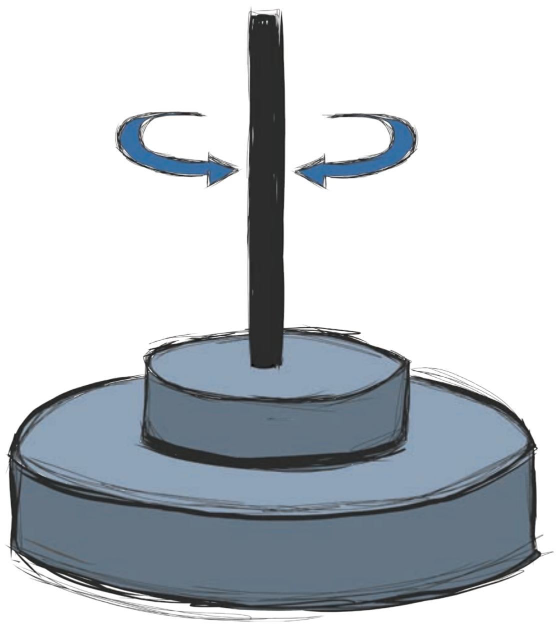
EFFECT OF BINDER GRADE ON RUTTING

Superpave guidelines have recommended using a higher PG grade for high-traffic volume roadways to minimize rutting. Results from the first cycle showed that permanent deformation was reduced by an average of 50% when the high-temperature grade was increased from PG 64 to PG 76. This two-grade bump is typical for heavy traffic projects, and these results validated one of the key benefits of modified asphalt binders.

The Alabama DOT also sponsored test sections to evaluate surface mixes designed with 0.5% more asphalt binder, and results showed that increasing the asphalt content of mixes containing modified binders did not adversely affect rutting resistance; however, mixes produced with neat binders were more sensitive to changes in asphalt content.

COMPARISON OF DIFFERENT TYPES OF BINDER MODIFICATION

Experiments with paired test sections in the first cycle compared mixes containing PG 76-22 polymer-modified asphalt binders using styrene butadiene styrene (SBS) and styrene butadiene rubber (SBR). Sections included dense-graded Superpave mixes, SMA mixes and porous friction course mixes. Excellent performance was observed in all mixes produced with modified binders regardless of the type of modifier used. In 2009, a similar experiment sponsored by the Missouri DOT and Seneca Petroleum comparing the performance of a surface mix containing an SBS-modified binder and a GTR-modified binder demonstrated that a GTR-modified binder can provide the same performance as traditional polymer modification.



EVALUATION OF ALTERNATIVE BINDERS

Three test sections were built in 2009 to evaluate Trinidad Lake Asphalt (TLA) and Thiopave® pellets for use in asphalt mixtures. TLA pellets are made from a naturally occurring asphalt binder source in Trinidad, while the Thiopave® pellets are produced based on a sulfur-modified asphalt formulation. Thiopave® pellets must be used in combination with a warm mix additive to lower the mixing temperature to 275°F or less to reduce hydrogen sulfide emissions to an acceptable level. All three asphalt layers of the TLA section were modified with 25% TLA based on weight of total binder. For the two Thiopave® sections, the base and intermediate mixes were modified with 30% and 40% Thiopave®, respectively, while the surface mixes were not modified with Thiopave®.

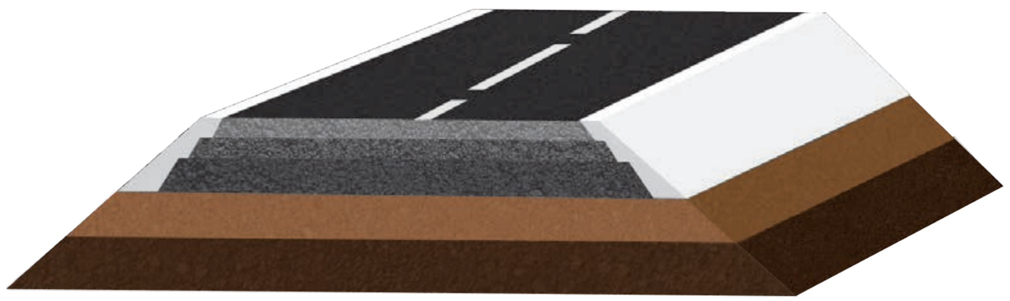
The field performance of the three test sections was compared with that of a conventional asphalt control section. Pavement response measurements indicated that all of the test sections remained structurally sound throughout the research cycle. No cracking was found, rutting was acceptable, and ride quality in each section was deemed excellent after 10 million ESALs.

STRUCTURAL PAVEMENT DESIGN AND ANALYSIS

ASPHALT LAYER COEFFICIENT FOR PAVEMENT DESIGN

Although many highway agencies are preparing for implementation of a mechanistic-based pavement design method, thousands of projects are still designed using the empirical pavement design method, which was largely based on the AASHO Road Test in the late 1950s. In simplified terms, the empirical method relates pavement serviceability to expected traffic and the structural capacity of the pavement structure. The pavement's structural capacity is calculated by summing the products of the thickness and the layer coefficient of each layer.

A study funded by the Alabama DOT re-examined the asphalt layer coefficient using the performance and loading history of all structural sections from the second and third Test Track cycles. These test sections included broad ranges of asphalt thickness, mix types, bases, and subgrades. The analysis indicated that the asphalt layer coefficient should be increased from 0.44 to 0.54. This 18% increase translates directly to an 18% reduction in the design thickness for new pavements and overlays. Alabama estimates a yearly savings of $25 to $50 million in construction costs since implementing the new layer coefficient in 2010.



STRAIN THRESHOLD FOR PERPETUAL PAVEMENT DESIGN

The perpetual pavement design concept has been validated using several Test Track sections. This design approach is based on engineering each pavement layer to withstand critical stresses so that damage never occurs in lower layers of the structure. On a life-cycle cost basis, perpetual pavements are more economical than traditional pavement designs and are less disruptive to traffic since roadway maintenance is minimized.

Two of the original 2003 structural sections were deemed perpetual as they carried more than three times their "design traffic" based on the 1993 AASHTO guide with only minor surface damage before the sections were replaced for another experiment. In the 2006 cycle, Oklahoma sponsored two sections to further validate the concept for pavements built on a very soft subgrade. One section was designed using the 1993 AASHTO guide, and the other section was designed using the PerRoad Perpetual Design program. The conventional design resulted in a 10-inch asphalt cross-section, whereas the perpetual design was 14 inches thick. Results validated the concept of limiting critical strains to eliminate bottom-up fatigue cracking. Economic analysis of the two pavement design alternatives demonstrated that Perpetual Pavement is more cost effective in a life-cycle cost comparison. The three perpetual pavement sections and nine other structural test sections that experienced bottom-up fatigue cracking in the 2003, 2006 and 2009 research cycles were later used to develop a limiting strain distribution that clearly separated the perpetual pavement sections from the others. The limiting strain distribution has been implemented in PerRoad for future perpetual pavement design that can sustain the heaviest loads and provide an indefinite structural life without being overly conservative.

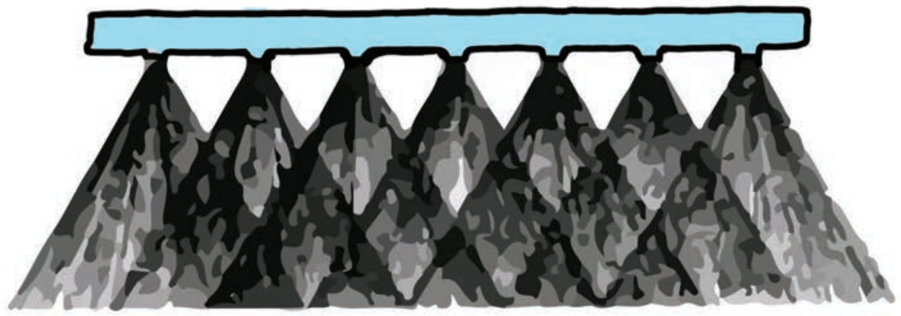
MEASURED VERSUS MEPDG PREDICTED PERFORMANCE

Fifteen structural study test sections were analyzed with the MEPDG using the default national calibration coefficients. For virtually all sections, the MEPDG over-predicted rutting, generally with errors in the range of 70 to 100%. The rutting predictions for most sections were significantly improved after calibrating the model coefficients. MEPDG fatigue cracking predictions with the default coefficients were also poor for the majority of the sections. In about half of the cases, the MEPDG significantly under-predicted fatigue cracking, but in a few cases it over-predicted the amount of fatigue cracking. Attempts to adjust the fatigue model coefficients did not improve the overall correlation of predicted versus measured fatigue.

DYNAMIC MODULUS PREDICTION

In mechanistic-based pavement design methods, dynamic modulus (E*) is a primary input for asphalt pavement layers since this property characterizes the effects of rate of loading and temperature on asphalt concrete. 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.

TACK COAT APPLICATIONS



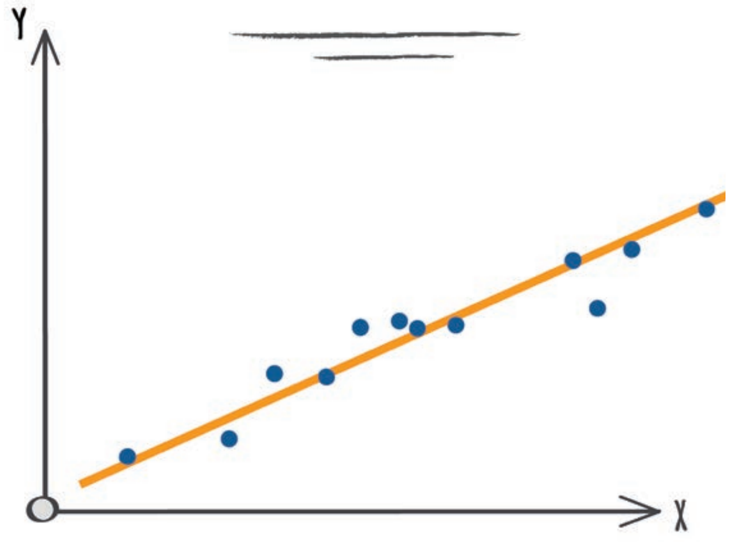
METHODS FOR IMPROVING OGFC PERFORMANCE

Delamination can significantly affect the longevity of OGFC mixtures and is due largely to construction practices and tack coat applications. Due to its high air voids content, an OGFC mix has less contact area with the underlying receiving surface, so a heavier tack coat is needed for an OGFC mix than for a dense-graded mix to form an adequate bond.

Two FDOT tack coat studies conducted in the 2009 and 2012 Test Track cycles evaluated several tack methods for improving OGFC performance. The same OGFC mix, which used a PG 76-22 and 15% RAP, was placed at a thickness of 0.75 inches in each test section after a tack coat was applied. Results of these studies found that a thick polymer-modified tack coat (CRS-2P) applied with a spray paver at a target rate of 0.20 gal/yd^2 significantly improved OGFC performance. In addition, a non-tracking hot-applied polymer tack applied with a conventional distributor at a target residual rate of 0.15 gal/yd^2 can be considered an alternative to CRS-2P applied with a spray paver, depending on paving conditions.

RELATIONSHIPS BETWEEN LABORATORY RESULTS AND FIELD PERFORMANCE

CRACKING TESTS



Due to increasing concerns that volumetric properties are not sufficient to ensure the long-term durability of asphalt mixtures, especially those with higher recycled contents, the Cracking Group experiment was planned, built, and executed in the sixth cycle to help DOTs select asphalt mixture cracking tests. The experiment includes (1) seven new test sections built on the test track to validate tests for top-down cracking and (2) eight rebuilt test sections on MnROAD's main-line test road for validating tests for low-temperature cracking. The seven test sections on the test track have the same pavement structure except for the surface mixes, which were designed with a range of recycled materials contents, binder types and grades, and in-place densities to achieve various levels of cracking performance.

The field cracking performance of the Cracking Group experiment at the end of the sixth cycle was used to provide a preliminary evaluation of five cracking tests as follows:

- While the Energy Ratio test indicated positive results in the previous evaluation at the NCAT Test Track, it did not properly identify the surface mixture with a substantial amount of cracking in the Cracking Group experiment.
- The semi-circular bend test and its Jc criteria (Louisiana method) was unable to distinguish mixes with significant cracking from those with no cracking in the test sections.
- The overlay test results (both the Texas method and the NCAT-modified method) ranked the mixtures largely in accordance with their anticipated level of field cracking performance. Both methods appear to appropriately rank the mixtures with different density levels. The mixture with a higher density level had higher cycles to failure than the control mixture with a lower density level.
- Since the Illinois Flexibility Index Test (I-FIT) and the indirect tensile asphalt cracking test (IDEAL-CT) are based on a similar calculation method, their results showed the same trends in most respects and ranked the mixtures largely in accordance with their anticipated cracking performance. However, a concern with both the I-FIT and IDEAL-CT methods is the impact of specimen density. Counter to the expected outcome, higher density specimens have lower FI and CT_{Index} results than lower density specimens for the same mix.

LAB TESTING OF FRICTION AND TEXTURE CHANGES

NCAT used Test Track data to validate a method for determining texture and friction changes of any asphalt surface layer subjected to traffic. The procedure involves making slabs of the pavement layer in the laboratory and subjecting the slabs to simulated trafficking in the three-wheel polishing device developed at NCAT. The slabs are periodically tested for friction and texture using the ASTM standards for the Dynamic Friction Tester and the Circular Track Meter. Excellent correlations were established between the friction results in the lab and the field.

RUTTING TESTS

Although most state DOTs indicate that rutting has been virtually eliminated as a primary distress, there is still interest in identifying reliable laboratory tests that can evaluate 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 to determine if laboratory test results correlate with actual rutting measured on the track.

Results have shown that dynamic modulus does not correlate well with rutting. However, the Asphalt Pavement Analyzer (APA) has consistently provided reasonable correlations with Test Track performance. Based on a correlation between APA results and rutting on the track in the third cycle, an APA criterion of 5.5 mm was established for heavy traffic surface mixes for tests conducted in accordance with AASHTO T 340-10.

The Hamburg wheel tracking test has been increasingly accepted in recent years, and numerous state DOTs now have Hamburg requirements for mix design approval. The test is considered to be a proof test for rutting and moisture damage susceptibility. Although there are no national criteria for Hamburg results, many highway agencies set the maximum rut depth between 4 and 10 mm at 20,000-wheel passes. NCAT conducted the Hamburg test in accordance with AASHTO T 324 at 50°C on 18 mixtures from the 2012 track cycle. Hamburg results correlated reasonably well (R^2 = 0.74) with rutting measurements on the track, and none of the test sections had any evidence of moisture damage.

The flow number (FN) test is another lab test to evaluate the rutting resistance of asphalt mixes. In the third cycle, NCAT used a confined FN 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. Using this method, a minimum FN of 800 cycles was recommended for heavy traffic pavements. More recently, NCHRP Report 673, A Manual for Design of Hot Mix Asphalt with Commentary, and NCHRP Report 691, Mix Design Practices for Warm Mix Asphalt, both recommended the FN test for assessing the rutting resistance of mix designs. The testing criteria and traffic level performance thresholds from these reports have been adopted in AASHTO TP 79-13. Flow number tests conducted on surface mixes from the fourth cycle did not correlate well with the measured rutting for the test sections. However, all results met the FN criteria in AASHTO TP 79-13 for 3 to 10 million ESALs of traffic.

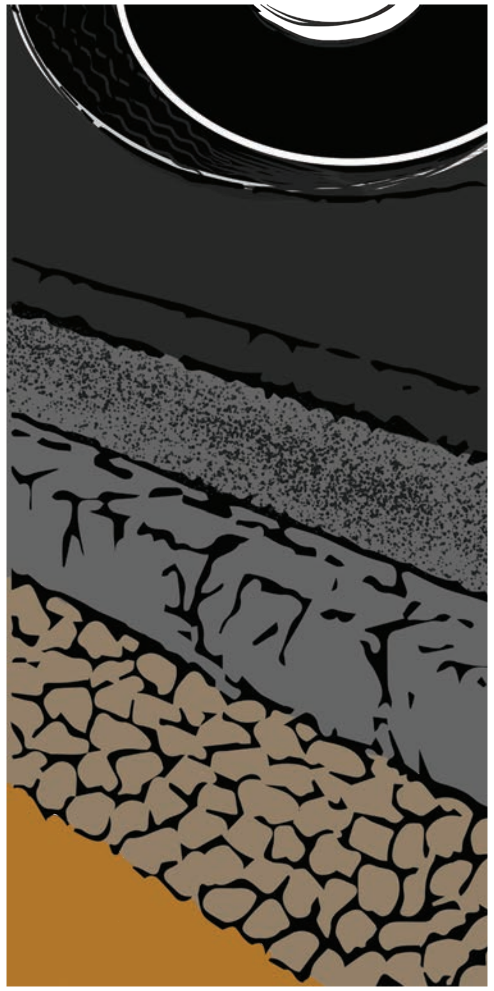
AIR VOIDS

Air voids in laboratory-compacted specimens is a common pay factor for asphalt pavements. The Indiana DOT sponsored Test Track research to identify an appropriate lower limit for this acceptance parameter. Surface mixes were intentionally produced with air voids between 1.0 and 3.5% by adjusting the aggregate gradation and increasing the asphalt contents. Results showed that rutting increased significantly when the air voids were less than 2.75%. When test results are below that value and the roadway is to be subjected to heavy traffic, removal and replacement of the surface layer is appropriate. It is important to note that the experiment used only mixes with neat (unmodified) asphalt binder and without recycled materials. Other surface mixes on the track containing modified binders or high recycled asphalt binder ratios that were produced with air voids below 2.5% have held up very well under the extreme traffic on the track.

INTERLAYERS

ALTERNATIVE INTERLAYERS

Several state agencies have used cracking relief interlayers to provide a discontinuity between the existing surfaces and new overlays so that existing cracks are not as easily reflected to the overlays. In Georgia, the most commonly specified interlayer is a single chip seal treatment placed on the existing surface. An asphalt levelling course is placed over the chip seal at 75 to 80 lbs/sy before placing an overlay. This method, however, has not been as effective as desired.



The Georgia DOT sponsored a study at the Test Track beginning in 2012 to evaluate two alternative interlayers. To simulate cracking, deep saw cuts were made in two test sections and filled with sand to avoid self-healing after placement of interlayers. One section was then treated with a double chip seal treatment with a sand seal top layer, and the other with a 9.5-mm open-graded interlayer (OGI). Both sections were then covered with a 9.5-mm NMAS dense-graded overlay. Cracking was beginning to develop in both sections after 10 million ESALs. The amount of cracking in the OGI section increased significantly in the second cycle with 50% of the saw cuts having reflected through to the surface after 20 million ESALs. For the other section, reflective cracking was observed in only 6% of the saw cuts. Cracks in both sections remained at low severity (≤ 6 mm). The maximum rut depth in the surface treatment interlayer section was 0.75 inches (21 mm) while it was only 0.25 inches (6 mm) in the OGI section.

FOUNDATION SUPPORT

ENGINEERED RAP BASE

Cold Central Plant Recycling (CCPR) is a highly sustainable method of combining RAP with foamed or emulsified asphalt and additives in a central recycling plant without the application of heat and has been used for rehabilitating low- and medium-volume roadways. This method was evaluated in three test sections beginning in 2012, complementing an existing project on I-81 in Virginia, for use on heavily loaded roadways. Two sections were designed to evaluate the difference between 6 and 4 inches of asphalt built over 5 inches of CCPR materials and 6 inches of aggregate base. In a third test section, the 6-inch aggregate base was replaced with an 8-inch cement-stabilized base (CSB) followed by 5 inches of CCPR materials and 4 inches of HMA. Through two research cycles and over 20 million ESALs, all three sections have performed extremely well with no cracking, minimal rutting, and no appreciable change in ride quality. Based on measured strains, the section with the CSB layer is expected to be perpetual, while the other two sections with aggregate base could develop bottom-up cracking, which will be validated in the current research cycle.

TIRE-PAVEMENT INTERACTION

NOISE AND PAVEMENT SURFACE CHARACTERISTICS

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 has indicated that the degree to which these factors influence noise levels is related to the weight of the vehicle and tire pressure. 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.

QUIET PAVEMENTS

Each cycle of the Test Track has included new-generation open-graded friction course mixtures featuring a variety of aggregate types. Testing has shown that these surfaces, also known as porous friction courses, eliminate water spray and provide excellent skid resistance.

HIGH-PRECISION DIAMOND GRINDING

Smoothness is the most important pavement characteristic from the perspective of users. Occasionally, pavement maintenance or rehabilitation results in a bump in the roadway surface that needs to be removed. Precision diamond grinding has been used on the track in each cycle to smooth out transitions between some test sections. None of the areas leveled with the grinding equipment have exhibited any performance issues and some were in service for up to 10 years with no performance problems. No sealing was applied to these treated surfaces.

HIGH FRICTION SURFACE TREATMENT (HFST)

A good friction surface is needed in critical braking and cornering locations for safe driving. While the current standard HFST has shown the highest friction and high macro-texture characteristics for skid resistance, it requires premium thermosetting polymer resin and imported calcined bauxite aggregate, making it an expensive surface treatment. Therefore, state agencies are interested in finding an alternative.

An FHWA-sponsored friction study conducted on the track from 2012 to 2014 used regionally available friction aggregates to replace calcined bauxite. The results showed that polymer resin bound surfaces with other regionally available friction aggregate sources did not provide the same level of surface friction as those with the calcined bauxite. A follow-up study in 2015 was then conducted on the track to evaluate asphalt (instead of polymer resin) bound surfaces with calcined bauxite as the primary friction aggregate. These surfaces included (a) two micro-surfacing treatments, one with a 50:50 aggregate blend of calcined bauxite and limestone sand and the other with a 100% sandstone blend, and (b) one thin overlay, using a 4.75 mm SMA mixture with 40% calcined bauxite, 59% granite, and 1% filler. They were placed using conventional asphalt construction equipment and methods instead of the specialized application equipment required to place the standard HFST. Both micro-surfacing sections maintained good friction and macrotexture through 10 million ESALs. For the microsurfaced sections, the average friction values (SN40R) were 55 for the calcined bauxite/limestone blend and 50 for the sandstone. Macro-texture (MPD) measurements were 0.70 mm and 0.90 mm for the calcined bauxite/limestone blend and the sandstone treatments, respectively. The SMA section was placed later, so it received only 3.4 million ESALs of traffic. This surface also had good friction (SN40R = 55), but its macro-texture was lower (MPD = 0.35 mm) than those of the microsurfacing treatments. The friction measurements for the three surfaces are lower than that of the standard HFST surface (SN40R = 65), which has been tested for five years with over 23 million ESALs on the track.

In 2015, the Oklahoma DOT sponsored a study to find a high friction asphalt surface mixture produced with aggregates available in Oklahoma. The surface mixture selected for evaluation was OGFC as it had the best macro-texture. Sandstone aggregate was selected for the mixture as it had the best friction characteristics among four locally available aggregates tested in a prior laboratory study. After 10 million ESALs of heavy truck traffic, no rutting or noticeable cracking was observed. The ride quality of the two sections did not change during the traffic period. The highest SN40R values of 57 were measured a few months after construction, and the final SN40R values of 53 were taken in the last three months of truck traffic. The measured friction values were higher than the typical SN40R of 45 to 35 for other dense-graded asphalt surfaces placed on the track but lower than the SN40R for the standard HFST placed in 2011, which were above 65 at the end of the same cycle. The OGFC surface had very good macro-texture with MPD of approximately 1.2 mm over the two years of traffic.

RESEARCH SPONSORS

The NCAT Test Track is funded and managed as a cooperative project. State agencies and industry sponsors have the opportunity to explore specific research needs that can be evaluated in one or two test sections, and broader research needs of the asphalt pavement community can be met through experiments involving multiple test sections.

Since the results of experiments are typically evident in the performance of the sections, the findings are generally easy to interpret. This gives highway agency sponsors confidence to make decisions regarding their specifications, construction practices and pavement design methods that can improve the performance of their roadways. Industry sponsors use the track to publicly and convincingly demonstrate their technology to the pavement engineering community.

AGENCY

Alabama Department of Environmental Management
Alabama DOT
Colorado DOT
Federal Highway Administration
Florida DOT
Georgia DOT
Illinois DOT
Indiana DOT
Kentucky Transportation Cabinet
Maryland DOT
Michigan DOT
Minnesota DOT
Mississippi DOT
Missouri DOT
Nebraska Department of Roads
New York State DOT
North Carolina DOT
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South Carolina DOT
Tennessee DOT
Texas DOT
Virginia DOT
Wisconsin DOT

INDUSTRY

Cargill
Collaborative Aggregates
FP2
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Modified Asphalt Solutions
Oldcastle Materials
Polycon Manufacturing
Seneca Petroleum Company
Shell Sulfur Solutions
Trinidad Lake Asphalt

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NCAT's mission is to provide innovative, relevant and implementable research, technology development and education that advances safe, durable and sustainable asphalt pavements.

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