# NCAT TEST TRACK

2000-2024

## 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 NCAT Test Track is a world-renowned accelerated pavement testing facility that combines full-scale pavement construction with heavy truck trafficking for rapid testing and analysis of asphalt pavements. It is the only facility in the United States 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 aggregates, asphalt binders, additives, asphalt mix designs, as well as more cost-effective asphalt pavement design, construction, and preservation methods. The research will continue to pay dividends for years to come.

# OVERVIEW

Located on a 309-acre site, the Test Track is a 1.7-mile oval track comprised of forty-six 200 foot test sections sponsored on three-year research cycles. The track is funded as a cooperative project among highway agencies and industry sponsors that have specific research objectives for their sections and shared objectives for the asphalt industry as a whole.

Test sections on the Test Track 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 trafficking and evaluation in the next cycle or are replaced with new research focuses.

Structural pavement sections have varying thicknesses that closely resemble real-world highway pavements. They have embedded strain and pressure sensors to evaluate real-time 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 existing sections 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, companion pavement sections were built at MnROAD and at the Test Track to evaluate asphalt mixture cracking tests and asphalt additives. The partnership also includes pavement preservation experiments to quantify the life-extending benefits of pavement preservation on both low- 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 the Test Track up to the end of the eighth research cycle in 2024 and their implementation into agency specifications and industry practices.

# RESEARCH CYCLES

**Each research cycle on the Test 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 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. The 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.

## FIRST CYCLE (2000-2003)

The first cycle began with the loading of 46 newly constructed test sections. The only variables were the properties of asphalt 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-empirical pavement design. Eight sections from the first cycle were completely removed down to the subgrade and reconstructed to evaluate different layer thicknesses of asphalt. Some of these structural sections used modified asphalt binders, and others used neat asphalt binders. Each structural section was built with embedded stress and strain gauges to continually measure the pavement response to traffic loading. In addition, 14 other sections from the original track construction were milled and overlaid with a new surface mix, and the remaining 24 sections were left in place to evaluate the effects of additional traffic and environmental exposure on their long-term durability and performance.

## THIRD CYCLE (2006-2009)

Twenty-two new sections (15 for mix performance evaluation and seven for 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. 16 sections from the second cycle (twelve mix performance and four structural) remained in place and accumulated a total of 20 million ESALs. . Additionally, a new warm mix asphalt (WMA) section was built later in the cycle

## 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 40 million ESALs, nine sections remaining from the second cycle had accumulated 30 million ESALs, and nine sections remaining from the third cycle had accumulated 20 million ESALs. Six agencies co-sponsored 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 technologies (WMT), high reclaimed asphalt pavement (RAP) contents, a combination of high-RAP content and WMT, 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 WMT and recycled materials. Other research topics of the fifth cycle included 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 as a 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 remained 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 top-down cracking performance. This experiment also expanded the partnership with MnROAD by building complementary test cells on the I-95 test road in Minnesota to identify the best lab tests and criteria for assessing resistance to thermal cracking. The other 10 new sections included four surface mix performance sections, four pavement preservation sections with chip seals, two sections with high friction thinlays and microsurfacing.

## SEVENTH CYCLE (2018-2021)

The seventh cycle continued to evaluate mixture cracking tests and pavement preservation treatments in collaboration with MnROAD, as well as new experiments focused on balanced mix design (BMD) and asphalt rejuvenators. A total of 18 sections were resurfaced or rebuilt for new experiments, while 28 sections remained in place for continued evaluation, including two sections that have been in service since the original construction of the Test Track in 2000. Experiments featured OGFC mixtures, bio-based spray-on and mix rejuvenators, interlay treatments to reduce reflection cracking, surface friction, mix designs to improve longitudinal joints, thick-lift paving, and the impacts of lime and cement-stabilized foundation layers on the pavement structural response under heavy loading and seasonal environmental conditions.

## EIGHTH CYCLE (2021-2024)

The eighth cycle included 17 new test sections and 17 test sections built in a previous cycle. Existing test sections featured BMD, reflection cracking treatments, bio-based spray-on and mix rejuvenators, thick lift paving, stabilized subgrade and base layers, cold-recycled RAP base layers, and in-place density. New test sections were built to evaluate BMD, the performance impacts of tack coat, surface friction, and the new Additive Group experiment featuring the fatigue cracking performance of asphalt mixtures modified with synthetic fibers, recycled plastics, and recycled tire rubber. Companion Additive Group experiment test cells were built at MnROAD in 2022 with a research focus on reflective and thermal cracking performance. This cycle was also the first to include experiments on the Test Track's off-ramp. Late in the cycle, trafficking eclipsed a significant milestone with the accumulation of 11 million miles driven by the Test Track's fleet of five trucks.

# PERFORMANCE TESTING

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

## MIXTURE TESTING

Asphalt Pavement Analyzer (APA)
Bond Strength
Cantabro
Direct Tension Cyclic Fatigue
Disk-Shaped Compact Tension (DCT)
Dynamic Modulus (E*)
Flexural Bending Beam Fatigue (BBF)
Flow Number (Fn)
Hamburg Wheel-Tracking Test (HWTT)
High Temperature Indirect Tension (HT-IDT)
Illinois Flexibility Index Test (I-FIT)
Indirect Tensile Asphalt Cracking Test (IDEAL-CT)
Indirect Tensile Creep Compliance and Strength
Overlay Test (OT)
Nflex Factor
Rapid Shear Rutting Test (IDEAL-RT)
Resilient Modulus (Mr)
Semi Circular Bend Test (SCB)
Simplified Visco-Elastic Continuum Damage (S-VECD)
Fatigue Test (a.k.a. Cyclic Fatigue)
Stress Sweep Rutting (SSR)
Tensile Strength Ratio (TSR)

## FIELD TESTING

Albedometer
Close-Proximity Noise Trailer
Dynamic Friction Tester
Falling Weight Deflectometer
Mobile Laboratory
Pavement Condition Data Collection Vehicle

## BINDER TESTING

Rotational Viscosity
Flashpoint
RTFO Aging
PAV Aging of Binder
Softening Point Test
Solubility
Penetration
Linear Amplitude Sweep
Elastic Recovery
Ductility
Storage Separation
Flash Point
+ Others

# KEY FINDINGS

The focus of Test Track is on practical research that will lead to improved specifications, construction methods, and design procedures. These key findings can be categorized into seven areas.

1. BALANCED MIX DESIGN
2. MIX DESIGN
3. AGGREGATE PROPERTIES
4. BINDER CHARACTERISTICS
5. STRUCTURAL PAVEMENT DESIGN AND ANALYSIS
6. TIRE-PAVEMENT INTERACTION
7. ADDITIONAL FINDINGS

# 1 BALANCED MIX DESIGN

## BALANCED MIX DESIGN (BMD) EXPERIMENTS

BMD presents a new era of asphalt mix design and acceptance system to improve the quality of asphalt mixtures using laboratory mechanical/performance tests while allowing innovations in material selection and production optimization for economics and sustainability. Over the last two cycles of the Test Track, ten test sections with various BMD research focuses were built under the sponsorship of the Kentucky, Oklahoma, Tennessee, and Texas DOTs and Cargill. These sections covered asphalt mixtures designed with a wide range of component materials, different BMD approaches per AASHTO PP 105, and different specification requirements for mixture volumetric, performance, and friction properties. Laboratory testing showed that all the BMD mixtures, including those with 30% to 45% RAP contents, recycling agents, and a dry recycled tire rubber (RTR) additive, and those with relaxed volumetric properties compared to the existing Superpave specifications, had balanced rutting and cracking resistance. These findings were supported by the excellent field performance of the test sections under accelerated pavement testing at the Test Track, highlighting the potential of BMD to extend the life span of asphalt pavements by improving the quality of asphalt mixtures.

The Texas DOT sections from the seventh cycle presents a valuable case study demonstrating the pavement life extension benefit of BMD for asphalt overlay applications. The BMD section significantly outperformed the volumetric control section  in the field cracking performance, providing a conservatively estimated life extension for 5.5 million ESALs of heavy traffic, as shown in Figure 1. The extended pavement life of the BMD section over the volumetric control section provided significant economic and environmental benefits from the “cradle-to-grave” life-cycle cost analysis and life-cycle assessment perspectives.

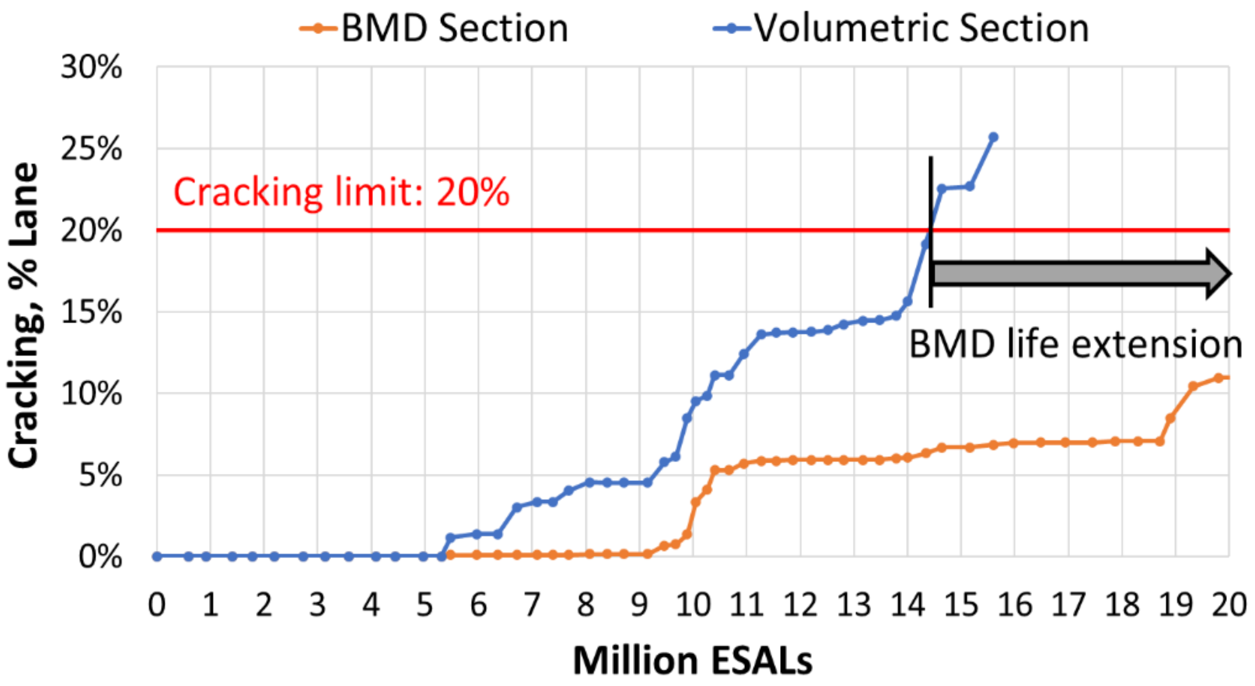



Figure 1. Field Cracking Performance of Texas BMD Section versus Volumetric Control Section

## CRACKING TESTS

With increased interest in BMD and performance tests, 11 state DOTs and the FHWA co-sponsored the Cracking Group experiment in the sixth research cycle. Seven test sections, constructed with varying surface mixtures but the same pavement structure, underwent evaluation with seven different laboratory cracking tests to gauge their correlation to top-down cracking performance on the Test Track.

The relatively thin construction of the test sections aimed to induce significant deflections in the asphalt layers due to heavy loading on the Test Track. Highly modified asphalt binder in the intermediate and base layers helped prevent bottom-up fatigue cracking. Consistent mix designs were applied to the lower two layers across all sections to facilitate comparison of top-down cracking performance without confounding results from differing supporting conditions. Surface layers were composed of asphalt mixtures with diverse expected cracking performance.

After six years of in-service aging and trafficking spanning two research cycles, significant variation in observed top-down cracking among the seven test sections highlighted the importance of surface mixture properties in top-down cracking performance. Key conclusions drawn from the analysis of seven cracking tests conducted in this experiment are as follows:

- Energy ratio results did not align with field top-down cracking performance, making it impractical for routine use in BMD, particularly for quality assurance testing, due to test complexity and duration.
- The NCAT-modified version of the overlay test exhibited good correlation with top-down cracking resistance, with faster testing times and lower coefficient of variation compared to the Texas procedure, though facing similar challenges in sample preparation and equipment costs.
- The Louisiana SCB test did not effectively distinguish mixtures with varying top-down cracking performance on the Test Track, while also suffering from time-consuming specimen preparation and non-alignment with standard methods of variability analysis.
- The flexibility index from the I-FIT showed fair correlation with top-down cracking performance, albeit with reduced statistical discrimination due to high variability and similar challenges in specimen preparation as the Louisiana SCB test.
- The AMPT cyclic fatigue test index parameter, Sapp, demonstrated strong correlation with top-down cracking in most test sections, except for one with a gap-graded asphalt rubber mixture, despite facing challenges related to sample preparation, equipment costs, and data analysis complexity, making it unsuitable for routine BMD use.
- The $CT_{Index}$ from the IDEAL-CT emerged as a robust indicator for resistance to top-down cracking, exhibiting strong correlations with field cracking performance and statistical discernibility between mixtures. However, similar to the I-FIT, the IDEAL-CT is influenced by specimen air void contents and requires constant air void contents during asphalt mixture comparisons. The IDEAL-CT method is deemed suitable for everyday use in BMD, including quality assurance testing.

## 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 Test Track, including repeated load tests, wheel-tracking tests, and rapid strength tests to determine if laboratory test results correlate with actual rutting measured on the track.

The Asphalt Pavement Analyzer (APA) has consistently provided reasonable correlations with Test Track rutting performance. Based on a correlation between APA results and rutting on the track in the 2006 research cycle, an APA criterion of 5.5 mm was established for heavy traffic surface mixes for tests conducted in accordance with AASHTO T340. The APA data from the 2009 research cycle was also correlated with the field rutting on the Track. The APA showed a reasonable correlation with field rutting (R2 = 0.70) after the data from two 50% RAP sections were removed.

The Hamburg wheel tracking test (HWTT) 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 the evaluation of rutting and moisture susceptibility. Many state agencies have different HWTT criteria that have been adopted for their local climate and materials. A maximum rut depth of 12.5 mm at 20,000 wheel passes is a commonly used failure criterion. NCAT conducted the Hamburg test in accordance with AASHTO T 324 at 50°C on 18 mixtures from the 2009 research cycle. Hamburg results correlated reasonably well (R2 = 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 evaluates the rutting resistance of asphalt mixtures through cyclic repeated load compression. In the 2006 research cycle, NCAT employed a confined FN test with 10 psi confining stress and 70 psi repeated axial stress, revealing a strong correlation with track rutting. Recommended by NCHRP Report 673 and NCHRP Report 691, the FN test criteria (0 psi confining stress and 87 psi repeated axial stress) and traffic level thresholds have been adopted in AASHTO T378.

In the 2009 research cycle, the FN test was conducted on 18 mixtures, showing a moderate correlation (R2 = 0.54) with field rutting after excluding data from sections with 50% RAP. All results in the 2009 study met AASHTO T378 FN criteria for 3 to 10 million ESALs of traffic.

More recently, two new 'rapid' rutting tests have been evaluated in conjunction with the Test Track. The High-Temperature Indirect Tension Test (HT-IDT, ALDOT Method 458, Draft ASTM Standard) and the IDEAL Rutting Test (IDEAL-RT, ASTM D8360) can be conducted on gyratory compacted specimens on the same day mix is produced. Each test only requires 45 minutes to 1 hour of conditioning time in a hot water bath, followed by a rapid strength test (less than 10 minutes for 3 replicates). Wheel tracking tests such as HWTT and APA are commonly used during mixture design, but their long test durations limit their application during mix production. During the 2021 Track, 14 unique mixes were tested using the two rapid rutting tests at 50°C as well as using the HWTT at 50°C and APA at 64°C. These mixtures were from multiple states containing various additives, binder types, binder contents, RAP contents, aggregate types, and aggregate gradations. None of these 14 mixtures exhibited a rutting failure on the Track during the 2021 research cycle.

The study showed the results from the two rapid rutting tests (HT-IDT and IDEAL-RT) correlated extremely well with each other. Both rapid rutting tests also showed a strong correlation with the HWTT test results. However, a good correlation was not observed between the rapid rut tests and the APA wheel tracking test results for this study. Based on the correlation between the HT-IDT and HWTT, it would be reasonable to select a threshold value of 20 psi for the HT-IDT as a pass/fail criterion for mixtures produced at the Test Track. Similarly, the correlation between IDEAL-RT and HWTT suggests that a minimum RT Index (IDEAL-RT Result) of 75 would be a reasonable pass/fail criterion for mixtures produced at the Track. These criteria may be further refined in the future.

Figure 2a. High-Temperature IDT (HT-IDT) Test

Figure 2b. IDEAL-RT Test

# 2 MIX DESIGN

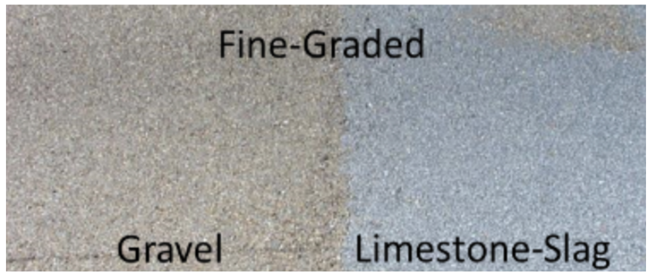
## STONE-MATRIX ASPHALT (SMA) MIXTURES

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. The 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 asphalt binder and an SMA with 5% recycled asphalt shingles (RAS) was successfully used in the 2012 Green Group Experiment. These two mixes did not contain added fibers as typically used with SMA, and had no issues with binder draindown. In 2018, ALDOT used the Test Track to evaluate a 4.75 mm NMAS SMA as a thinlay treatment option for high volume roads. As of 2024, this mix has shown minimal rutting and cracking after 20 million ESALs of traffic.

## FINE-GRADED VS. COARSE GRADED MIXTURES

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 fine-graded mixtures with the same aggregate.

In the first cycle of the Test Track, the issue of aggregate gradation 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. Comparisons of friction test results (ASTM E 274) for coarse and fine mixture pairs with the same aggregates did not indicate either gradation type to be consistently better than the other. However, tire-pavement noise was statistically lower for fine gradations. Based on these findings, many state highway agencies revised their specifications to allow the use of more fine-graded mix designs.





## WARM-MIX TECHNOLOGY (WMT) MIXTURES

Warm Mix Technology (WMT) represents a group of technologies that allow a reduction in the temperatures at which asphalt mixes are produced and placed. NCAT's first experience with WMT at the Test Track was in the 2003 research cycle. An early version of MeadWestvaco's (now Ingevity) Evotherm® technology was used in overlays to repair two test sections with extensive damage near the end of the research cycle. These two sections were opened to traffic immediately after construction and remained in service throughout the 2006 cycle with rutting performance comparable to hot mix asphalt (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 WMT could sustain extremely heavy traffic.

In the 2009 research cycle, additional WMT test sections were constructed as part of the Group Experiment. They aimed to compare pavement performance using two different WMT types (foaming, chemical additive) and the combination of high-RAP content with WMT against a control HMA section. All sections were built on the same stiff subgrade, with identical aggregate base and asphalt layer thickness. By the end of the 2009 research cycle and after 10 million ESALs of trafficking, no cracking was observed in any section.

During the 2012 research cycle, after 20 million ESALs, cracking levels varied: the WMT foaming section had 22% lane area cracked, WMT additive section 15%, high-RAP WMT section 6%, and the control section 10%. Despite representing practical differences between sections, all cracking remained below the commonly held 25% threshold for failure representation. Additionally, all sections exhibited satisfactory rutting performance, bolstering confidence in WMT implementation by agencies despite initial rutting concerns raised by laboratory tests.

## HIGH-RECLAIMED ASPHALT PAVEMENT (RAP) MIXTURES

For nearly two decades, Test Track experiments have evaluated high-RAP content mixtures and have provided practical insights into achieving good performance along with economic and sustainability advantages. These studies, along with others, have supported the slow but steady increase in the maximum RAP contents permitted by state DOTs and helped move the national average RAP content of 16.2% in 2009 to 21.9% in 2021.

Numerous Test Track experiments have evaluated high-RAP content mixtures. The first experiment involved six overlay moderate and high-RAP mix test sections built in 2006 that were trafficked for six years and 20 million ESALs. The four high-RAP content overlays used the same 45% RAP mix design with different binders. The use of a softer virgin binder (a PG 52-28) was shown to provide better resistance to raveling and top-down cracking. The study also concluded that using a polymer-modified virgin binder provided no benefit for rutting or cracking for mixes containing 20% or 45% RAP.

The second high-RAP experiment began in 2009 and used 50% RAP volumetric mix designs in each pavement layer. This was the first "group experiment" and featured four comparison sections, including 50% RAP HMA, 50% RAP WMA, virgin HMA, and virgin WMA. All sections were fully instrumented to evaluate how the test sections responded to loading and environmental changes over two full cycles and 20 million ESALs. The 50% RAP HMA test section had no distresses at the end of two cycles and outperformed all of the other sections in the experiment in all performance measures, including fatigue cracking. The excellent fatigue cracking performance was partly attributed to the higher stiffness of the 50% RAP mixes, which resulted in substantially lower tensile strains at the bottom of the test section compared to sections with all virgin mixtures.

Another experiment that featured an interesting comparison of moderate and high-RAP content mixtures was the Cracking Group experiment, conducted from 2015 to 2021. The experiment's control mix was a conventional 20% RAP Superpave mix with a PG 67-22 binder. One of the other test sections used the same aggregate and RAP sources as the control mix but increased the RAP content to 35% and used a softer virgin binder that graded as a PG 64-28. After two cycles of trafficking and environmental exposure, the 35% RAP mix had only 1% lane area cracking compared to 45% lane area cracking for the control mix.

Other moderate and high-RAP experiments have been evaluated on the Test Track for the Mississippi DOT and the Florida DOT. Cargill and Collaborative Aggregates have also sponsored Test Track evaluations of their bio-based rejuvenators for high-RAP mixtures.

The Test Track has demonstrated that high-RAP content mixtures can perform equal to or better virgin than low-RAP content mixtures. NCAT strongly recommends using Balanced Mix Design tests with relaxed legacy criteria for high-RAP mix design approval and Quality Assurance testing.

## OPEN-GRADED FRICTION COURSE (OGFC)

During the first three Test Track cycles (2000-2009), more than ten open-graded friction course (OGFC) mixtures using a wide variety of aggregate types, also known as porous friction courses (PFC), were placed on the Test Track. In general, all the OGFC sections significantly reduced water spray and tire-pavement noise while providing excellent skid and rutting resistance. Consequently, many states started adopting OGFCs to improve wet weather driving visibility, as shown in Figure 4. Typically, the aggregate shape (flat and elongated) requirements for OGFC mixtures are very strict based on European experience. However, GDOT validated the feasibility of using coarse aggregates with a relaxed flat and elongated requirement for OGFC mixtures in 2006 and 2009 Test Track cycle. In addition, state DOTs usually don't attribute any structural value to OGFC layers. However, the structural characterization of sections containing OGFC indicated that the OGFC does contribute to the structural integrity of the section with a revised structural coefficient of 0.15 during the 2009 Test Track cycle.

Figure 4. Comparison of Driver's View on Rainy days on Dense-graded Mix (Left) and OGFC Mix (Right).

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 to form an adequate bond for an OGFC mix than for a dense-graded mix. 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/yd2 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/yd2 can be considered an alternative to CRS-2P applied with a spray paver, depending on paving conditions.

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 the 2012 Test Track cycle, ALDOT sponsored three test sections to evaluate potential changes in its mixture components 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.

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 the 2012 Test Track cycle, ALDOT sponsored three test sections to evaluate potential changes in its mixture components 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 showed excellent resistance to raveling, cracking, and rutting after 30 million ESALs were applied from 2012 to 2021. Laboratory and field performance results indicated these proposed adjustments had the potential to improve the long-term performance of OGFC mixtures. In addition, the 9.5 mm mix in Section E9A is still permeable (0.03 cm/sec or 26 m/day) after the application of 20 million ESALs, as shown in Figure 5.

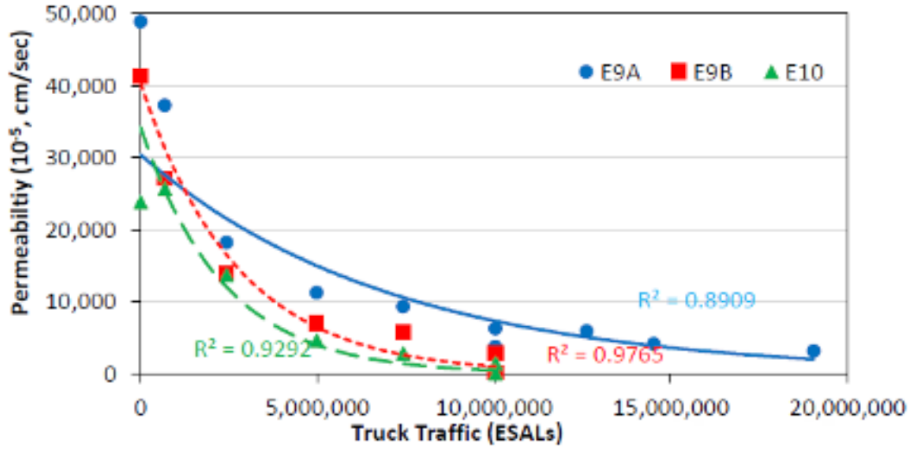



Figure 5. Field Permeability Performance.

The current method to determine the optimum binder content (OBC) is based on the oil absorption test results for OGFC mixtures in Alabama. This method typically yields an OBC of 6.0% for most mixtures regardless of aggregate type, which is the minimum permissible binder content. In 2021, ALDOT investigated the feasibility of using a more rigorous high-performance-based OGFC design methodology to improve durability by considering the mixture performance during the design process. This adjusted design method uses the Superpave Gyratory Compactor (SGC) for laboratory compaction and determines the OBC based on mixture properties that include air voids, Cantabro loss, permeability, and moisture susceptibility. The proposed volumetric and performance criterion included an air voids range of 15-20%, a maximum Cantabro loss of 15%, a maximum draindown of 0.3%, and a minimum TSR and conditioned splitting tensile strength of 0.70 and 50 psi.

The OGFC mixture designed with challenging sandstone and slag was produced and constructed on the 2021 Test Track. This mixture had no cracking or raveling, and rutting was about 2.5 mm after 10 million ESALs. The field permeability of this section reduced with increasing trafficking, but the OGFC section is still permeable (0.04 cm/ sec or 38 m/day) after 10 million ESALs. Based on the preliminary field performance, the high-performance OGFC mixture design is recommended to replace the original ALDOT design method to improve the durability of OGFC mixtures in the field.

## DESIGN GYRATIONS

The results from the Test Track and data collected from various field projects across the United States as part of NCHRP project 9-29 have shown that the gyratory compaction effort specified in AASHTO standards was too high. The high Ndesign numbers tended to grind aggregate particles and break them down much more than what occurs in pavements during construction or under traffic. In the past, mix designers often used coarse-graded mixes to meet the volumetric mix design criteria. However, these mixes are more challenging to compact in the field and are more permeable, which can lead to durable issues. Asphalt mixtures on the Test Track were typically designed with Ndesign ranging from 50 to 70 gyrations using the Superpave gyratory compactor (SGC) and performed exceptionally well under heavy loading. As a result, many states have significantly reduced their Ndesign levels.

Additionally, using coarse-graded asphalt mixtures designed at high Ndesign gyrations can also make compaction more challenging at the longitudinal joint, making it more permeable and susceptible to freeze-thaw damage in states such as Kentucky. In addition to improving compaction practices, the Kentucky Transportation Cabinet (KYTC) also explored the potential use of a fine-graded mixture with a lower Ndesign of 65 gyrations. This mixture was compared to a previously KYTC-approved coarse-graded mixture designed with a higher Ndesign of 100 gyrations in two adjacent sections. The longitudinal joints of these sections were constructed following standard practices. Field permeability tests showed that the fine-graded mixture was 20% less permeable than the coarse-graded mixture, making the joint less susceptible to potential moisture and freeze-thaw damage. After 20 million ESALs, no cracking and rut depths less than 5.5 mm were observed in the two sections. In addition, the section with 100-gyration mixture had 100% cracking at the joint, while section S7B had 64%.

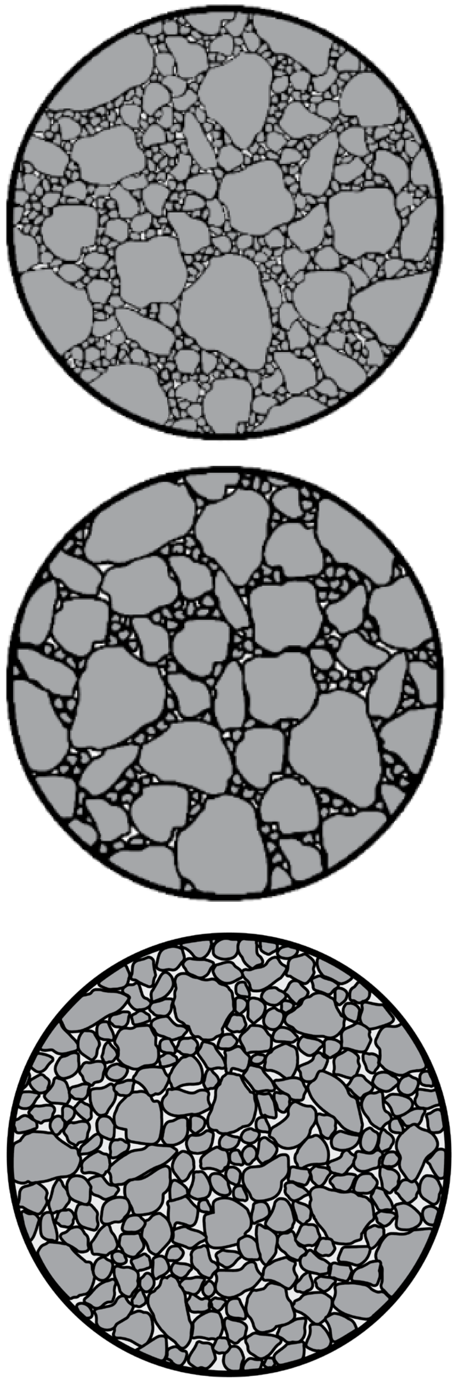


Figure 6. Illustrations of (top) Dense-Graded-, (middle) Gap-, and (bottom) Open Aggregated Blends in Compacted Asphalt Mixture Samples

# 3 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-style 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. The Georgia DOT used the Test Track to evaluate the effect of using local aggregates with a less strict flat and elongated requirement for their OGFC mixes. Test Track performance showed that the lower-cost local aggregates did not affect performance, while improving drainage characteristics.

Figure 7. Flat and Elongated test and appartus.

## ELIMINATION OF THE RESTRICTED ZONE

The original Superpave mix design procedure included a restricted zone within the gradation band for each nominal maximum 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.

# 4 BINDER CHARACTERISTICS

## EFFECT OF BINDER GRADE ON RUTTING

Superpave guidelines recommend a higher Performance Grade (PG) binder be utilized for roadways with high traffic volumes to minimize rutting. Results from the first cycle showed that permanent deformation was reduced by an average of 50% when the high-temperature grade of the binder was increased from PG 64 to PG 76. These findings also indicated the benefits of using modified asphalt binders for heavy traffic conditions. The Alabama DOT also sponsored test sections to evaluate surface mixes designed with 0.5% more asphalt binder. The results showed that increasing the asphalt binder content in mixes with modified binders did not negatively impact rutting resistance. However, mixes produced with neat asphalt binders were more sensitive to the increased asphalt content. Thus, it is crucial to choose the appropriate binder and design the asphalt mix to ensure that pavements can withstand heavy traffic loads with minimum rutting.

## ASPHALT BINDER MODIFICATION

During the first research cycle, experiments were conducted to compare mixes with PG 76-22 asphalt binders that were modified with styrene butadiene styrene (SBS) and styrene butadiene rubber (SBR). These mixtures included dense-graded Superpave, porous friction course, and SMA. Excellent field performance was observed in all mixes regardless of the type of modifier used.

A similar experiment was sponsored by the Missouri DOT and Seneca Petroleum in 2009 to compare the performance of a surface mix containing an SBS-modified binder and a ground tire rubber (GTR) modified asphalt binder. The findings demonstrated that a binder modified with GTR can perform similarly to a binder modified with SBS.

In 2021, a comprehensive experiment compared recycled GTR and post-consumer recycled PCR plastic to SBS for asphalt binder modification. Each test section utilized an identical 12.5-mm NMAS dense-graded mixture design, incorporating 20% RAP with a design asphalt binder content of 5.6%. These sections were constructed as 5.5-inch thick-lift pavements. After 10 million ESALs, field data showed minimal rutting in all sections, indicating no negative impact on rutting performance from the additive technologies.

While the section with the GTR-modified binder developed some cracking, the sections with SBS (control) and PCR plastic-modified binders remained intact without cracking. All test sections will be retained for continued traffic in the next research cycle, allowing for a more comprehensive evaluation of their long-term field performance.

## EVALUATION OF ALTERNATIVE BINDERS

Three test sections were built in 2009 to evaluate the effectiveness of Trinidad Lake Asphalt (TLA) and Thiopave® pellets for use in asphalt mixes. TLA pellets are made from a natural asphalt source in Trinidad, while Thiopave® pellets are made following a sulfur-modified asphalt formulation. Additionally, Thiopave® pellets must be combined with a WMT, which lowers the mixing temperature to 275°F or below to reduce hydrogen sulfide emissions.

The TLA section included three asphalt layers, and they were all modified with 25% TLA based on the total binder weight. In the two Thiopave® sections, the base and intermediate mixes were modified with 30% and 40% Thiopave®, respectively. The surface mixes, however, were not modified with Thiopave®.

The performance of three test sections in the field was compared to that of a conventional asphalt control section. Measurements of the pavement response showed that all the test sections remained structurally sound during the research cycle, with acceptable rutting, no cracking, and excellent ride quality after 10 million ESALs.

# 5 STRUCTURAL PAVEMENT DESIGN AND ANALYSIS

## DYNAMIC MODULUS PREDICTION

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

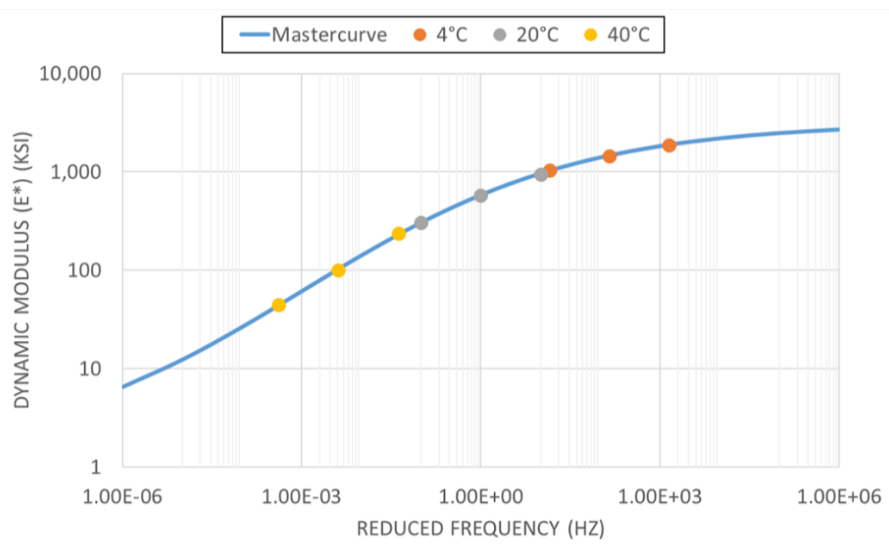



Figure 8. Dynamic Modulus Master Curve.

## ASPHALT LAYER COEFFICIENT FOR PAVEMENT DESIGN

Although many highway agencies are preparing for implementation of a mechanistic-empirical (ME)-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, which took place from 1958 to 1960 in Ottawa, Illinois. In simplified terms, the empirical method relates pavement serviceability to expected traffic and the structural capacity of the pavement system. 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. A subsequent study using sections from the fourth test cycle that featured sustainable asphalt paving materials validated the previous finding. This 18% increase in structural coefficient translates directly to an 18% reduction in the design thickness for new pavements and overlays, as shown in figure 9, which compares using 0.44 versus 0.54 over a range of traffic levels for a particular set of design conditions. Alabama DOT estimates a yearly savings of $25 to $50 million in construction costs since implementing the new layer coefficient in 2010.

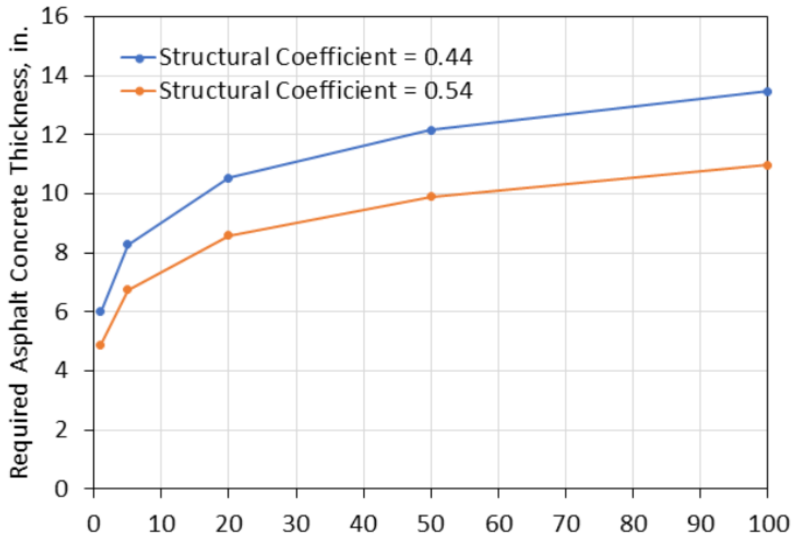



Figure 9. Impact of Structural Coefficient with Traffic Level.

## MEASURED PERFORMANCE VERSUS MEPDG PREDICTED PERFORMANCE

Fifteen structural sections were analyzed with the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG) using the default national calibration coefficients. The predicted pavement distresses were then compared with the distresses observed in the test sections. The comparison showed the MEPDG over-predicted rutting in all sections, with errors ranging from 70% to 100%. However, rutting predictions were significantly improved after calibrating the model coefficients. Additionally, MEPDG fatigue cracking predictions with the default coefficients were poor for most sections. In about half of the cases, the MEPDG significantly under-predicted fatigue cracking, while it over-predicted the amount of fatigue cracking in a few cases. Attempts to adjust the fatigue model coefficients did not improve the overall correlation of predicted versus measured fatigue cracking.

## MAXIMUM THICKNESS OF ASPHALT PAVEMENTS

Traditional pavement designs often result in excessively thick pavements in heavy traffic conditions. However, perpetual pavement designs validated through Test Track research focus on optimizing thickness to provide the desired performance for over 50 years without using unnecessary materials. The maximum thickness is achieved by keeping critical stresses and strains within safe limits, where additional material does not significantly enhance pavement performance. This thickness typically does not exceed 15.5 inches of asphalt, even in the most demanding scenarios.

## STRAIN THRESHOLD FOR PERPETUAL PAVEMENT DESIGN

The perpetual pavement design concept has been validated through several Test Track sections. This approach involves designing each pavement layer to withstand critical stresses, ensuring that damage never occurs in the lower layers of the structure. Perpetual pavements are more cost-effective than traditional pavement designs, especially for high-traffic routes. They are also less disruptive to traffic since roadway maintenance is minimized.

Two structural sections built in 2003 for Alabama DOT were considered perpetual since they carried more than three times their "design traffic," based on the AASHTO Guide for Design of Pavement Structures, 1993, with only minor surface distress before being replaced for another experiment. In the 2006 cycle, Oklahoma DOT sponsored two sections to further validate the concept for pavements built on soft subgrades. One section was designed using the 1993 AASHTO guide, and the other section was designed using the PerRoad Perpetual Pavement design program. The conventional design resulted in a 10-inch asphalt cross-section, whereas the perpetual design was 14 inches thick.

The field performance of these sections confirmed the concept of limiting critical strains to eliminate bottom-up fatigue cracking. A life cycle cost analysis of the two pavement design alternatives demonstrated that the perpetual pavement design is more cost-effective. The three perpetual pavement sections and nine other structural test sections that experienced bottom-up fatigue cracking in the 2003, 2006, and 2009 cycles were later used to develop a limiting strain distribution that separated the perpetual pavement sections from the others. This limiting strain distribution has been implemented in PerRoad Version 4.3, which provides for perpetual pavement designs that can sustain the heaviest loads and provide a long-life pavement structure without being overly conservative.

# 6 TIRE PAVEMENT INTERACTION

## HIGH FRICTION SURFACE TREATMENT (HFST)

For safe driving, a good friction surface is needed in critical braking and cornering locations. 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 more cost-effective alternatives.

An FHWA-sponsored friction study conducted on the Test Track from 2012 to 2014 used regionally available friction aggregates to replace the imported 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 of the calcined bauxite. A follow-up study in 2015 was then conducted on the Test 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.

In 2015, the Oklahoma DOT also sponsored a study to find a high friction asphalt surface mixture produced with aggregates available in Oklahoma. The surface mixture selected for evaluation was an OGFC, as it had the best macro-texture. Sandstone aggregate was selected for the mixture as it has 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 nor 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.

## 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 (TWPD) developed at NCAT. The slabs are periodically tested for friction and texture using the ASTM standards for the Dynamic Friction Tester (DFT) and the Circular Track Meter (CTM).

The Kentucky Transportation Cabinet (KYTC) utilized the TWPD and DFT in 2021 to design mixes to achieve specific field friction targets on the Test Track. Mix designs were tested in the lab before construction to select aggregate blends that provided specific levels of friction in lab testing. These mixes were placed on the Test Track, and the friction performance was measured monthly. At the end of 10 million ESALs, the field friction level matched the expected friction from the TWPD and DFT during the design process. This study confirmed to KYTC the feasibility of including friction as a mix design target in the future.

Gradation data and mean profile depth (MPD) from mixes in the initial four Test Track cycles (2000 – 2012) were merged to illustrate the relationship between gradation and texture. Figure 10 depicts a strong correlation between the percentage passing the #8 sieve (or the Primary Control Sieve Index) and MPD.

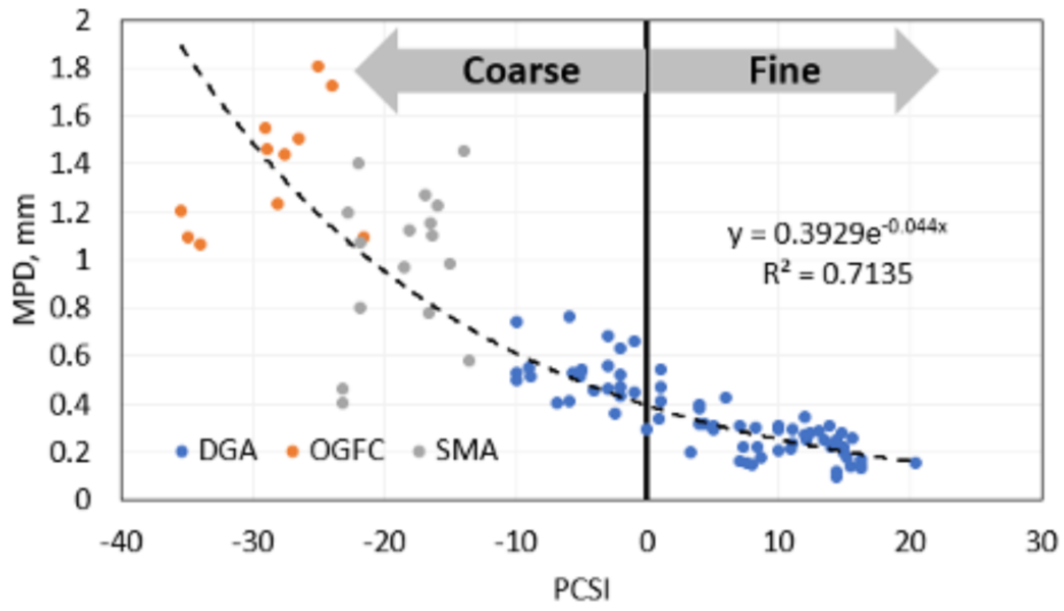



Figure 10. Relationship between Gradation-Type (PCSI) and MPD.

## POLISHING AND FRICTION

In 2003, the South Carolina DOT (SCDOT) evaluated a surface mix containing a new aggregate source on the Test 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 SCDOT to make an assessment in less than two years without putting the driving public at risk. Similarly, in 2018, the West Virginia DOT evaluated relaxing a maximum limit on a local aggregate source with known polishing issues. Results from laboratory testing and two Test Track sections confirmed the need for the maximum limit to ensure a safe driving surface


Figure 11. NCAT Three Wheel Polishing Device.

The Mississippi and Tennessee DOTs followed similar experiments to assess blends of limestone and gravel on mix performance and friction. Both agencies 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.

## NOISE AND PAVEMENT SURFACE CHARACTERISTICS

Noise generated by tire-pavement interaction is significantly impacted by surface layer macrotexture and porosity. Testing on the Test Track has shown that these factors' influence on noise levels correlates with vehicle weight and tire pressure. For lighter vehicles, surface porosity is the primary factor affecting noise attenuation, while for heavier vehicles with higher tire pressures, surface macrotexture and positive texture at the tire-pavement interface play a larger role. To mitigate pavement noise, two potential approaches are using open graded friction courses (OGFC) and employing a small nominal maximum aggregate size mix for the surface layer.

# 8 ADDITIONAL FINDINGS

## THICK LIFT PAVING

Experimental work with thick lift paving began at the Test Track in 2018 when the South Carolina Department of Transportation (SCDOT) funded a section to examine the constructability, structural characteristics, and performance of an 8-inch thick section paved in a single pass. Advantages of this approach include eliminating lift interfaces, reducing construction time, and simplifying construction. Potential liabilities were identified as longer cooling times that could extend the time before reopening to traffic, initial smoothness, and long-term performance. Key findings from the SCDOT section right after construction included:

- The construction of a single 8-inch lift is viable. Care should be taken regarding the cooling time needed to open to traffic, but this can be somewhat controlled by coordinating the time of year and time of day for paving.
- Achieving density with an 8-inch lift was a non-issue. Density exceeding 95% of the theoretical maximum was accomplished with standard rollers and roller patterns; no specialized processes or equipment were needed.
- As-built smoothness can be an issue with thick-lift paving and certainly was with this section. The problem was rectified somewhat with diamond grinding. If paving crews were given more opportunities to pave thick lifts, as-built smoothness could be greatly improved. In practice, SCDOT has found that having an additional lane for material transfer vehicles, trucks, and rollers can help minimize dips in the longitudinal pavement profile.

The section was trafficked through the initial two years of testing, accumulating approximately 10 million ESALs. During that time, rutting increased to approximately 0.15 inches, which was considered good performance. A small amount of what was considered top-down cracking formed at the end of the test cycle but only represented 0.7% of the lane area, which was also considered good performance. Pavement roughness decreased over time as the traffic smoothed out the initial pavement roughness built into the section.

The section was performing well enough that the SCDOT elected to continue trafficking into the next cycle and apply another 10 million ESALs. During this time, rutting increased to approximately 0.25 inches, the length of top-down cracking grew to 5% of the lane area without an increase in severity, and the smoothness continued to improve. All these measurements were considered to be a good performance of the section.

The technique has worked very well at the Test Track, so much so that a subsequent study (Additive Group (AG) experiment) at the track used it to construct numerous sections. It is a viable approach in real-world construction. As noted above, care should be taken with cooling times and smoothness, but the approach does not cause a density, rutting, or severe cracking liability.

## THIN LIFT OVERLAY MIXTURES

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. In 2003, the Mississippi DOT sponsored a test section with a 4.75 mm surface mix containing limestone screenings, fine crushed gravel, and local sand with a polymer-modified asphalt binder. This 20-year-old section has carried more than 70 million ESALs with less than 3 mm of rutting and less than 5% 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 binder, 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, which demonstrates that a low cost per mile can be achieved as a result of the use of local materials, RAP, and neat asphalt binder in a thin surface layer without compromising performance.

In 2015, the Tennessee DOT 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 a 0.13 RAP binder ratio and PG 64-22 neat asphalt binder. The mixture showed excellent performance with no cracking, less than 2.0 mm rutting, and good smoothness after approximately 30 million ESALs. The mixture also maintained a stable friction value and had a slight increase in macrotexture under traffic.

Asphalt thinlays perform excellently on the Test Track, proving to be cost-effective for highway agencies in maintaining road network performance.

## ENGINEERED RAP BASE

Cold central plant recycling (CCPR)—a highly sustainable method of combining RAP with foamed or emulsified asphalt and additives in a central recycling plant without the application of heat—has been used for rehabilitating roadways ranging from low volume to heavily trafficked interstates. There are multiple sections of CCPR on the Test Track, including one from the 2012 test cycle that has experienced over 40 million ESALs. This section, sponsored by the Virginia DOT, consists of 4 inches of HMA over 5 inches of CCPR with a 6-inch aggregate base. The test section showed no signs of deterioration until 29.7 MESAL, so it was left in place for another 10 MESALs and will be removed in 2024 after a deep forensic investigation and mechanistic characterization.

Another section from the 2021 Test Track cycle consists of a 2-inch SMA overlay above 4.5 inches of re-recycled CCPR, meaning an existing CCPR material was recycled yet again. Finally, the use of CCPR with typical stabilizing agents as well as rejuvenators was investigated on 5 sections on the off-ramp of the Test Track, with 4 inches of CCPR and nothing more than a 1-inch overlay. In all cases, CCPR has performed well under heavy traffic as a high-quality, engineered RAP base.


Figure 12. Core from Section S12 with HMA over CCPR base.

## ALTERNATIVE INTERLAYERS

Several state agencies use cracking relief interlayers to provide a discontinuity between the existing surfaces and new overlays to reduce reflective cracking. In Georgia, the most commonly specified interlayer is a single chip seal treatment placed on the existing surface. This method, however, has not been as effective as desired. Therefore, the Georgia DOT sponsored a study at the Test Track beginning in 2012 to evaluate 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 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 section with the OGI interlayer increased significantly in the second cycle, with 50% of the saw cuts reflecting 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.


Figure 13. Interlay section on NCAT Test Track

In 2018, Georgia DOT expanded its investigation of cracking relief interlayers, placing six different approaches in two Test Track sections, which included two geotextiles (GlasGrid® and PETROMAT®), virgin chip seal, RAP chip seal, asphalt rubber gap graded (ARGG) mix, and an OGI. All of the interlayers were topped with a 9.5-mm NMAS dense-graded mix. After 20 million ESALs, one of the sections exhibits minor rutting (RAP chip seal with 0.46-inch), and only two exhibit minor reflective cracking (ARGG with 2.4%, OGI with 0.2%).


# RESEARCH SPONSORS

The NCAT Test Track is funded and managed as a cooperative project. Highway 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 the Test Track's 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 for materials, mixes, and construction practices, as well as pavement design methods that can improve the performance of their roadways.**

**Industry sponsors can use the Test Track to publicly and convincingly demonstrate their product or technology to the pavement engineering community.**

## AGENCY

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

## INDUSTRY

BASF
Cargill
Collaborative Aggregates
CRH
$FP_2$
Kraton Polymers
Modified Asphalt Solutions
Oldcastle Materials
Polycon Manufacturing
Seneca Petroleum Company
Shell Sulfur Solutions
SoyLei Innovcations
Trinidad Lake Asphalt
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