

Asphalt Technology News

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Warm-Mix Asphalt Technologies Gaining Ground Due to Benefits, Good Performance

Warm-mix asphalt (WMA) is gaining acceptance across the U.S., with at least 45 states either actively using WMA technology or having constructed a trial project. A number of states, including Alabama, California, Florida, Illinois, New York, North Carolina, Ohio, Pennsylvania, Texas, Virginia, Washington and Wisconsin, have adopted permissive specifications allowing the use of WMA on many highway projects.

Potential economic and environmental benefits, including less fuel usage and lower emissions, have spurred interest in using WMA technology to reduce production temperatures to 275°F or less. Early performance of WMA projects has been very good—comparable to that of conventional hot-mix asphalt (HMA).

Early WMA Performance is Favorable

Laboratory test results on some WMA mixtures indicate that they could be more susceptible to rutting and moisture damage. Lower temperatures can result in incomplete drying of the aggregate, compromising the bond between asphalt and aggregate. With reduced mixing temperatures there is also less binder aging, which can result in lower tensile strengths and/or increases in rutting in lab tests.

However, field evaluations have not shown any practical difference in rutting between WMA and control HMA sections. One case study is a WMA project in Missouri, which has no appreciable rutting in any of the WMA or HMA sections after two years of heavy traffic. The warm-mix technologies used in the Missouri trial were Aspha-min, Sasobit and Evotherm ET. In addition, no moisture

damage was observed in the WMA sections evaluated. Tensile strength of the WMA was shown to increase over time so that tensile strength was similar to the HMA after two years. A field trial in Ohio also revealed that WMA sections with Aspha-min, Sasobit and Evotherm performed as well as or better than HMA control mixes in laboratory testing for rutting and moisture susceptibility (Asphalt Pavement Analyzer, Hamburg rut testing and tensile strength ratio).

NCHRP 9-47A

NCAT and a team of researchers are working on NCHRP 9-47A, a project that will document field performance of WMA technologies across the U.S., compare engineering properties of WMA to HMA, and evaluate energy savings and emissions reductions for WMA production. Researchers will monitor short-term WMA performance over a two-year period and will use the Mechanistic-Empirical Pavement Design Guide

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A warm-mix asphalt (WMA) placement job in Indiana

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(MEPDG) to predict long-term performance.

NCAT and Advanced Materials Services (AMS) are currently documenting 14 regionally diverse WMA projects and testing materials from the eight projects that are new construction (see Table 1). A variety

Location	WMA Technologies	Estimated Tonnage
Indiana	Evotharm DAT, Advera WMA and Heritage wax	20,000
Michigan	Advera and Evotharm 3G	10,000
Virginia	Astec DBG	60,000
Montana	Evotharm 3G	20,000
Washington	Maxam and AQUABlack	75,000
New York	Sonneborn, Hydro-green and Cecabase	TBD
Pennsylvania	Meeker Aqua Foam	TBD
Florida	Terex WMA Foam	TBD

Table 1. New construction projects to be documented as part of NCHRP 9-47A

of WMA technologies will be included. Documentation at several of the projects will include an asphalt plant energy audit and stack emissions testing, as well as workspace respiration monitoring to measure asphalt fume exposure levels for paving crew members. Six existing sites, as shown in Table 2, are being monitored for performance. Both new and existing sites have control HMA sections for comparison.

Location	Construction Date	WMA Technologies	Total Tons Placed
Missouri	Sept. 2006	Evotharm ET, Sasobit and Aspha-min	6,600
New York	July 2007	LEA	19,000
Colorado	Aug. 2007	Evotharm DAT, Sasobit and Advera	3,000
Tennessee	Oct. 2007	Astec DBG, Advera, Evotharm DAT, and Sasobit	3,500
Texas	June 2008	Astec DBG	75,000
Washington	June 2008	Sasobit	13,000

Table 2. Existing projects being monitored for performance as part of NCHRP 9-47A

Test Track Puts New Asphalt Technologies to the Test

The current cycle of the NCAT Pavement Test Track includes the first test sections sponsored by private businesses to validate the benefits of their technologies. Kraton Polymers, Shell and Trinidad Lake Asphalt are taking advantage of the opportunity to prove their products through real-world performance testing on the track, laboratory testing and advanced pavement modeling. The models will allow the analysis of the unique paving technologies in virtually any pavement loading and environmental condition.

Technologies provided by the above firms were used to build structural test sections that are equipped with high-speed instrumentation arrays. Strain gauges are embedded at the bottom of the asphalt layers to monitor pavement response to traffic loading. Data from these devices are obtained safely and efficiently via a wireless data-collection system.

Performance of the test sections are tracked weekly. An inertial profiler is used to measure the International Roughness Index (IRI), macrotexture and rut depth. Also, sections are visually inspected for signs of cracking. Any cracks that appear will be carefully monitored, with the location and extent of cracking recorded. Approximately 5 million equivalent single-axle loads (ESALs) have been applied to date—50 percent of the projected traffic loading for the testing cycle—with a scheduled project completion date of September 2011.

Kraton

The Kraton section contains highly polymer-modified mixes, incorporating 7.5 percent styrene-butadiene-styrene (SBS) in all three lifts. This high level of polymer modification yields mixes that are very stiff but strain-tolerant in the laboratory, allowing the section to be designed with a reduced total asphalt thickness of 5.75 inches. In comparison, other comparable structural sections at the track have 7 inches of asphalt. This reduction in total asphalt thickness with Kraton's highly polymer-modified mixes is a potential economic benefit for owner agencies, according to Buzz Powell, NCAT's assistant director and manager of the test track. "A potential advantage of this technology is the cost-to-benefit ratio associated with building thinner pavements while achieving comparable performance," says Powell.

Laboratory results and theoretical pavement modeling indicate that mixes with this level of modification provide increased resistance to both rutting and fatigue. As temperatures climbed this summer, the Kraton section experienced extremely high strain levels, yet performance has been excellent to date. There are no signs of fatigue cracking, despite the high deflections measured.

Shell Thiopave

Shell Thiopave is a sulfur technology that replaces a percentage

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of the asphalt binder in a mix. The two Thiopave sections have binder layers containing 30 percent sulfur by weight of asphalt and base layers containing 40 percent sulfur. The surface layers on both sections are conventional hot-mix asphalt (HMA). Because the specific gravity of sulfur is higher than the specific gravity of asphalt binder, a mix that contains 40 percent sulfur gravimetrically reduces the asphalt binder requirement by approximately 25 percent. One section has an extra layer, giving it a total asphalt thickness of nine inches, while the other section has seven inches of asphalt, similar to the structural sections within the Group Experiment. Thiopave is a pelletized sulfur product, so no plant modifications are required for its use. In addition, Thiopave mixes are produced at warm-mix temperatures to avoid the emission of toxic hydrogen sulfide fumes. Replacing a significant portion of asphalt binder could make Thiopave an economically favorable choice, says Powell. The fact that Thiopave mixes are produced at warm-mix temperatures is a potential economic, as well as environmental, benefit of the technology. Life-cycle cost may also be reduced when factoring in the potential for increased pavement life. Performance to date for both Thiopave sections has been favorable on the track and in the laboratory.

Trinidad Lake Asphalt

Trinidad Lake Asphalt (TLA) is a natural asphalt that was used in the

first asphalt pavements built in the U.S. more than 100 years ago. TLA is still used today in high-stress applications around the world, and it is now produced in a pelletized form to facilitate shipping and introduction into modern asphalt plants. To prevent coalescence during transport and storage, the pellets are coated with a small amount of clay material, which should be accounted for in the mix gradation.

The TLA section has a total asphalt thickness of seven inches like the other sections in the Group Experiment. TLA pellets account for 25 percent of the total binder in the mix. The remaining binder is PG 67-28. No plant modifications are required to incorporate the TLA pellets, which are added to the mix as if they were recycled asphalt pavement (RAP) with a high residual asphalt content.

Use of TLA in the U.S. was limited in the past because of the difficulty of introducing bulk material shipped from Trinidad and Tobago into the plant. Hardened material in drums had to be stripped and melted to facilitate mixing. TLA pellets now offer a viable alternative, especially when the cost of refined liquid asphalt is high. Powell says, "It's another tool in the toolbox to protect against potential price increases in liquid asphalt." Performance of the TLA section has been favorable, with rutting results comparable to the control section, a PG 76-22 mix, within the Group Experiment.

Ongoing track testing will provide valuable performance data on technologies from Kraton Polymers, Shell and Trinidad Lake Asphalt.

Test Track Data Used to Validate Mechanistic Pavement Design Models

Asphalt pavement thickness historically has been designed based on vehicle type, standardized axle loads and material properties based on results from the AASHTO Road Test in the late 1950s. In recent years, however, pavement design has begun to shift toward a mechanistic-empirical framework that uses engineering principles to design pavement structures that will resist specific distresses, including fatigue cracking and rutting, over the required performance period.

Mechanistic-empirical (M-E) design incorporates material properties and environmental data, and uses mechanical analysis to more accurately model a pavement structure. Pavement response, which is calculated based on expected traffic loading, can then be used to predict pavement performance through empirical correlations. M-E design is slated to become the new AASHTO standard, with DarWIN M-E software scheduled for release in early 2011. As M-E design is implemented, there is an ongoing need for local calibration/validation of the empirically derived pavement performance models, which are dependent on both materials and climate. Data from structural sections at NCAT's test track provide a perfect opportunity to compare actual pavement performance with that predicted by M-E design models.

Comparing Actual and Predicted Performance

A variety of inputs are needed in the Mechanistic-Empirical Pavement Design Guide (MEPDG) analysis procedure, including the following:

- detailed traffic data, referred to as load spectra
- detailed climate data, such as air temperature, rainfall, wind speed, relative humidity and percent cloud cover
- mechanistic material properties—dynamic modulus (E^*) for hot-

mix asphalt (HMA) and resilient modulus (M_r) for granular base and subgrade materials

- HMA properties, such as asphalt content, lift thickness and density

These inputs are readily available for the structural sections of the completed 2003 and 2006 research cycles at the test track. These sections were instrumented with strain gauges to measure pavement response under loading and were subjected to 10 million equivalent single-axle loads (ESALs) during each two-year testing cycle. Design

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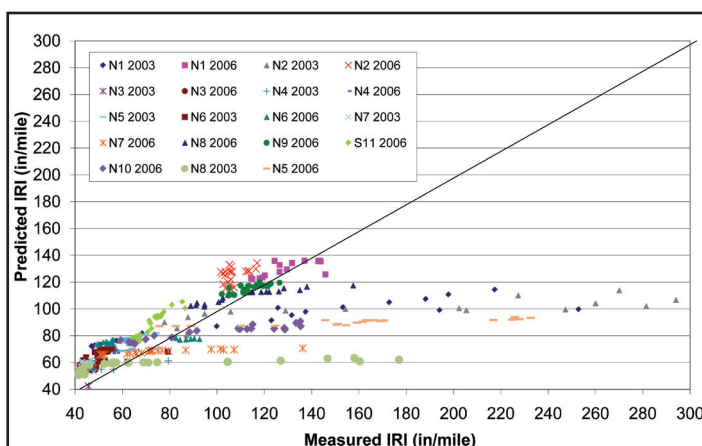


Figure 1. Comparison of measured and MEPDG-predicted IRI values for all sections

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variables included total hot-mix asphalt (HMA) thickness, HMA mix type, base material type and subgrade material type. All structural sections were assessed on a weekly basis for surface performance (rut depth, fatigue cracking and international roughness index, or IRI) as well as structural response (strain and pressure).

A comparison of measured and predicted IRI values for all sections (Figure 1, previous page) shows that the MEPDG model gives fairly reasonable results. Several sections, most notably N1 2003 and N2 2003, exhibited severe fatigue cracking—well beyond what is typically considered failure—and the resulting roughness is reflected in the measured IRI data but not in the MEPDG-predicted values for those sections, since the MEPDG model is not based on such severe distress. When comparing actual and predicted rut depths for all sections (Figure 2), it can be seen that the MEPDG rutting model overpredicts permanent deformation, but this can be calibrated or corrected with a simple offset. However, a comparison of measured and predicted fatigue cracking for all sections (Figure 3) reveals mixed results. In several cases, the MEPDG fatigue model does not match actual performance.

NCAT plans to continue MEPDG validation/calibration efforts as data becomes available for structural sections currently under loading at the test track.

Test Track Data Used in TexME Calibration

Recent research conducted by the Texas Transportation Institute (TTI) also employed data from previous test track structural sections in calibrating and validating distress prediction models within the proposed TexME design system.

To predict rutting, TTI selected the VESYS layer rutting model, which accounts for the permanent deformation properties of each layer. Material properties were determined using dynamic modulus and repeated load testing. Calibration of the proposed rutting prediction model involved three correction factors—pavement temperature, modulus and HMA thickness—that were determined using field rutting data. Eight structural sections from the 2006 NCAT Test Track cycle, representing a range of rut depths from low to very high, were used to determine the pavement temperature and modulus correction factors. In addition, the LTPP SPS-5 sections on US175 in Texas were used to determine the thickness correction factor. The correction factors were established by minimizing the difference between predicted and measured rutting. The accuracy of the calibrated rutting model was verified using data from three sections of the 2000 test track cycle, with predicted rutting generally matching the rutting observed in the field.

The proposed TexME fatigue cracking model, which considers crack initiation and crack propagation, uses an enhanced two-step Overlay Test to determine HMA fracture properties. Preliminary calibration included data from seven 2006 test track sections, some with no fatigue cracking and others exhibiting severe fatigue damage. The differences between measured and predicted fatigue cracking were minimized in order to develop the necessary calibration factors. Figure 4 illustrates the measured and predicted fatigue cracking for section N7. Data from two sections of the 2003 test track cycle were used to validate the fatigue cracking model.

Performance data from the current test track cycle will allow further validation/calibration of the TexME distress prediction models.

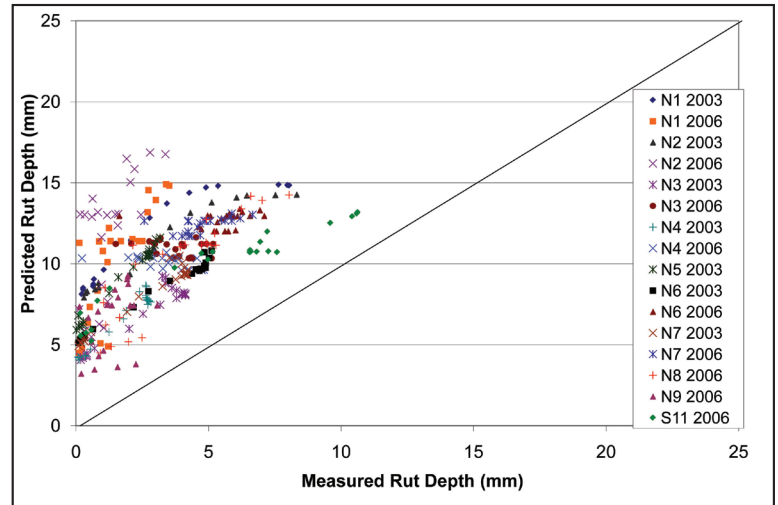


Figure 2. Comparison of measured and MEPDG-predicted rut depths for all sections

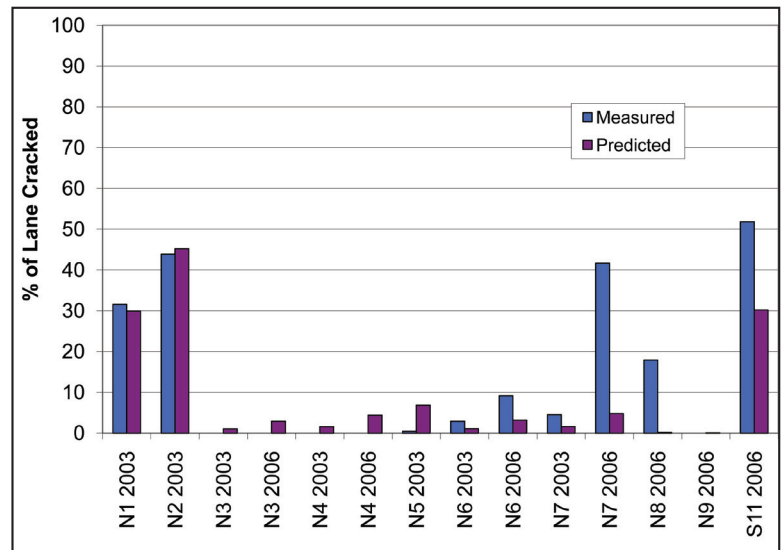


Figure 3. Comparison of measured and MEPDG-predicted fatigue cracking for all sections

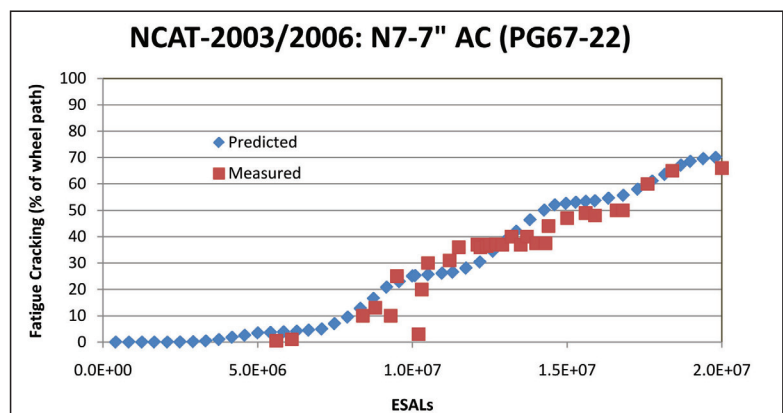


Figure 4. Comparison of measured and predicted fatigue cracking for section N7 using the TTI-developed fatigue model

NCAT invites your comments and questions, which may be submitted to Karen Hunley at karen.hunley@auburn.edu. Questions and responses are published in each issue of *Asphalt Technology News* with editing for consistency and space limitations.

Randy Mountcastle, Alabama Department of Transportation

Are any states using asphalt rubber binder (ARB) as a substitute for Styrene-Butadiene-Styrene (SBS)?

Do any states use a double-layer open-graded friction course (OGFC)?

Don Watson, NCAT

AASHTO T 168/ASTM D 979 procedures for sampling HMA from a truck transport require taking samples at random from the truck in approximately three equal increments and combining to form one representative sample. Some of the large truck beds in use today make this virtually impossible without the technician having to climb into the truck. How are states addressing this issue of getting random, representative samples from large truck beds without compromising the safety of the technician?

Most agencies specify that the HMA mixture temperature be within a certain tolerance of that specified in the mix design or Job Mix Formula for the project; otherwise, the mix may be rejected. Has anyone conducted research to show that mix produced at temperatures lower than the allowed tolerances is detrimental to HMA quality and long-term performance?

For agencies that have implemented PWL specifications for HMA acceptance, what were the greatest challenges to implementation? How did you overcome those challenges?

What changes are agencies anticipating or planning to make in order to meet the new FHWA regulations on noise? Do quieter pavements fit into those plans?

Dale Rand, Texas Department of Transportation

We are developing wording to address sample custody in all of our future HMA specifications. The Federal Highway Administration (FHWA) is particularly concerned about how we handle roadway cores to ensure that the opportunity for fraud is minimized or eliminated. We are not aware of any fraudulent activity; however, as a result of fraud in some other parts of the country, this has become a high priority to the FHWA. We rely on the contractor to obtain the cores from the roadway, and in some cases, deliver them to our lab at the HMA production facility, which can be located an hour or two from the job site. We currently do not have a system in place that would ensure the cores could not be switched or altered in some way. We are exploring several ideas on how to address this situation in an effort to come up with something the FHWA will buy off on. Our situation, like many others, is that we typically only have one inspector available on the project and the inspector cannot take off for several hours to deliver cores to our testing lab. In the past, we instructed the contractor (actually the truck drivers) to transport these cores for us, but we have been informed by the FHWA (who is reviewed by the Office of Inspector General [OIG]) that we can no longer continue this practice. This all came to light when the OIG started reviewing stimulus projects in Texas. We would like to know if any other states are facing a similar situation and if so, what is your proposed solution?



The Australian Asphalt Pavement Association visited NCAT in August as part of its 2010 U.S. Study Tour.

Asphalt Forum Responses

The following responses have been received to questions shared in the Spring 2010 Asphalt Forum.

1. What criteria do agencies use to assess aggregate polishing characteristics for use in surface mixtures and/or chip seals? Other than the British Pendulum Test, what tests are used or recommended? (Don Watson, NCAT)

Texas Department of Transportation, Dale Rand

Texas has dropped the polish value test using the British Pendulum device. We now classify our aggregates based primarily on their acid insolubility results and secondarily on their magnesium sulfate soundness loss results.

Missouri Department of Transportation, Joe Schroer

Acid insoluble residue is used to measure non-polishing aggregates. Field measurements are made with a skid trailer.

Tennessee Department of Transportation, Mark Woods

Tennessee classifies its limestone sources for surface aggregate by a ranking system that is based on silica dioxide content, acid insoluble residue, BPN and calcium carbonate content. Dependent on preliminary test results, source suppliers may be required to place two-year field test sections to be evaluated with ribbed-tire friction testing.

Alabama Department of Transportation, Randy Mountcastle

Alabama uses the BPN.

Florida Department of Transportation, Greg Sholar

For friction course aggregate properties we run the LA Abrasion test (Florida Test Method) on coarse and fine aggregate. In addition, we run Acid Insolubility using the Florida Test Method. To measure field friction performance, we use either the Dynamic Friction Tester (ASTM E-1911) or locked wheel trailer (ASTM E-274) using a ribbed test tire (ASTM E-501). For monitoring surface texture loss we use either the Circular Track Meter (ASTM E-2157) or friction truck mounted texture laser (ASTM E-1845), measuring mean profile depth (MPD).

Ohio Department of Transportation, David Powers

Ohio DOT, through a series of research studies with University of Akron, is developing a method to polish and test 6-inch gyratory specimens for friction determination. The method would involve the polishing of specimens with a specially designed polishing machine and obtaining a friction number with the British Pendulum procedure. The process could be used for mix design approval and for quality assurance and/or control. The goal was to have a straightforward process for testing compared to other approaches. The Ohio DOT is currently in the middle of validating the lab and field (multi-year) correlations. An important component is the specimen polishing machine. We are working with a manufacturer on its development, and we would like to hear from any states that who

may be curious about this approach. Please feel free to contact me at david.powers@dot.state.oh.us.

Iowa Department of Transportation, Scott Schram

The Iowa DOT has revised frictional aggregate requirements for interstate surface mixes. Iowa classifies frictional characteristics of aggregate sources based on grain size and other quality measures (Types 1 through 5). Type 2 is the highest classification available in and around Iowa (quartzite and steel slag). For mixes containing more than 40 percent limestone, at least 25 percent of the combined fine aggregate and 30 percent of the combined coarse aggregate shall be Type 2. For mixes containing less than 40 percent limestone, at least 25 percent of the combined coarse aggregate shall be Type 2 (quartzite or steel slag).

In addition, the fineness modulus of the proportion of Type 2 material in the total aggregate shall be at least 1.0. At least 80 percent of the coarse aggregate shall be Type 4. Limestone sources have less than 15 percent magnesium oxide (MgO) content.

2. Which states use VMA as an asphalt mixture acceptance criterion during daily production? If VMA is used for acceptance, how is G_{sb} determined? Is it based on test data at the time of production or historical data? (Don Watson, NCAT)

Texas Department of Transportation, Dale Rand

Texas uses VMA as a daily production test. We determine the VMA based on the effective specific gravity value that is back-calculated from the Rice Gravity (G_{mm}). We know this method is incorrect since it includes absorbed asphalt in the VMA. We account for this by increasing our VMA requirement. You could say we are extremely wrong but extremely accurate. We chose this path as the lesser of two evils since the "extremely correct" option is also extremely inaccurate based on our experiences. We have approximately 1500 certified HMA technicians. Our annual proficiency testing program shows that the Rice Gravity (G_{mm}) is the most precise test we have. When we did similar proficiency testing to determine G_{sb} values using the conventional methods, the results were highly variable to say the least. After about three years of trying to reduce the variability for G_{sb} (especially on fine aggregate), we opted to go the other direction. Since we determine asphalt content and a G_{mm} value for every subplot, we can easily determine a VMA value on each subplot (or at least our version of VMA).

Missouri Department of Transportation, Joe Schroer

Missouri uses VMA for acceptance during construction, which is determined with the G_{sb} from the job mix formula. We currently have pilot projects that determine the G_{sb} from the combined cold feed using the CoreLok device for the VMA calculation.

Asphalt Forum Responses

Tennessee Department of Transportation, Mark Woods
TDOT does not use VMA for acceptance.

Alabama Department of Transportation, Randy Mountcastle
In Alabama, G_{sb} is determined during design and only changes if the mix significantly changes.

Florida Department of Transportation, Greg Sholar
VMA is not an acceptance criterion during production. However, during mix design verification, both the contractor and the FDOT use historical G_{sb} data from the aggregate mines for VMA calculations. Typically, it is the average of the last 30 G_{sb} tests performed at the mine.

3. Has anyone stored warm mix overnight in a silo? If so, at what temperature? Did it contain RAP? (Chris Jones, Wiregrass Construction Company)

Texas Department of Transportation, Dale Rand
Texas does not allow storing HMA for more than 12 hours; however, at least one HMA producer has stored WMA with RAP overnight at roughly 270° F, and they reported no problems with the mix the next day.

Florida Department of Transportation, Greg Sholar
FDOT is not aware that this has occurred in Florida.

Specification Corner

Alabama

We've allowed a non-contact virtual "ski" for years, but now our specification explicitly allows this. We also allow warm-mix asphalt (WMA) on all but our heaviest-use roads, with up to 35 percent RAP. We are trying to promote WMA and increase our RAP use. We are experimenting with longitudinal joint sealer for surface mixes. We've used tack coat, PG 67-22 and trackless tack. We have had permeable joints in the past (remember the high N_{design} of the early Superpave?), and we are trying to make sure that never happens again. We are in the process to convert all our gyros (state and contractor) to internal angles.



A group from the Federal European Highway Research Laboratories (FEHRL) toured NCAT's laboratories and pavement test track on September 24, 2010.

Relationships between Laboratory-Measured Characteristics of HMA and Field Compactability

Randy West and Fabricio Leiva

Achieving target density is vital to building long-lasting hot-mix asphalt (HMA) pavements that resist distresses such as rutting and moisture damage. However, meeting specified density levels can be challenging, as some mixes require greater compactive effort than others.

Compactability describes the relative ease of compacting an HMA mixture to reach acceptable density levels. Several laboratory-measured parameters have been suggested as indicators of HMA compactability, but most have not been correlated with actual pavement construction data. A practical approach is needed to evaluate lab compactability and use it to estimate the required field compactive effort for HMA mixtures. This would enable mix designers to make adjustments as needed during the mix design process to improve field compactability.

The Study

The primary objective of this study was to evaluate the following laboratory-measured mixture parameters and determine correlations with field compactability:

1. Percentage of theoretical maximum specific gravity (G_{mm}) at the initial number of gyrations (N_{ini})
2. Compaction slope, determined from the Superpave gyratory compactor (SGC)
3. Number of gyrations required to achieve 92 percent G_{mm} (N_{92})
4. Compaction energy index (CEI), determined from the SGC
5. Number gyrations required to reach the locking point of the mixture
6. Coarse and fine aggregate ratios, determined by using the Bailey method
7. Mix characteristics, including gradation, aggregate shape, binder grade and volumetric properties
8. Primary control sieve index (PCSI), representing the relative coarseness or fineness of the gradation



Monitoring field compactability on the NCAT Pavement Test Track

A second objective was to evaluate mix characteristics, such as gradation and binder grade, as factors affecting compactability.

Data from Superpave mixes placed on the NCAT Test Track during the 2000 and 2003 cycles were used to evaluate laboratory-measured compaction parameters, as well as field compaction. Both surface and intermediate mixes, representing a variety of aggregates, gradation types and binder grades were included in the analysis. Accumulated compaction pressure (ACP), a concept used to quantify compactive effort applied during rolling operations, was then related to laboratory compaction parameters.

To refine the compaction models, several additional steps were taken. Laboratory specimens were compacted to field lift thickness to determine the number of gyrations to reach 92 percent G_{mm} and actual field density. A number of mixes placed on the track in 2003 and 2006 were also used to obtain ACP at 92 percent G_{mm} , and the results were correlated with laboratory compaction parameters using multiple regression analysis. Finally, one of the compaction models was validated using data from NCHRP 9-27, *Relationships of HMA In-Place Air Voids, Lift Thickness and Permeability*.

Conclusions and Recommendations

CEI, N_{92} , compaction slope and locking point were found to be simple laboratory compactability parameters. PCSI and the fine aggregate ratio (FA_c) determined by the Bailey method, both of which describe gradation properties, can also be used to indicate laboratory compactability.

A multiple analysis of variance (MANOVA) was used to determine the relative effect of physical properties on laboratory compaction parameters. This analysis revealed that laboratory compaction was significantly affected by gradation type, and to a lesser degree, aggregate type and aggregate size. As expected, the most easily compacted mixes in the gyratory compactor were fine-graded, while stone matrix asphalt (SMA) mixes tended to require the greatest laboratory compactive effort.

An analysis of variance (ANOVA) was also used to determine which mixture and construction variables significantly affected ACP in the field. Both the ratio of lift thickness to nominal maximum aggregate size ($t/NMAS$) and mix temperature had a significant effect on ACP. Much higher compaction energy was required for $t/NMAS$ less than 3:1 and for mixes with temperatures less than 225°F at the first pass of the break-down roller. Due to a more rapid loss of mix temperature, mixes with lift thicknesses less than 50 mm required more compactive effort to achieve target density. Although temperature substantially affected ACP for $t/NMAS$ less than 3:1, the effect of temperature was minor for $t/NMAS$ ratios greater than 4:1. Although binder grade was not significant at a 5 percent level of significance, it did influence ACP, with stiffer binders requiring greater compactive effort. Furthermore, mixes with higher binder contents and finer gradations required less compactive effort, as expected.

Due to the range of factors affecting field compaction, a single

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factor correlation could not be found to effectively describe the relationship between laboratory and field compaction. However, multiple regression analysis resulted in a model ($R_2 = 0.82$) that includes four significant factors: FA_c , PCSI, surface temperature at the start of field compaction and the number of gyrations to reach field density for specimens compacted to field lift thickness (N_{FTFD}). Thus, an additional step in the mix design process—compacting specimens to field lift thickness and calculating the number of gyrations to reach target density—can be used to help predict required field compactive effort. This model was also verified using data from 16 surface mixes placed across the U.S. as part of

the NCHRP 9-27 study.

Another model ($R_2 = 0.92$) was developed to predict the ACP required to achieve a reference density level of 92 percent G_{mm} . This model, which was not independently validated, includes the following terms: FA_c , PCSI, percent passing the 0.075 mm sieve, binder grade, compaction slope, locking point, lift thickness and surface temperature at the start of field compaction.

The models developed in this study can be used by mix designers to predict the compactive effort required to meet target density in the field. Thus, adjustments can be made to avoid designing mixes that require unnecessarily high field compaction energy.

Bond Strength and Non-Destructive Testing to Identify Delamination

A strong bond between pavement layers is necessary to ensure long-term performance of newly constructed asphalt pavements and overlays. To create a good bond between asphalt layers, tack coats (typically asphalt emulsions or paving grade asphalt binders) are often used.

As a vehicle moves over a pavement, horizontal friction forces at the contact between tires and the pavement surface induce shear stresses through the pavement. If the induced shear stress is greater than the bond strength at a layer interface, debonding may occur, causing pavement distresses such as slippage failures (Figure 1). Slippage failures can be seen in areas where traffic accelerates, decelerates or turns, inducing high shear stresses. In delaminated areas the pavement no longer acts as a monolithic structure. The critical tensile strain will be located at the debonded interface rather than the bottom of the hot-mix asphalt (HMA), causing other distresses, such as fatigue cracking. These pavement distresses require extensive and costly repairs, including patching or complete reconstruction.



Figure 1. Example of pavement distress caused by debonding.

Structural Analysis to Characterize Shear Stress Distribution

NCAT researchers conducted a structural pavement analysis to better understand the shear stress distribution throughout the pavement structure. The analysis showed that the critical shear stress at the interface underneath the surface layer is primarily affected by the thickness and stiffness of the surface layer, as well as the variation in stiffness caused by seasonal temperature variations. Subgrade stiffness and total asphalt thickness had less of an effect on the critical interface shear stress.

Surface layer thicknesses from 0.5 to 2.0 inches were analyzed, with thinner surface layers exhibiting higher interface shear stresses. A maximum shear stress of 92 psi was determined for the minimum surface layer thickness of 0.5 inches. Interface shear stress decreased as surface layer thickness increased, with an interface shear stress of approximately 40 psi occurring at a depth of 2.0 inches.

Experiment to Establish Preliminary Bond Strength Requirement

The bond strength between pavement layers can be determined using destructive testing, such as the bond strength test developed at NCAT in the first phase of a study funded by the Alabama Department of

Transportation (ALDOT). This method, adopted as ALDOT Procedure 430, shares some similarities to bond strength tests used in Europe and some states, including Florida. In this procedure, cores are placed in a bond strength loading frame and the layers are sheared apart using the Marshall load frame apparatus at a loading rate of two inches per minute and at a test temperature of 77°F. Interface bond strength is then calculated by dividing the maximum shear load by the cross-sectional area of the core.

In the second phase of the study sponsored by ALDOT, NCAT investigated bond strengths at five sites that were constructed in the first phase. These pavement sections have been in service for more than four years and show no signs of debonding. Surface layers varied in thickness from 0.7 to 2.1 inches. Tack coats, including asphalt emulsions and a paving grade asphalt binder, were used on new and milled asphalt surfaces and on old Portland cement concrete. The average bond strengths for these five sites were all greater than 100 psi. In addition, nine in-service pavement sections exhibiting slippage failures were also investigated.

Cores were extracted in the delaminated areas and from intact areas nearby. Average bond strengths for the intact areas all exceeded 87 psi.

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—Continued from Pg. 9

In the areas with slippage failures, some specimens broke during coring, and the remainder of the cores from the failed areas had bond strengths ranging from 25 to 60 psi.

Based on results from the structural pavement analysis and field experiments, a preliminary bond strength requirement of 100 psi, tested according to the ALDOT-430 procedure, was recommended for further evaluation of the interface bond between surface and underlying layers.

Tack Coat Investigation

Parts of the second phase of the ALDOT-sponsored study focused on evaluating bond strength with regard to tack coat types, application



Figure 2. GPR unit used in field evaluation at the test track



Figure 3. Seismic wave technology used in field evaluation at the test track

rates, surface preparation and curing time. Four types of emulsions (CRS-2, CRS-2L, CQS-1H and NTSS-1HM) and a paving grade asphalt binder (PG 67-22) were compared at three application rates—low, medium and high, based on existing ALDOT specifications. Specimens were also prepared without tack coats for comparison. The experiment used three surface preparation types: milled, micro-milled and new surfaces.

In the laboratory, slabs were prepared and cored to evaluate bond strength. A field study was also conducted at the test track and several sites across the state to validate the effects of the experimental factors examined in the lab. Cores were extracted following construction, as well as at three months and six months after construction to compare bond strength over time.

Findings from the study include the following:

- Bond strength is improved when the lower surface is either milled or micro-milled.
- Tack coats should be used at higher application rates on milled surfaces—approximately twice the rate used on new asphalt surfaces.
- Each type of tack used at ALDOT-specified application rates can provide an interface bond strength higher than the preliminary requirement of 100 psi, although bond strength was higher for PG 67-22 and NTSS-1HM.

Using NDT to Identify Delamination

Poor bond between HMA lifts is difficult to determine before surface pavement distresses become visible. Project R06(D) of the second Strategic Highway Research Program (SHRP 2) is investigating nondestructive testing (NDT) methods that potentially could be used to identify delamination between HMA layers before distress appears. If a rapid NDT method could identify and quantify delaminations following construction or as part of a pavement-management system, then repair or rehabilitation could be considered before problems arise. This ongoing investigation is a collaborative effort between NCAT, Infrasense, the U.S. Army Corps of Engineers' Engineering Research and Development Center (ERDC), and the Center for Nondestructive Evaluation (CNDE) at Iowa State University.

The original project goal was to find a technology capable of testing an entire lane width in a single pass at safe operating speeds, but the scope broadened to examine more of the available technologies, such as point-load tests.

Several nondestructive testing methods were included in a recent field evaluation at NCAT's test track, where sections both with and without delaminated areas were built in the non-trafficked inside lane. These NDT methods include ground-penetrating radar (GPR) and infrared (IR) thermography, as well as seismic wave and deflection measurement methods.

Based on the results, two technologies were selected for further evaluation. A GPR unit manufactured by 3-D Radar (Figure 2) provided full-lane width coverage at speeds of 20 to 30 mph. The other technology, developed by Olson Engineering (Figure 3), uses seismic wave technology with a traveling point-load system.

Training Opportunities

NCAT offers a variety of training opportunities to fit your needs. To register for a class or for more information, please visit our website at www.ncat.us or call Linda Kerr at 334.844.7308 or Don Watson at 334.844.7306.

NCAT to Host AMPT Training

After conducting a pilot course last May, the Federal Highway Administration (FHWA) and National Highway Institute (NHI) are planning to launch the National Training Course for the Asphalt Mixture Performance Tester (AMPT) at the National Center for Asphalt Technology (NCAT) this fall. The goal of the course is to introduce the AMPT equipment as well as associated test and analysis procedures into accepted engineering practice.

Participants will receive hands-on training using the AMPT to perform dynamic modulus and flow number testing of asphalt concrete. The results of these standard tests may be used to differentiate between materials and mixtures and, further, these properties can be directly input into the AASHTO Mechanistic-Empirical Pavement Design Guide (MEPDG). The course will also provide training in various analyses that can be performed using data obtained from the AMPT, and it includes lectures on the background of these tests. Ultimately, the course is intended to help transition AMPT technology from the research stage to standard practice and routine use, as specified by the highway agencies, industry and contractors.

This national, coordinated workshop was developed through funding from FHWA and the Transportation Pooled Fund (TPF) study, TPF5-178, titled "Implementation of the AMPT for Superpave Validation." More than 21 state highway agencies and the Ministry of Transportation of Ontario, Canada are participating in this study. The pooled-fund study provides participants with the AMPT system, funding for two participants to attend the training course and participation in studies to



An NCAT engineer leads an NHI AMPT Training Course.

properly implement the equipment. Pooled-fund participants will have priority in attending the first offerings of the AMPT training course. More information on the pooled fund study can be found at www.pooledfund.org/projectdetails.asp?id=405&status=4.

The FHWA is currently consulting with pooled-fund participants to determine a course schedule. For more information about the AMPT course, please visit www.nhi.fhwa.dot.gov/Home.aspx.

HMA Continuing Education Courses Available

The National Center for Asphalt Technology (NCAT) and Auburn University's Engineering Continuing Education Department have developed an educational partnership to offer hot-mix asphalt (HMA) training courses for engineers to earn CEUs to comply with the requirements of state licensing boards. These courses are part of Auburn's Engineering Professional Development program and are available either on DVD or through web-based instruction. Some of the offered courses include:

- Asphalt Binder Tests and Specifications
- Aggregate Properties and Aggregate Selection for Mix Design
- Superpave and Marshall Mix Design
- Hot-mix Asphalt (HMA) Performance Testing
- HMA Plant Operation
- HMA Delivery and Placement
- HMA Compaction
- HMA QC/QA

- Accelerated Pavement Testing
- Pavement Maintenance, Rehabilitation and Preservation

In addition to the training courses listed, NCAT is also providing three introductory, free webinars on the topics of warm-mix asphalt, use of RAP in HMA and recognizing pavement distress. Other courses are also available in the areas of civil engineering, land surveying, structural engineering, electrical engineering, ethics and legal, and management. Visit www.engce.auburn.edu/courses for the list of courses, descriptions and to order online (or call 800-446-0382). If you order online you can also take the exam online. The mailing address is

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