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Analysis of the Impact of In-Place Air Voids on Pavement Performance

Air voids are an important parameter in asphalt pavement construction. If air voids are too high or too low, pavement life can be reduced. The objective of NCHRP Project 20-50 (18) was to determine the effects of as-constructed air voids on performance using field data from the Long-Term Pavement Performance (LTPP) program. Although a similar study was conducted in 2001 under NCHRP Project 20-50 (14), revisiting the topic was warranted because a much larger LTPP dataset is now available. The study focused on performance related to four distress types: rutting, fatigue cracking, thermal cracking, and roughness. A major challenge was isolating the influence of air voids from the many other factors affecting performance, including climate, traffic, and pavement structure. Three analysis methods were used: (1) dividing the LTPP sections into common data subgroups to help isolate the effect of air voids, (2) using regression modeling, and (3) using an artificial neural network (ANN). Validation efforts were conducted using data from the NCAT Test Track and the Minnesota DOT's MnROAD facility.

Data from 426 LTPP test sections were extracted with a nearly even split between new construction and rehabilitated sections. All of the sections had a minimum of five years of field performance monitoring (over half had more than ten) and at least three distress surveys (over two-thirds had more than eight). All four climate regions were represented with a higher proportion from wet-no freeze and wet-freeze regions. As-constructed air voids ranged from 1% to more than 14%. The mean of all wheel path as-constructed air voids was slightly lower than the mean of all non-wheel path air voids, reflecting a delay between when sections were opened to traffic and when the LTPP team collected as-constructed data. Where available, non-wheel path air voids were used for the analysis. Data for all asphalt layers was needed to account for performance related to the surface (rutting and thermal cracking) as well as full depth (fatigue cracking).

LTPP cracking data was recorded relative to physical location rather than cause; therefore, this study used wheel path cracking to quantify fatigue cracking and used transverse cracking to quantify thermal cracking. Sections with porous surface mixes were removed from the study due to their high air voids. Different dates were selected to initiate performance time: open to traffic date for rutting, fatigue cracking, and roughness; construction completion date for thermal cracking; and LTPP assignment date for rehabilitation sections that had no other dates recorded. Some sections experienced additional construction events during the monitoring period; those events that resulted in significantly different performance were considered as separate analysis periods.

Assembling and processing the data was time intensive, requiring additional steps to develop a reliable and complete dataset for analysis methods 2 and 3. This dataset included more detailed climate, material stiffness, and layer thickness variables than the dataset used in method 1. Layer attributes were combined into LTPP section-level attributes; for example, a representative air voids value was computed for each section as the average of air voids for each layer weighted by layer thickness. For variables other than air voids with a low percentage of missing values, approximate values were determined by predictive models. The final analysis dataset for each performance type included section attributes merged with time-dependent data (climate and traffic) for each performance measure.

Analysis method 1 created a matrix of 48 subgroups delineated by climate, traffic, and pavement structure such that similar performance was expected in each subgroup, with as-constructed air voids being a distinguishing factor. A total of 27 subgroups had a sufficient number of LTPP sections for analysis. From each section's performance curve, representative values were established for each distress. Rutting was evaluated at four, six, and eight years as well as the time to reach 0.3 inches of rutting. The performance criteria for fatigue cracking was the percentage of wheel path cracking after 10 years. For thermal cracking, the number of years before transverse cracks appeared and the length of transverse cracking were determined. Roughness was analyzed after 10 years of traffic and the time for roughness to increase by 25 in/mi from the initial post-construction measurement. Graphs were created for each subgroup by plotting the performance value and as-constructed air voids for each section. Sections were classified as "meeting expectations" if the plot showed better performance for lower as-constructed air voids, sections were classified as "contradicting expectations" if worse performance was observed for lower air voids, and sections were

Table 1. Summary of Analysis Results

Performance Measure	Pavement Type	Analysis Method 1	Analysis Method 2	Analysis Method 3
Rutting	New	57% met 21% contradict	Approx. $R^2 = 0.31$ Nominally contradict	Predicted $R^2 = 0.46$ Nominally met
	Rehabilitated	67% met 0% contradict	Approx. $R^2 = 0.16$ Minimally contradict	Predicted $R^2 = 0.47$ No influence
Fatigue Cracking	New	82% met 9% contradict	Approx. $R^2 = 0.41$ Significantly met	Predicted $R^2 = 0.62$ Mixed expectation
	Rehabilitated	40% met 30% contradict	Approx. $R^2 = 0.35$ Nominally met	Predicted $R^2 = 0.46$ Significantly met
Thermal Cracking	New	42% met 50% contradict	Approx. $R^2 = 0.38$ Nominally met	Predicted $R^2 = 0.36$ No influence
	Rehabilitated	50% met 50% contradict	Approx. $R^2 = 0.32$ Nominally met	Predicted $R^2 = 0.30$ Nominally met
Roughness	New	54% met 38% contradict	Approx. $R^2 = 0.24$ Nominally met	Predicted $R^2 = 0.19$ Nominally met
	Rehabilitated	25% met 42% contradict	Approx. $R^2 = 0.21$ Nominally met	Predicted $R^2 = 0.39$ Nominally met

classified as "no influence" if similar performance was observed over a range of as-constructed air voids. As seen in Table 1, the impact of as-constructed air voids was mixed for analysis method 1.

Analysis method 2 used statistical regressions to assess the influence of as-constructed air voids on pavement performance. Input variables were normalized so that each would be weighted equally in the analysis. A separate model was developed for each combination of pavement type and distress. Each model was fitted to a typical curve for each distress considering model fit and complexity. For analysis method 2, the influence of air voids was also mixed. Table 1 lists approximate R^2 for each model and whether the model prediction met or contradicted expectations. A series of performance curves created using average input variables and incremental as-constructed air voids are available in the User Guide prepared for the project.

Analysis method 3 used an artificial neural network (ANN) to examine the influence of as-constructed air voids. ANN is an adaptive information processing approach that establishes correlations between input and output variables through interconnected neurons (weight factors) that are adjusted using a minimum error function. Eight models were developed – one for each combination of pavement type and distress – each having slightly different input parameters (climate, traffic, material, and structure characteristics) and different numbers of neurons within the ANN architecture. For each model, LTPP sections were randomly divided into two groups: a training-validation cluster used to develop the ANN model and a test cluster used to evaluate model prediction accuracy. Training-validation clusters were further subdivided into training and validation subsets. The ANN model predictions and measured pavement performance were generally in good agreement within the training-validation clusters. Prediction accuracy was lower for the test clusters, which may be attributed to measurement variations within individual parameters as well as the relatively small dataset with respect to the diversity of the LTPP sections. Overall, the ANN models had better prediction accuracy than the regression models developed in analysis method 2. As shown in Table 1, the influence of as-constructed air voids for analysis method 3 was also mixed.

Broadly speaking, this study concluded that lower as-constructed air voids have a positive impact on asphalt pavement performance. However, the influence is not consistent among the types of distress and type of project (new construction or rehabilitation).

Validation of these results involved two approaches. The first compared analysis method 1 results with AASHTO Pavement ME predicted performance (rutting and fatigue cracking) over a range of air voids. Nine LTPP sections were selected from two subgroups (dry-no freeze and wet-no freeze, both with medium thickness and low traffic). The Pavement ME rutting and fatigue trends agreed with the study for the dry-no freeze subgroup but differed for the wet-no freeze subgroup. The second validation approach compared actual performance at MnROAD and the NCAT Test Track to predicted performance using the models developed with each analysis method. Data from both sources were filtered to exclude sections with porous surface mixes as well as sections outside the range of pavement structures and traffic conditions seen within the LTPP dataset. Because the Test Track uses accelerated loading (approximately 10 years of heavy loading applied within a two-year cycle), a time shift was applied to the performance curves to approximate normal traffic. The regression models developed using analysis method 2 were applicable to some but not all cases for MnROAD and the Test Track. The ANN models developed using analysis method 3 better fit the LTPP data but were not applicable to the MnROAD and Test Track data. Caution should be used when applying these models to parameters outside the LTPP dataset.

The results of this study will provide better information for agencies to determine if their construction standards should be modified to improve pavement performance. This decision will be based on how well the agency's climate and pavement program compares to the data used in this study. Implementation guidance is contained in the report, as well as direction for agencies that want to perform an in-house study with their own data.

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Message from the Director

New Ways

One thing for sure is that the pandemic has forced us to find new ways to do many things: working from home, new ways to meet, new ways to greet, new ways of getting entertainment, new ways to worship. Although we all look forward to getting back to the normal ways when the pandemic is over, I think that some of the new ways are going to stick.

In the world of research, we are constantly exploring new ways, such as new ways of designing mixes, new ways of designing pavements, new ways of constructing pavements, new ways of rehabilitating pavements, and new ways of evaluating additives.

We often lament that our industry is slow to change. Change is not easy; it is often messy. Changing one thing frequently results in a cascade of other changes that must follow. Perhaps it is human nature, but we shouldn't resist change out of stubbornness or desire to maintain our comfort level. We should seek better ways, even if it is a small change. Will the result of the new way be better? Will it cost less? Will it be more efficient? Will it be safer? Will it be more sustainable? When it comes to spending the public's money, we need to answer those questions as clearly as possible.

A few years ago, I learned a new way to do a very simple thing that you may think is trivial, but it gives me a little bit of satisfaction nearly every day. What I learned was a new way to tie my shoelaces. The way I had learned to tie my shoes when I was a little boy had worked for nearly 50 years, but there was always a flaw – the bow would naturally settle at a twisted angle across the shoe. I learned from YouTube how to tie the knot so that the bow lays nicely across the shoe. This new way didn't change my life in a significant way, but a small flaw is now gone. I did a tiny amount of research (thanks, YouTube) and voila! – a better way.

Sometimes change is not just about making improvements; sometimes it is necessary to survive. In nature, organisms that don't adapt, don't survive. The same is true in business; organizations that don't adapt don't survive. As business strategy expert Gary P. Hamel said, "You can't build an adaptable organization without adaptable people-and individuals change only when they have to or when they want to."

I hope that you will join us in the search to reveal the weaknesses and flaws and then adapt to new ways that are truly better. Our survival may depend on it.

Randy C. West, Ph.D., P.E.
NCAT Director and Research Professor

Rehabilitating Concrete Pavements with Slab Fracturing

The benefits of using asphalt overlays for rehabilitation of Portland cement concrete (PCC) pavements are grounded in economics and long-term performance. The Federal Highway Administration reports that the U.S. has 108,603 lane miles of composite pavements (PCC overlaid with asphalt), which is nearly double the lane miles of PCC-surfaced pavements. This means that nearly two-thirds of the concrete pavements in the U.S. have been overlaid with asphalt. However, a persistent problem with asphalt overlays on PCC pavements is reflective cracking of joints and cracks through the asphalt overlays over time. Ultimately, reflective cracking leads to a shortened performance life of the overlay. Rather than removing the concrete, which can be costly to the owner agency and increase delay time for the traveling public, slab-fracturing techniques can be used prior to placement of an asphalt overlay to significantly reduce stress concentrations at concrete joints and cracks.

Slab-fracturing techniques include three methods: crack and seat for PCC without steel reinforcement, break and seat for PCC with steel reinforcement, and rubblization for any type of concrete pavement. Crack and seat is intended to reduce the effective slab length of PCC pavements by producing tight surface cracks. Break and seat is similar but typically requires greater fracturing effort. The rubblization process typically fractures slabs into fragments with a nominal size of 4 to 8 inches. Since the existing pavement remains in-place, there are no hauling or disposal costs, resulting in substantial cost savings for state agencies.

Researchers at NCAT recently completed a project sponsored by the National Asphalt Pavement Association (NAPA) to synthesize historical and recent experiences with rehabilitation methods of PCC pavements with asphalt overlays. A survey of stakeholders indicated that crack and seat and rubblization are more popular than break and seat for PCC rehabilitation. Most PCC rehabilitation projects have more than 4 inches of asphalt overlay placed on fractured slabs. Although a majority of state agencies still use the AASHTO 1993 design method, Wisconsin uses the AASHTO 1972 design method; Indiana, Missouri, and Wyoming use Pavement ME Design; and California, New York, and Illinois use their own mechanistic-empirical design methods.

SLAB FRACTURING TECHNIQUES FOR PCC REHABILITATION

NCAT researchers also analyzed Long-Term Pavement Performance SPS-6 experiment data to compare slab fracturing methods to alternative concrete rehabilitation treatments such as minimum and maximum restoration of PCC and overlays with sawed and sealed joints. They found that rubblized PCC with more than 5 inches of asphalt overlay practically inhibits reflective cracking. According to the statistical analysis, there are no significant differences in performance measures of smoothness, rut depth, and longitudinal cracking for the different treatments involving asphalt overlays on PCC.

NAPA IS-117 recommends that in order to eliminate reflective cracking, crack and seat and break and seat projects should have less than 5 percent exceeding E_{pcc} = 1000 ksi. However, as shown in Figure 1, NCAT researchers found that most of the SPS-6 projects had slab moduli above the 1000 psi threshold but still had good reflective cracking performance. Thus, the IS-117 recommended threshold for E_{pcc} is not suitable for recent slab fracturing projects. The researchers used a finite element analysis to determine that rubblized PCC with more than 8 inches of asphalt overlay could be a perpetual structure if the foundation is strong enough.

In addition, two case studies were documented: one crack and seat project in Wyoming and one rubblization project in Colorado. These projects used different design methods. Wyoming used the mechanistic-empirical methodology to

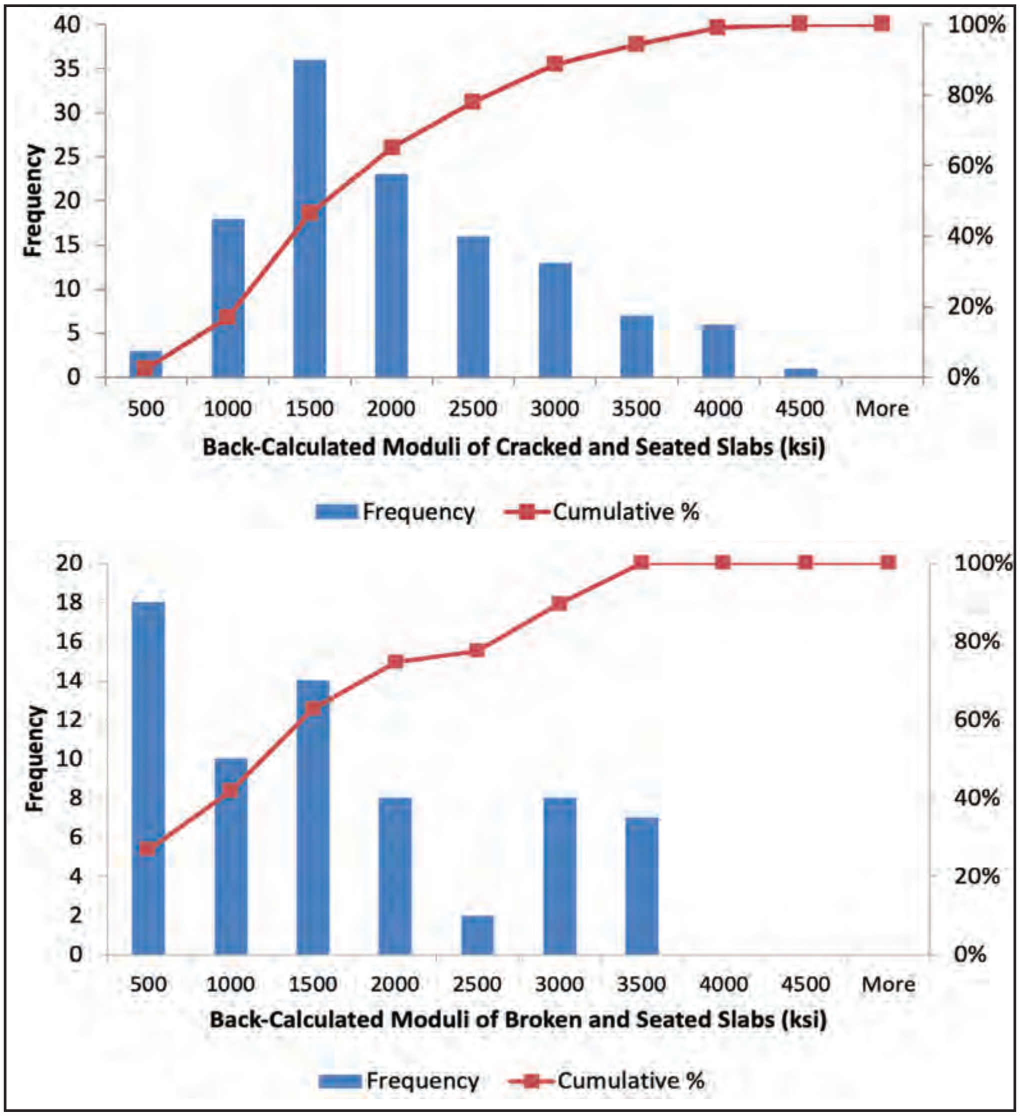

Figure 1. Distribution of Back-Calculated Moduli of Fractured Slabs

determine the asphalt overlay thickness, while Colorado used the AASHTO 1993 design method. The details are covered in NCAT Report 20-03, Benefits of Rehabilitating Concrete Pavements with Slab Fracturing and Asphalt Overlays.

The key findings of this project are also recorded in a NAPA webinar with the same title. The project outcome informs owner agencies and the industry that slab fracturing techniques are the most effective PCC rehabilitation methods.

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Implementation Spotlight

Highly Polymer Modified Binder Solves Rutting Issue in Alabama

The NCAT Test Track has conducted high-value research for agency and industry sponsors since the completion of the inaugural research cycle in 2000. Numerous findings that offer great value for agencies have been implemented from each of the previous seven research cycles. An excellent example of a new technology proven to be successful is highly polymer modified (HiMA) binder for specific cases where enhanced rutting and/or cracking performance is needed. As a result of Test Track research successes with both new pavement construction and pavement rehabilitation, the Alabama Department of Transportation (ALDOT) chose HiMA binder to solve a rutting problem on a high truck traffic, stop-and-go project on US 231 after a high profile and costly rutting failure.

The 4.9-mile project ran from the south city limits of Troy, Alabama to north of State Route 10 with several signalized intersections. This section of U.S. 231 is located within an area that provides multiple points of access from connecting roads and supports a high level of truck traffic. Rehabilitation was needed because of severe rutting in the relatively new pavement, which was worse at locations where trucks brake and accelerate. The failing pavement was a two layer stone matrix asphalt (SMA) mill/inlay, expected to be both durable and rut resistant; however, it was placed and later patched on this project with poor results.

The 10-inch asphalt pavement needed to be rehabilitated quickly in order to correct deep rutting that was steadily getting worse. ALDOT was skeptical about installing SMA again because it had already failed twice (including the original construction in 2008 and isolated patching later that same year). A solution was needed that would address the isolated structural inadequacies observed in forensics while at the same time provide long term rutting resistance in the binder layer. As seen in Figure 1, the binder layer appeared to be the primary source of the rutting when trenches were cut in 2008.

The distressed condition on this section of U.S. 231 was in several ways similar to a section on the Test Track that was subjected to an innovative rehabilitation alternative in the summer of 2010. This test section consisted of 10 inches of hot-mix asphalt (HMA) built on an imported soft subgrade to simulate in-service pavement construction in Oklahoma. The section exhibited extensive cracking at the end of the 10 million ESAL 2006 research cycle and failed again after it was rehabilitated with a 5-inch mill and inlay (the standard at the time in Oklahoma). Forensics conducted after the rehabilitation failure indicated that the pavement in this section had full depth cracking and rutting extending into the subgrade. Rut depths before the rehabilitation were as much as an inch and had returned up to a depth of 1½ inches by the time the conventional rehabilitation failed. Based on the excellent performance of a relatively thin HiMA modified test section in the previous research cycle, a 5¾-inch HiMA inlay was used to repair this failed test section and turn a full depth failure into a perpetual pavement.

Based on the success of the HiMA modified Superpave mixes on the Test Track, a similar approach was recommended to ALDOT. NCAT recommended that the badly rutted pavement on the US 231 project be milled to a minimum depth of 3.8 inches (the depth below which no rutting was noted when forensics were conducted in the fall of 2008) and inlaid with dense-graded HiMA Superpave mixes. ALDOT chose to mill the project 4 inches and replace it with a 2½-inch thick

Figure 1. Rutting Observed in Binder SMA During Forensic Trenching

HiMA Superpave binder mix and a 1½-inch thick conventional polymer modified Superpave surface. In this manner, use of the costly HiMA binder was targeted in the higher shear binder layer where rutting had been forensically observed. Work was completed at night in the summer of 2012.

Rutting performance data from ALDOT's Pavement Management Division is shown in Figure 2. High average rut depths were measured before and after the 2008 SMA inlay. Standard deviations are also high prior to 2012 because the rut depths in intersections were so much worse than the rest of the project. Since the 2012 HiMA repair, average rut depths and standard deviations have been significantly reduced.

ALDOT is pleased with the performance of the HiMA mixes on this project and has since used it in other parts of the state to address specific rutting and/or cracking problems and to increase structural capacity where it is not possible to increase thickness due to grade limitations such as at bridges and sections with curbs and gutters. Because the need for HiMA binder is greatest on roadways that exhibited rapid failures in the past, ALDOT minimized the risk of implementation by relying on the proven performance of HiMA from the NCAT Test Track.

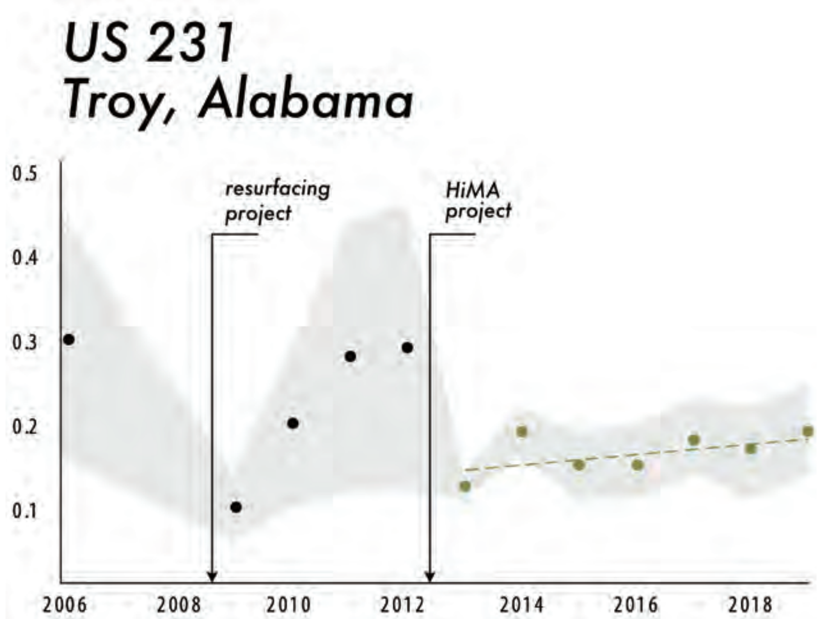

Figure 2. Average Rutting by Year (Bands Show ±1 Standard Deviation)

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For more information on the data, contact Frank Bell at bellf@dot.state.al.us

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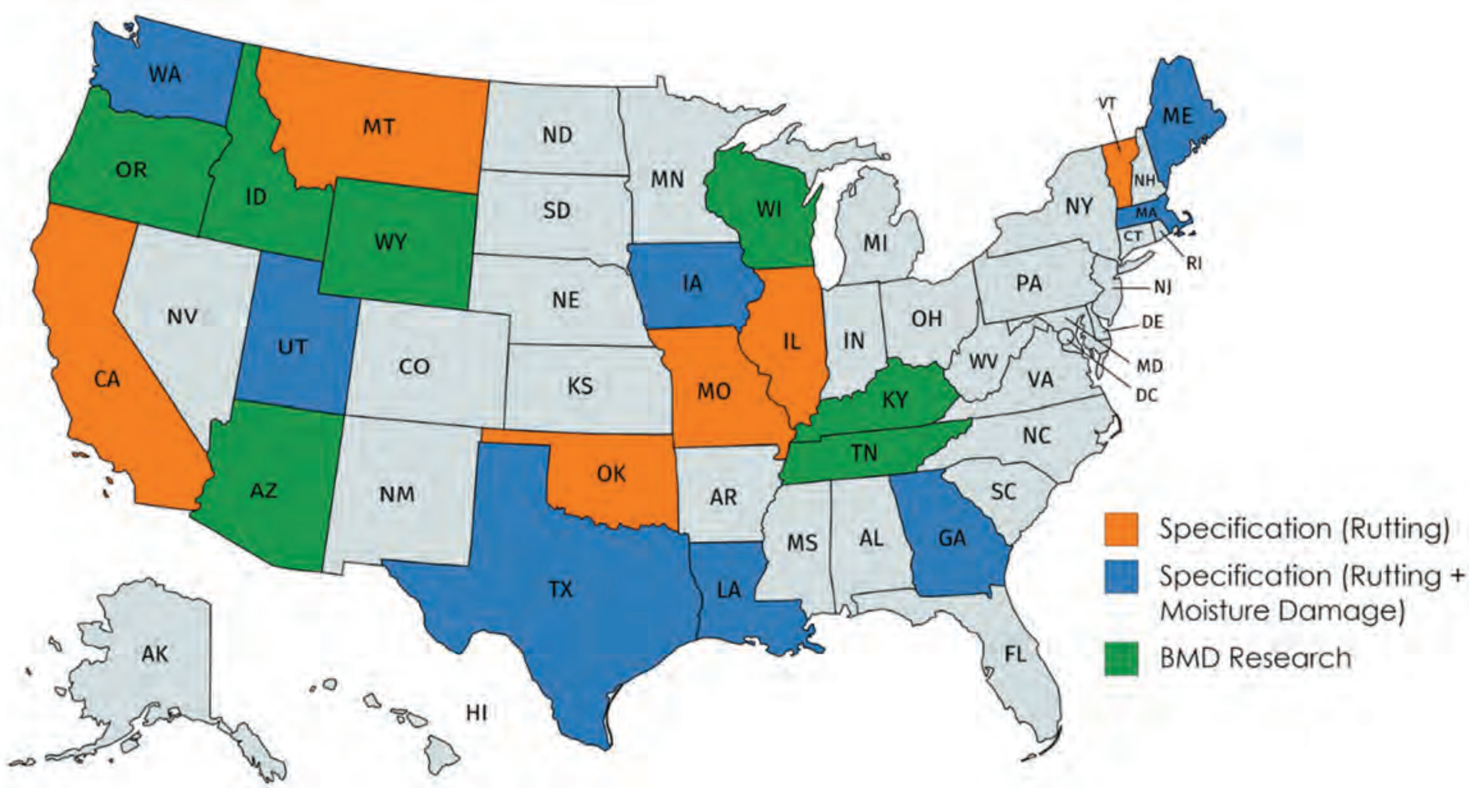
Using the Hamburg Wheel Track Test for Balanced Mix Design

The Hamburg Wheel Tracking Test (HWTT) per AASHTO T 324 is widely used by asphalt researchers and pavement engineers to evaluate the rutting resistance and moisture susceptibility of asphalt mixtures. According to a recent NCAT survey of state highway agencies and the asphalt pavement industry, 14 states currently require the HWTT in their provisional or standard specifications for asphalt mix design. Among these states, six use the HWTT as a pure rutting test while the rest use it as a combined rutting and moisture damage test. Additionally, there are seven states that have selected the HWTT as a performance test for balanced mix design (BMD) and are currently conducting research to benchmark existing mix designs or develop preliminary performance criteria for BMD pilot or shadow projects.

A typical HWTT rut depth curve consists of a post-compaction phase, a creep phase, and sometimes a stripping phase. Traditional HWTT parameters include total rut depth (TRD) at a certain number of wheel passes, creep slope (CS), stripping slope (SS), and stripping inflection point (SIP). There is a consensus among the existing literature that TRD and CS are often used to evaluate the rutting resistance of asphalt mixtures, while SS and SIP are mainly used for the assessment of moisture susceptibility.

Over the years, asphalt researchers have proposed alternative HWTT parameters to improve characterization of the rutting and moisture resistance of asphalt mixtures. These alternative parameters include the corrected rut depth (CRD), rutting resistance index (RRI), and stripping number (SN). CRD represents the projected HWTT rut depth caused only by permanent deformation of the mixture, which is isolated from the rut depth due to the stripping of asphalt binder from the aggregates. RRI is calculated based on the rut depth and number of wheel passes at completion of the test, which allows the direct comparison of HWTT results with different test termination points. A normalized RRI (NRRI) can also be used to account for different criteria dependent on binder grade. SN, developed as an alternative moisture susceptibility parameter to SIP, is defined as the inflection point of the HWTT curve fitted with a three-parameter deformation model. It represents the maximum number of wheel passes that the mixture can resist in the HWTT before stripping occurs.



Use of Hamburg Wheel Track Test by State Highway Agencies in the U.S.

Although most of the traditional and alternative parameters can identify asphalt mixtures that are extremely susceptible to rutting and/or moisture-related distresses, little information is available as to how they correlate to actual pavement field performance. In recognition of this limitation, researchers at NCAT and the Texas A&M Transportation Institute (TTI) collaborated on a study where they compiled a HWTT database with test results of over 70 plant-produced mixtures. These mixtures were collected from 17 field projects evaluated in several NCHRP projects, an LTPP test section, and test sections on the NCAT Test Track. HWTT testing was conducted at NCAT and TTI laboratories over the last 10 years. The database was then analyzed to determine the correlation of various HWTT parameters to field performance data and estimate the within-laboratory repeatability of HWTT rut depth measurements.

Details about the development of alternative HWTT parameters can be found in the following issues of *Transportation Research Record: Journal of the Transportation Research Board*.

Yin, F., E. Arambula, R. Lytton, A. E. Martin, and L. G. Cucalon. Novel Method for Moisture Susceptibility and Rutting Evaluation Using Hamburg Wheel Tracking Test. No. 2446, 2014, pp. 1-7.

Wen, H. F., S. H. Wu, L. N. Mohammad, W. G. Zhang, S. H. Shen, and A. Faheem. Long-Term Field Rutting and Moisture Susceptibility Performance of Warm Mix Asphalt Pavement. No. 2575, 2016, pp. 103-112.

Yin, F., C. Chen, R. West, A. E. Martin, and E. Arambula-Mercado. Determining the Relationship Among Hamburg Wheel-Tracking Test Parameters and Correlation to Field Performance of Asphalt Pavements. No. 2674(4), 2020, pp. 281-291.

The correlation evaluation of HWTT rutting parameters was conducted using 17 mixtures from the NCAT Test Track. The analysis results indicated that the RRI and CS parameters showed the best correlation to pavement rut depth measured after 10 million ESALs of heavy truck traffic ($R^2 = 0.924$ and 0.881, respectively), followed by CRD ($R^2 = 0.586$) and then TRD at 20,000 passes ($R^2 = 0.283$). The field correlation of HWTT moisture susceptibility parameters was evaluated based on a receiver operating characteristic (ROC) analysis, using all mixtures in the database. The ROC analysis, simply described, assesses the degree of correspondence between the HWTT results and field performance that is qualitatively categorized as either 'with moisture distress' or 'without moisture distress'. The ROC analysis identified 9,000 and 2,000 passes as the best criterion for SIP and SN, respectively. However, these criteria should be used with caution because they were developed with a limited number of mixtures with signs of moisture damage in the field and thus, warrant further verification with additional laboratory and field data. Finally, the within-laboratory repeatability of HWTT rut depth measurements was determined largely in accordance with ASTM C670. The maximum allowable differences in rut depth measurements between two HWTT replicates (e.g., results of the left wheel versus right wheel from the same run, or results of the same wheel from two separate runs) were calculated to be 2.3, 3.9, 4.6, and 4.7 mm for TRD at 5,000, 10,000, 15,000, and 20,000 wheel passes, respectively. Therefore, it is recommended that the two sets of HWTT replicate results with a difference greater than these allowable differences should not be accepted.

In addition to these research findings of the NCAT/TTI study, another recommendation for consideration by states interested in adopting HWTT for BMD is to use a standardized data analysis program (or software) for mix design approval and/or production acceptance. To ensure consistency between the contractor and agency results, specific instructions should be provided regarding the number and locations of deformation readings (along the track length) used for data analysis and the calculation of selected test parameters, among others. A good example for reference is provided by the Iowa Department of Transportation in Matls IM 319 at iowadot.gov/erl/current/IM/content/319.htm.

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Compounding Mixture Durability by Making Incremental Specification Improvements

When Dave Brailsford became the performance director of the British Olympic cycling team in 2003, it had been almost a century since the team had won its only Olympic gold medal. The team's performance was so underwhelming that one manufacturer was reluctant to sell them bikes due to their negative impression. Instead of making a major disruptive change, Brailsford and his coaches committed to a strategy that he referred to as "the aggregation of marginal gains" to compound incremental improvements in every aspect of cycling. In just five years, the British cycling team dominated their events at the 2008 Olympic Games, winning eight gold medals while the second-place French team won only two. The British team continued to outperform other Olympic teams, winning eight gold medals in 2012 and six in 2016.

Following a similar approach, the Georgia Department of Transportation (GDOT) has made incremental changes to their standard construction specifications over the years to improve the durability of asphalt mixtures containing RAP. Based on an in-house study, GDOT developed the corrected optimum asphalt content (COAC) approach for asphalt mix designs incorporating recycled materials with implementation of the 75:25 COAC in 2012. With this approach, 75% of the RAP binder was credited to the total asphalt binder in the mix, so additional virgin asphalt binder in the amount of 25% of the RAP binder was added to the volumetric optimum binder content determined at 4.0% design air voids per AASHTO R 35-09 Section 10.5. Based on the positive effect of this change, GDOT further enhanced the durability of asphalt mixtures in the state by implementing the 60:40 COAC in 2019, thus increasing the amount of virgin asphalt binder added to the optimum binder content from 25% to 40% of the RAP binder.

Like several other states, GDOT has been waiting for recommendations drawn from the Cracking Group experiment at the NCAT Test Track to select a cracking test for implementation. As the indirect tension asphalt cracking test (IDEAL-CT, ASTM D8225-19) shows positive correlations with the cracking performance of the surface mixtures after five years of heavy truck traffic, GDOT sponsored a study at NCAT with the goal of implementing this test for a balanced mix design approach to further improve the durability and cracking performance of asphalt mixtures in Georgia. The study includes three main tasks: (1) determine the effect of COAC ratios on the cracking and rutting performance of asphalt mixtures; (2) benchmark the cracking tolerance index (CT_{index}) of plant mixes being produced in Georgia; and (3) compare the CT_{index} between laboratory-produced and plant-produced 60:40 COAC mixtures. Results will help determine preliminary CT_{index} thresholds for future implementation in GDOT specifications for asphalt mix design approval and acceptance testing. Laboratory testing for the first two tasks has been completed, with preliminary results as follows.

Effect of COAC Ratios on Cracking and Rutting Resistance of Asphalt Mixtures

Figures 1 and 2 show the effect of COAC ratios on the cracking and rutting resistance of a 9.5 mm and a 12.5 mm NMAS Superpave mixture, respectively, using the IDEAL-CT and Hamburg wheel tracking test. For each NMAS, a virgin mix and a 30% RAP mix, both designed with a PG 64-22 binder and approved by GDOT, were selected for this evaluation. The 30% RAP mix design was tested at three COAC ratios: 100:0, 75:25, and 60:40. The IDEAL-CT was conducted in accordance with ASTM D8225-19 on lab-mixed, lab-compacted (LMLC) specimens that had been short-term oven aged (STA) for four hours at 135ºC and then critically aged for an additional eight hours at 135ºC prior to being compacted to the target 7±0.5% air voids. Hamburg testing was conducted at 50ºC in compliance with AASHTO T 324-19 on LMLC specimens short-term oven aged and compacted to the target 7±0.5% air voids.

The changes to COAC that GDOT made to their standard construction specifications over the years have made a positive impact on CT_{index} and cracking resistance, while having a minor impact on the rutting resistance for both 9.5 mm and 12.5 mm Superpave mixtures. In fact, the CT_{index} values for the 9.5 mm mixtures with 75:25 and 60:40 COAC ratios are much higher than that of the 9.5 mm virgin mixture. The

CT_{index} values for the 12.5 mm mixtures with 75:25 and 60:40 COAC ratios are also similar and slightly higher than that of the 12.5 mm virgin mixture.

CT_{index} of Plant Mixes Being Produced in Georgia

The IDEAL-CT was also conducted on plant-produced asphalt mixtures sampled by GDOT for all mix types across the state during the 2019 and 2020 construction seasons. These mixtures were brought to the NCAT laboratory where they were reheated and reduced to the sample size for preparing test specimens. Two types of plant-mixed, lab-compacted (PMLC) specimens were prepared at the target 7±0.5% air voids: one using reheated plant mix and the other using reheated plant mix plus an additional eight hours of critical oven aging at 135ºC.

Figure 3 shows cumulative distributions of CT_{index} results for the reheated plant mix specimens. There are significant differences in CT_{index} results between SMA, surface mixes (i.e., 4.75, 9.5 and 12.5 mm NMAS) and intermediate/base layer mixes (i.e., 19.0 and 25.0 mm NMAS). The differences are likely attributed to the differences in the optimum binder content, VMA and RAP content.

The difference in CT_{index} within a mix type is also significant. As an example, the lowest average CT_{index} of multiple replicates for SMA is 75 while the highest average is 224, which is approximately three times higher than the lowest average. This suggests that the volumetric requirements in the current specifications for mix design approval and acceptance testing are not sufficient to ensure that the mixtures within a mix type are produced with similar resistance to cracking.

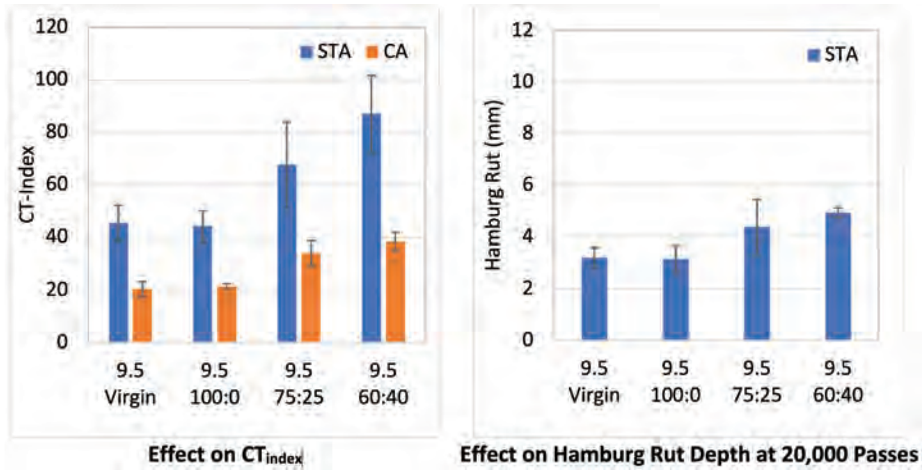

Figure 1. Effect of COAC Ratios on Cracking and Rutting Resistance of a 9.5 mm Superpave Mix

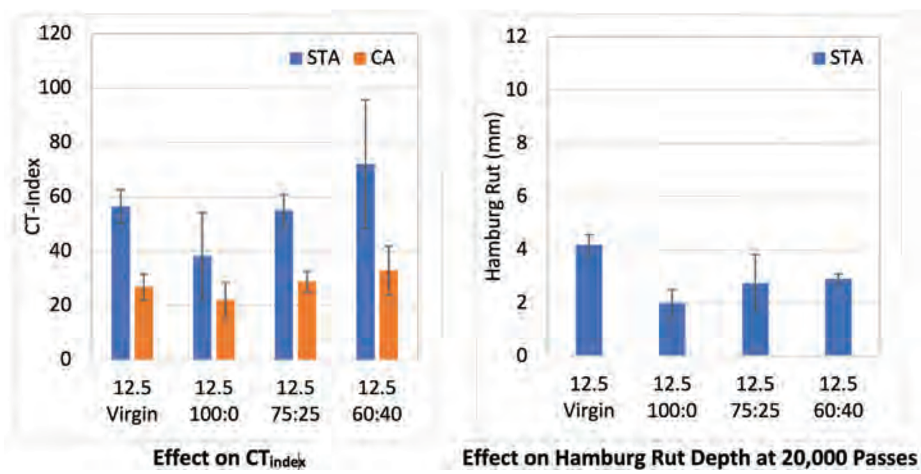

Figure 2. Effect of COAC Ratios on Cracking and Rutting Resistance of a 12.5 mm Superpave Mix

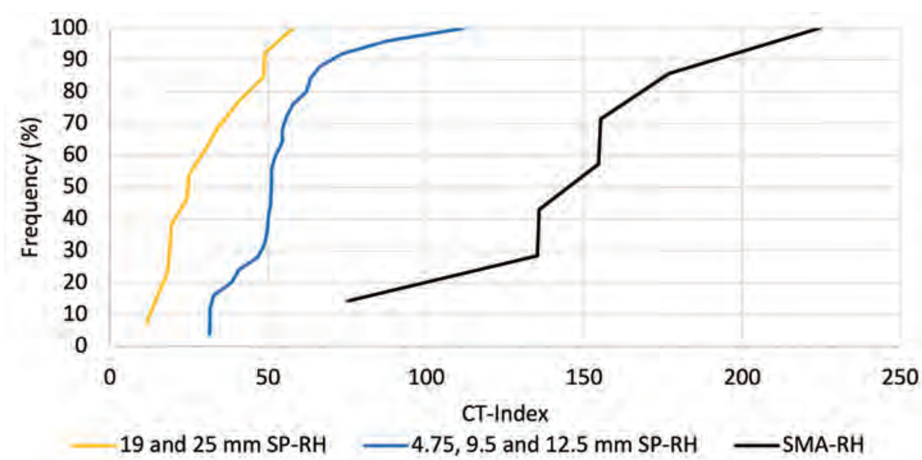

Figure 3. CT_{index} of Reheated Plant Mix Specimens

While the effect of critical aging is different from one mix to another, the CT_{index} of a critically aged plant mixture is approximately 45% lower than that of the reheated plant mix, as shown in Figure 4.

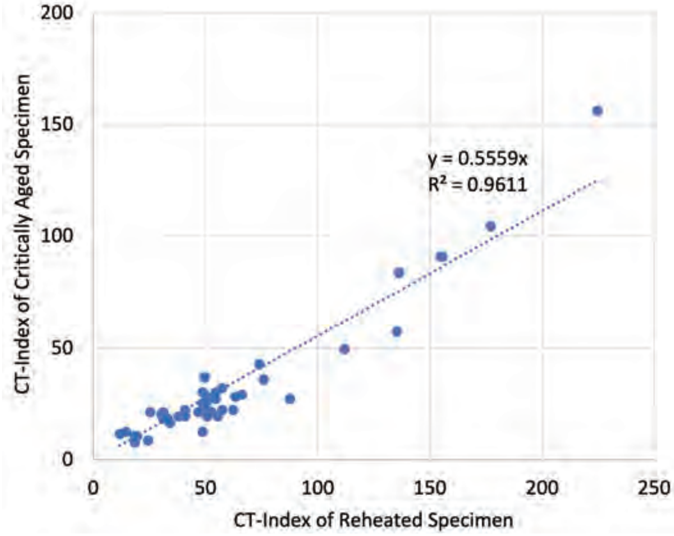

Figure 4. Effect of Critical Aging on CT_{index} of Reheated Plant Mix Specimens

Summary

With the implementation of the COAC approach for asphalt mix design, GDOT has seen improvement in the durability of asphalt mixtures produced with RAP. The results of this study suggest that RAP mixtures produced with the 60:40 COAC implemented in 2019 can have an equivalent or better CT_{index} than corresponding virgin mixtures while maintaining satisfactory rutting resistance. However, the difference in CT_{index} is still significant within each mix type designed and accepted based on the current specifications, potentially increasing GDOT's risk of accepting asphalt mixtures with undesirable cracking resistance. Therefore, future adoption of an implementable cracking test for a balanced mix design approach in conjunction with the COAC approach can help ensure that asphalt mixtures produced with RAP in Georgia will have more consistent durability and cracking resistance, leading to more balanced performance in the field.

For more information, contact Nam Tran at nht0002@auburn.edu

Women of Asphalt Mentorship Program

WOMEN OF ASPHALT
LEAD & INSPIRE

Women of Asphalt (WofA) is a national organization supporting women who work in the asphalt industry through mentorship, education, and advocacy. Formed in 2018, WofA seeks to encourage workforce diversity not only by supporting women currently in the industry but also by inspiring other women to pursue careers in it. WofA hosts events at World of Asphalt each spring and also produces a podcast, Women of Asphalt: Where We Belong. Membership in WofA is free; sign up at womenofasphalt.org.

A primary goal of WofA is to provide networking and mentoring opportunities for its members. Mentoring is particularly valuable for women working in a male-dominated field. Being able to identify with a role model and interact with her in a positive way helps increase confidence for mentees. Mentors also provide wisdom, perspective, and encouragement. A good mentoring relationship can foster success by enhancing professional networks, facilitating knowledge transfer, developing leadership and professional skills, and promoting personal development.

Register to become a mentor and/or mentee in the new WofA Mentorship Program at womenofasphalt.org/networking-and-mentoring. Mentors and mentees will then be matched, and WofA will provide resources for all participants, including a mentorship guidebook and an online training webinar. New mentoring relationships will begin in January 2021, with mentors/mentees meeting virtually or in person on a monthly basis through the end of the year. Participants may also choose to engage through other WofA events and training.

Tracking of Tack Coats

The most notable aspects of a recently completed paving project should be a smooth ride and a great appearance, not a trail of tracked tack material leading all the way back to the asphalt plant. In addition to making surrounding projects look terrible, tracked tack can create a potential safety problem if the material builds up at an intersection and reduces pavement friction. Most importantly, tracking removes tack material from the pavement, jeopardizing the bond between asphalt layers. Proper bonding is critical to the life of a pavement; one study showed that interface bond strength between pavement layers could be reduced by up to 70% if only 50% of the surface was tacked or if there was a loss of tack material caused by tracking. Understanding the specific cause(s) of tracking on a project is key to preventing this issue. In general, three types of tracking commonly occur on paving projects: unbroken and/or uncured asphalt emulsion, softness of residual asphalt binder, and dirt on the underlying surface.

Tracking of Unbroken/Uncured Asphalt Emulsion

The most common cause of tracking is construction vehicles driving over an unbroken and/or uncured asphalt emulsion. An asphalt emulsion is a combination of microscopic-sized asphalt binder, water and an emulsifying agent, which allows the material to remain liquid and be applied at relatively lower temperatures (70 - 160°F). After applying the emulsion to the pavement surface, a chemical change occurs in the emulsifying agent causing the asphalt and water to physically separate into two distinct phases. At this point, the emulsion begins to "set" or "break," which means the microscopic-sized asphalt particles begin to flocculate into small clumps and then coalesce together. As this happens, the emulsion color changes from brown to black.

When all of the water has evaporated, the emulsion is considered to be "cured" and ready for paving. Curing is essential, as this is the point when the mechanical properties of the asphalt binder essentially reform. Once the emulsion has fully cured, the residual asphalt will then properly bond to the layer below it and the next layer can be paved. Although emulsions are very popular and widely used, the time it takes for them to properly break and cure is a drawback, delaying paving operations and creating the potential for tracking if the emulsion is paved over before it has properly broken and cured. Emulsions require more time to break and cure when air and pavement temperatures are cooler and humidity levels are higher (such as night paving).

Several options are available to mitigate this type of tracking: 1) allow adequate time for the material to properly break and cure prior to driving over it or paving; 2) use a hot-applied product, either straight asphalt binder or a hot-applied trackless product; 3) use a "trackless" tack product that has shorter break and set times; 4) ensure that the application rate is correct and the emulsion is not diluted; or 5) use a spray paver.

Residual Asphalt Binder Too Soft

Another common type of tracking occurs after the asphalt emulsion has fully broken and cured, yet the residual asphalt binder still sticks to the tires of

Example of tack tracking

construction vehicles that drive over it. This is likely due to the residual asphalt of the emulsion being too soft for the temperatures at the paving site. In general, stiffer binders are less likely to track in hot weather than softer binders. High air and pavement temperatures are the most important factors affecting this type of tracking behavior. Tracking of this nature can also occur when straight asphalt binders are used for tack coats. For example, if a PG 52-22 binder was used for tack on a daytime project in the middle of summer in south Texas, it would likely be too soft and track during construction.

The most common methods used to resolve this type of tracking include: 1) use a reduced-tracking emulsion which has a harder residual binder; 2) use a hot-applied product, either straight asphalt binder or a hot-applied trackless product (making sure that the high temperature PG grade is adequate for the environment); or 3) use a spray paver.

Underlying Surface is Dirty or Dusty

Another cause of tracking is an underlying surface that is dirty or dusty. In these situations, the tack coat material sticks to the dust/dirt, not to the underlying pavement surface. Any vehicular traffic that drives on the pavement will then pick up the tack material simply because it isn't properly bonded to the underlying surface.

Properly cleaning the pavement surface prior to applying tack will minimize this type of tracking. Cleaning can be accomplished by mechanical brooming, flushing the surface with water, blowing off debris using high-pressure air, or a combination of these. Allowing traffic on the underlying surface (if feasible) is another method of assuring that the surface is adequately cleaned.

Tracking of tack coat materials must continually be addressed, as it can be a major problem in terms of performance, safety and aesthetics. Properly identifying the cause of tracking is key to finding potential solutions.

For more information, contact Jim Musselman at jim.musselman@auburn.edu

CAPRI will be a new way to identify and prioritize asphalt pavement research needs, exchange technical information, develop guidance on current issues, and develop strategies for implementing technologies to improve asphalt pavements.

Round Robin Study Assists With Balanced Mix Design Implementation

In 2018, NCAT initiated a round robin study for several mixture performance tests being considered for balanced mix design (BMD) implementation. A study overview was detailed in the fall 2019 NCAT newsletter. The study included the Hamburg Wheel Tracking Test (AASHTO T 324-19), the Illinois Flexibility Index Test or I-FIT (AASHTO TP 124-20), the Asphalt Pavement Analyzer or APA (AASHTO T 340-10), and the IDEAL Cracking Test or IDEAL-CT (ASTM 8225-19).

In Phase I, participating labs received a sufficient amount of plant-produced mix to fabricate specimens for their respective tests. The 9.5 mm NMAS mix with PG 64-22 binder and intermediate RAP content was designed using a BMD process. Each lab received detailed, test-specific instructions for specimen fabrication and testing along with a data file for reporting results. In Phase II (cracking tests only), prepared specimens of the same mixture from Phase I were shipped to each participating lab along with instructions for testing. These Phase II specimens were all fabricated by the same NCAT technician using best practices. A flow chart summarizing the testing plan is shown in figure 1.

As of fall 2020, all tests for both phases of the study have been completed. Upon completion of each test and phase, a blind data summary report was sent to the participating labs. These reports did not include any laboratory names, but instead assigned each laboratory a number and revealed that number only to the participating lab submitting the data.

The data collected from the round robin are also being used for test variability analysis. ASTM E 691-19 Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method provides a method for calculating both within-lab and between-lab coefficients of variation (COV). Some preliminary variability analysis was provided in the fall 2019 newsletter – however, this analysis has been updated using the more appropriate method from ASTM E 691-19. It should be noted that ASTM E 691-19 recommends between three and six materials (mixes in this case) be used to develop precision statements. This study included only one mix. However, the data can still be used to provide preliminary estimates of test variability.

A summary of the preliminary ASTM E 691 within-lab and between-lab COV estimates for the NCAT Round Robin are shown in Table 1. Key observations from this data include the following:

- Hamburg variability was assessed for rut depths at 20,000 wheel passes. Twenty-nine labs were included in the ASTM E 691 COV calculations. Three labs were removed as outliers for various issues. The Hamburg rut depths had a within-lab COV of less than 10 percent; between-lab COV was 25.9%, respectively. Except for one of the excluded labs, stripping was not observed. A mixture that exhibits stripping would likely have greater variability or necessitate an alternate method of analysis.
- The APA had a within-lab COV of 18.3% and a between-lab COV of 29.6% for automated rut depth measurements. These COV values are higher than what was obtained for the Hamburg, albeit with much fewer labs (29 for Hamburg vs. 9 for APA).
- For the IDEAL-CT CT_{Index}, the within-lab COV was similar for Phase I and Phase II at just below 20%. The within-lab variability was consistent with NCAT's experience with the IDEAL-CT. However, the between-lab COV for CT_{Index} dropped from 35.3% to 20.2% from Phase I to Phase II. This highlights the importance of consistent sample fabrication on CT_{Index} results.

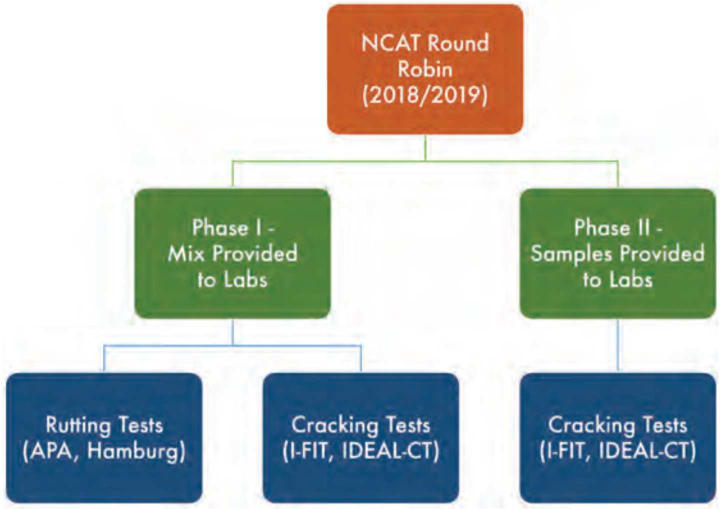

Figure 1: NCAT Round Robin Study Scope

Table 1: ASTM E691-19 Variability Estimates – NCAT Round Robin (Single Mixture)

Test ID	Phase	Participating Labs	Test Parameter	Average Result	Within-Lab CV (%)	Between-Lab CV (%)
Hamburg	I	29	Rut Depth – 20,000 passes (mm)	3.53	9.4	25.9
APA	I	9	Auto. Rut Depth (mm)	2.9	18.3	29.6
IDEAL-CT	I	15	CTIndex	111.1	19.5	35.3
IDEAL-CT	II	14	CTIndex	103.7	18.8	20.2
I-FIT	I	19	Flexibility Index (FI)	3.95	30.3	47.6
I-FIT	II	12	Flexibility Index (FI)	3.53	46.9	53.4

- Variability for the I-FIT Flexibility Index (FI) was significantly higher than expected for both Phase I and Phase II of the study. AASHTO TP 124-20 recently added precision estimates based on I-FIT data from three separate round robin studies. These precision estimates have a within-lab COV of 27.1% (consistent with NCAT experience with the I-FIT) and a between-lab COV of 34.1% for FI. Variability estimates from the NCAT Round Robin were above these precision estimates, as shown in Table 1. For the single mixture used in the NCAT Round Robin, several labs reported replicates in the expected range (FI between 2 and 6) as well as multiple replicates with an FI below 1. This caused several labs to report very high COV values for both phases, which drove the high variability. The root cause is unknown but is believed to be a mix-specific issue.

A draft NCAT report summarizing the key findings from the study is currently being prepared. NCAT is also planning to conduct additional round robin studies to assist agencies and contractors with BMD implementation efforts. The future studies may include some of the rapid QC rutting tests that are gaining interest, such as the high temperature indirect tension test (HT-IDT). NCAT is also currently discussing providing the IDEAL-CT data to ASTM to assist in the development of a precision statement for the ASTM D 8225 IDEAL-CT standard.

For more information, contact Adam Taylor at tayloa3@auburn.edu

Identifying Potential Bias Between IDEAL-CT Machines

Left to Right: Troxler / TestQuip, Humboldt, and Instrotek machines

Many contractors are beginning to conduct their own performance testing to benchmark their mixes and determine how to adjust them. In states that are moving toward balanced mix design, performance test results will be part of mix design submissions for approval to their particular agency.

Inevitably, differences in testing results will occur from one lab to another. This happens for a variety of reasons, but the most common have to do with differences in sampling, testing, or the materials. Proper training, sampling best practices, and systematically following a procedure can dramatically reduce or limit variability in testing results. Following proper and consistent specimen preparation practices is the best way to reduce testing variability. One source of variability between-labs is differences in the testing devices. The magnitude of these effects is often unknown because they are very difficult to isolate. An ongoing study at NCAT is investigating differences in IDEAL-CT test equipment and how to establish an estimate of machine-to-machine bias using six common test machines/devices and seven different mixtures.

Mix designers often go to great lengths to minimize sources of variability and bias, so machine to machine bias should be treated the same way. The significance of bias between machines will depend on the situation. If a mix is designed and/or produced on the fringes of the agency's specification, there is greater risk of having a mix rejected or subject to additional time-consuming testing. Knowing that mix rejection could hinge on differences between test devices would allow the contractor to make a necessary adjustment.

Researchers at NCAT are evaluating differences between test machines on the IDEAL-CT results by carefully preparing specimens to minimize sampling and materials variability. Each specimen is prepared the same way from splitting, heating, compacting, bulking, conditioning, and testing to minimize variability. Preliminary analysis shows that over half of the machine-to-machine comparisons yielded differences of 10-30% of the average CT_{index} for a particular mix. The average difference between two machines was 6 CT_{index} units (and ranged from 0 to 21 units).

A difference of 6 units may seem insignificant but consider this example. A state implementing BMD sets a CT_{index} minimum threshold of 50. A contractor prepares a mix design with a CT_{index} of 55 (tested in their own lab) and submits the mix to the state for testing. Based on the distribution of possible differences between machines from the NCAT study, the contractor would have a 50% chance of having their mix fail to meet the acceptance criteria by dropping 6 CT_{index} units to a 49, even if the contractor made the specimens themselves.

Contractors could make specimens from a few mixes in their own labs and have them tested at the agency's lab to help establish if a bias exists between the two machines. Taking care to prepare specimens as consistently as possible to reduce variability between specimens and randomly splitting the specimens into two groups such that the average air void contents are equal will help isolate differences caused by machines. Ultimately, the process of establishing bias is very important and must be done well to avoid overestimating bias. An upcoming NCAT report will include a case study of this procedure and examples of data analysis. A framework for the determination of bias will be discussed further in that report.

For more information, contact Nathan Moore at ndm0005@auburn.edu

Specification Corner

Alabama DOT
Alabama has a possible cold central plant recycling specification in the works, we are updating our milling specification, and we are updating tack and joint sealant specifications to match the latest research.

One balanced mix design trial project is complete and another has been scheduled.

Colorado DOT
Colorado DOT is looking at developing a pilot project specification for alternative binders on cold in-place recycling projects.

Delaware DOT
Delaware DOT is currently looking into creating a trackless tack specification.

Florida DOT
Florida DOT has one substantial change for the January 2021 asphalt specifications regarding the amount of allowable RAP in a mixture. The change came after the University of Florida completed a funded research project for FDOT. The amount of RAP will now be based on its gradation (% passing the No. 16 sieve and high temperature recovered binder grade). These changes apply to all mixtures that contain a PG 76-22 PMA binder and are placed below the surface layer. Criteria are established for coarse RAP, intermediate RAP and fine RAP. The coarser the RAP and the lower its PG grade, the more of it can be used.

Michigan DOT
We are reducing the number of Superpave mixes to align with AASHTO guidelines and national best practices with implementation corresponding with new standard specifications that will be implemented starting with the August 2021 letting.

Montana DOT
We have implemented a longitudinal joint compaction specification on most paving projects of 91% minimum in most situations and 90% minimum on thin lifts. A 1.05 pay factor is applied to lots with 92% to 95% compaction using $4.50/foot of joint as a unit cost. The special provision can be downloaded at mdt.mt.gov/other/webdata/external/const/specifications/special-provisions/401-02-LONGITUDINAL-JOINT.docx.

We have also added an option to accept mix on a tiered scale in certain situations when it performs poorly in the Hamburg, found in Section 400 of our standards at mdt.mt.gov/business/contracting/standard_specs.shtml.

Oklahoma DOT
Oklahoma DOT is currently moving from PI to IRI, implementing balanced mix design and limiting the use of REOB, PPA and establishing Delta Tc limits.

Utah DOT
We continue to have good success with our Delta Tc binder specification as it has replaced our direct tension specification.

Vermont AOT
We have instituted a requirement to have Hamburg and I-FIT results be submitted for mix designs on mainline paving operations. These results are for informational purposes only, but project-specific pass/fail criteria has been piloted on three agency projects. We have begun looking at the IDEAL suite of rutting/cracking tests as "surrogate" tests during QA production.

We have dropped the minimum 0.5% dosage rate requirement for anti-stripping additives in mix designs containing granite and/or quartzite aggregates. Instead, we will start requiring ASTM D 3625 (boil test) results to be submitted with each mix design, with weekly testing conducted during production of each approved mix design to verify that no change in stripping potential has occurred.

We are planning on switching to AASHTO M 332 MSCR grading for our PG binders in the near future. A firm switchover date has not yet been established due to COVID-19 and other internal challenges.

We have been hard at work developing a new tiered approach to our HMA specifications, which would see almost all mixture acceptance testing fall under QA testing protocols and allow for sampling of mixtures using other methods allowed under AASHTO R 97. We expect to have these revisions finalized for the next edition of our Standard Specifications for Construction to be tentatively published for the 2023 construction season.

West Virginia DOT
West Virginia tentatively plans to eliminate Marshall mix design and introduce balanced mix design.

Asphalt Forum

NCAT invites your comments and questions, which may be submitted to Christine Hall at christine@auburn.edu. Questions and responses are published with editing for consistency and space limitations.

Colorado DOT is interested in the balanced mix design concept and plans on collecting IDEAL-CT data on current HMA production samples.
-Michael Stanford, Colorado DOT

How is density handled for portions of intersecting side streets that may be part of the scope of work for the mainline project? Are they included in density testing or are they exempted?
-Greg Sholar, Florida DOT

Asphalt Forum Responses

The following responses have been received to questions shared in the previous issue.

Do you use the spray paver with a 4.75 dense-graded mix? Do you have concerns with the water in the emulsion being trapped between the two lifts? Do you use the spray paver with larger NMAS mixes?
-Jerry Geib, John Garrity; Minnesota DOT

Zane Hartzog, Alabama DOT
No, we don't use mixes that small. We use a spray paver to apply some tack coats, such as UltraFuse.

Michael Stanford, Colorado DOT
Spray pavers are not used on Colorado DOT projects.

Shane Biddle, Delaware DOT
No.

Greg Sholar, Florida DOT
Florida DOT does not use spray pavers.

Kevin Kennedy, Michigan DOT
We do not use a spray paver with dense graded mixtures, but we are discussing pilot projects. We do have nova-chip projects.

Dan Oesch, Missouri DOT
We have had occasional issues with blistering when utilizing a spray paver with 4.75 mm dense graded mixtures.

Eric Biehl, Ohio DOT
We don't see spray pavers used in Ohio.

Kevin Suitor, Oklahoma DOT
Oklahoma DOT uses a spray paver almost exclusively in several divisions. Divisions have limited use of 4.75mm mixes. However, we do see use of larger NMAS mixes. There has been no mention of issues of water between the lifts.

Matthew Chandler, Tennessee DOT
We do not use spray pavers.

Howard Anderson, Utah DOT
We are starting to use and see spray pavers more. We have no concerns with the emulsion being between the two lifts as we mostly use spray payers for bonded wearing courses (BWC), which have a thin top lift. We are looking at using spray pavers for larger NMAS mixes, but have no experience to help you yet.

Aaron Schwartz, Vermont AOT
Vermont doesn't currently allow spray pavers other than for our ultra-thin bonded wearing course (UTBWC) mixtures.

Shawn Jack, West Virginia DOT
West Virginia has not used spray pavers.

I am curious to know how other states have been affected by the changes to AASHTO T 324 Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures. Research conducted for the purpose of better standardizing equipment requirements resulted in changes to the method that caused one widely used manufacturer's legacy equipment to be out of compliance. However, there is a long history of performance using that particular device. The changes to T 324 allow an agency to deviate from certain requirements and I'm curious if any have done so. We are trying to develop a comparative database to show that the legacy machine is still accurate, but are currently using another manufacturer for contract quality assurance (QA) and payment.
-Oak Metcalfe, Montana DOT

Michael Stanford, Colorado DOT
Colorado DOT uses a newer Hamburg that meets the T 324. We have not seen a significant difference in test data from the original Hamburg Wheel Tracker versus the newer equipment.

Shane Biddle, Delaware DOT
At this time, Delaware DOT does not run T 324.

Greg Sholar, Florida DOT
Florida DOT retrofitted our Hamburg, which is used only for research purposes. We have not developed a comparison database between old and new, as we just had the machine retrofitted.

Kevin Kennedy, Michigan DOT
Michigan does not use the Hamburg as part of our mix design process.

Dan Oesch, Missouri DOT
Luckily our equipment was new enough that it meets the new requirement.

Eric Biehl, Ohio DOT
Ohio currently uses the asphalt pavement analyzer (APA).

Kevin Suitor, Oklahoma DOT
Oklahoma DOT has a long history of using the legacy equipment. We are reluctant to automatically update our machines and hold the contractors to new performance measures. We are developing a small database comparing the old equipment with the new and are seeing a small difference. We will be addressing these issues with the industry over the next few months.

Cliff Selkinghaus, South Carolina DOT
We have one of those machines and the manufacturer does not support/offer a package to upgrade the unit for this change in test compliance. We had a research project that utilized this machine and we in turn received it once completed, and later found it to not be compliant to the most recent T 324.

Howard Anderson, Utah DOT
Utah has continued to use our own Hamburg procedure along with AASHTO T 324. We continue to use the PMW equipment and have a new Cox machine. We get similar results with it and the PMW or Troxler machine.

Aaron Schwartz, Vermont AOT
Vermont doesn't deviate from the equipment requirements in AASHTO T 324 overall, but we do have other deviations (test temperature, definition of average rut depth, etc.) from the procedure that are covered in Section 406 of our Standard Specifications for Construction and our Bituminous Concrete Mix Design Submittal Policy.

Shawn Jack, West Virginia DOT
West Virginia has not yet implemented use of AASHTO 324, though we plan to implement it as is.

How many revisions do you allow on a job mix formula (JMF) before the mix needs to be redesigned?
-Tony Collins, North Carolina DOT

Zane Hartzog, Alabama DOT
We allow three revisions.

Michael Stanford, Colorado DOT
It varies depending on what is being revised.

Shane Biddle, Delaware DOT
We have no set limit.

Greg Sholar, Florida DOT
Florida DOT does not have a limit on the number of revisions. However, each revision must meet strict specification revision requirements and must then be proven with field test results.

Kevin Kennedy, Michigan DOT
We have no defined limit.

Dan Oesch, Missouri DOT
We have no set number.

Oak Metcalfe, Montana DOT
We don't control JMF other than the control sieves after mix verification. Our specification is based on the contractor choosing volumetric "targets" within the acceptable ranges for VMA, VFA, Voids, and D/A. We follow that up with a Hamburg test at least once per project with a maximum of 13mm of rut after 10,000 passes, tested at 14°C below the high PG temp. Density is 93% minimum. As long as those parameters are met, they can alter their JMF as they choose.

Eric Biehl, Ohio DOT
Ohio DOT doesn't allow a mix design to be revised. However, during production, there can be one adjustment to the gradation and/or a reduction of RAP within the first three days of production for a project. We allow binder additions of the same PG grade and modifier with a one AC point design to confirm the volumetrics and any performance tests are met (PG 64-22 and PG 58-28 don't require a one point design).

Kevin Suitor, Oklahoma DOT
Oklahoma DOT allows three changes to the JMF before the mix is terminated and the contractor has to redesign.

Cliff Selkinghaus, South Carolina DOT
Three revisions are allowed in South Carolina; however, we require a redesign if the request is too far away from the original design.

Matthew Chandler, Tennessee DOT
In Tennessee, the gradation of one screen size is generally allowed after the JMF is approved, though it is somewhat unofficial. We also accept binder grade change, switching between terminals/suppliers or change of the anti-strip agents on the basis of TSRs only. As we move to a more balanced mix design approach, I see the same options becoming less or going away.

Aaron Schwartz, Vermont AOT
Vermont doesn't specify a maximum cap on the number of allowed revisions so long as test results substantiating the revisions are provided with each request made by the producer. A new mix design will be required if the aim on four or more sieves is changed, if the aim on one sieve changes by more than 5% (0.5% on the #200 sieve) and/or if the binder content deviates by more than 0.2% from the original design binder content. All of this is described in our bituminous concrete mix design submittal policy.

Shawn Jack, West Virginia DOT
West Virginia has a mix verification process that allows yearly changes to maintain volumetric requirements. Specific testing (e.g. sand equivalency and fine aggregate angularity) related to aggregate blend changes must occur, but the mix does not need to be redesigned. Any revisions to binder grade require a new design.

What states require the use of liquid antistrip agents in all mixes and what are the required dosage rates?
-Kevin Suitor, Oklahoma DOT

Zane Hartzog, Alabama DOT
The TSR dictates the amount of antistrip to be added (minimum of 0.25%). Antistrip is required for OGFC.

Michael Stanford, Colorado DOT
Colorado DOT still requires lime (1%) in all HMA.

Shane Biddle, Delaware DOT
Delaware DOT does not require antistrip.

Greg Sholar, Florida DOT
Florida DOT's OGFC mix type containing granite aggregate requires hydrated lime. However, all other mix types require liquid antistrip (LAS) or lime, but no contractor uses lime where not mandated. Therefore, in the majority of our mixtures, LAS is required. Most are approved at a 0.5% dosage rate, but a few have been approved at a lower dosage rate. For LAS approval, FDOT tests eight mixture types, comprising two NMAS (9.5 and 12.5) and four aggregate types commonly used in Florida (two granites and two limestones). A minimum TSR of 0.8 and a minimum dry tensile strength of 100 psi for all eight mixtures must be obtained for a LAS to be included on our approved products list.

Kevin Kennedy, Michigan DOT
If a mix design passes the TSR test, no antistrip is required. If it fails, it is up to the designer to determine the amount needed to pass the test.

Dan Oesch, Missouri DOT
We have a TSR requirement but no requirement to use liquid antistrip.

Eric Biehl, Ohio DOT
Ohio DOT doesn't require all mixes to have antistrips. We have stipulations on what mixes may need them and only require it if the TSR fails.

Cliff Selkinghaus, South Carolina DOT
We permit antistrips in any mixes that require PG 64-22 in South Carolina. The dosage rate is 0.7%, terminally blended only.

Matthew Chandler, Tennessee DOT
Tennessee requires antistrip agents in all mixes. The minimum rate is 0.3% and the maximum is 0.5% by weight of binder.

Howard Anderson, Utah DOT
The state of Utah requires 1.0% hydrated lime by dry weight of the virgin aggregate in all of our HMA type materials using a pugmill/slurry method. We have done this for about 25-plus years and have eliminated our stripping problems.

Aaron Schwartz, Vermont AOT
We are in the process of eliminating our 0.5% minimum dosage requirement for liquid antistrip agents.

Shawn Jack, West Virginia DOT
West Virginia does not require the use of antistrip agents.

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