ASPHALT TECHNOLOGY NEWS

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NCAT COMPLETES HMA FIELD COMPACTABILITY STUDY

The National Center for Asphalt Technology (NCAT) has completed a hot mix asphalt (HMA) field compactability study sponsored by the Federal Highway Administration.

Meeting the specified density of HMA in the field is often cited as a difficult challenge for asphalt pavement construction. Since the introduction of Superpave designed mixtures this challenge has increased. Overall, Superpave mixes have been cited as more difficult to compact in the field than Marshall/Hveem mixes and greater compactive efforts have been needed to achieve similar density levels.

The importance of achieving a well-compacted asphalt pavement is crucial to avoiding numerous types of premature distresses including permanent deformation, moisture-induced damage and cracking. Numerous factors affect the asphalt contractor's ability to achieve the target density for HMA mixtures, such as weather, support of underlying layers, layer thickness, compaction equipment, experience of roller operators, and mixture characteristics.

Compactability of HMA mixtures is often used to describe how easy or difficult a mixture is to compact on a roadway. Several asphalt researchers have proposed laboratory-measured parameters of mixtures and/or their components as indicators of HMA compactability and/or resistance to permanent deformation. However, most of these measured mixture characteristics have not been validated with actual field performance.

The primary objective of this research was to evaluate a variety of mixture characteristics and determine if they are correlated to compactability in the field. A second objective was to explain

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Compactability of HMA mixes in the field was evaluated in this study.

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National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

NCAT Completes HMA Field Study

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why some mixtures are more compactable than others using basic mix parameters such as gradation, aggregate shapes, binder grade, and mix volumetric properties. This analysis included parameters obtained from quality control samples and specimens compacted to the field lift thickness. The underlying goal of this study was to identify a practical method to evaluate the compactability of an HMA mixture in the laboratory for use by mix designers and quality control technicians to help them achieve suitable levels of density in the field.

The first part of this study included a comparison between laboratory-measured characteristics of HMA, an evaluation of the effect of physical properties on the Superpave gyratory compactor (SGC) parameters, and an assessment of variability among observations. The mixture characteristics that were part of the evaluation included:

- Percentage of maximum theoretical specific gravity at N_{ini} (%G_{mm} @ N_{ini}). It has been used as an indicator of mix compactibility during construction.
- Compaction slope determined from compaction in the Superpave gyratory compactor (SGC).
- Number of gyrations required to achieve 92 percent of the maximum theoretical specific gravity (N@92%G_{mm}).
- Compaction energy index (CEI) determined from the SGC compaction process. The CEI, which is essentially the area under the compaction curve, was developed at the University of Wisconsin.
- Number of gyrations with the SGC to reach the locking point of the mixture. The locking point used in this study is defined as the first instance of two consecutive gyrations resulting in the same compacted sample height.
- Coarse aggregate (CA) and fine aggregate (FA) ratios as determined using the Bailey method. FA_c ratio (coarse portion of the fine aggregate) and FA_f (fine portion of the fine aggregate) were also considered. All of these ratios define the shape of the gradation curve and represent packing characteristics of the mix.
- Mix parameters such as gradation, aggregate shape, binder grade, and mix volumetric properties.

The data used for this part of the study came from the Superpave mixtures placed on the NCAT Test Track in the first two cycles (2000 and 2003). This data set is well suited for this analysis because of the wide variety of mixtures included in the cycles and the uniformity in construction operations at the track. This analysis included 35 different surface mixtures and seven binder mixtures placed on the track in 2000; and 17 surface mixtures and 22 binder mixtures placed in 2003. The data used to determine the laboratory-measured mix characteristics were obtained from quality control samples taken during track construction. Three gyratory samples were compacted for each section.

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Randy West, Director
Prithvi (Ken) Kandhal, Associate Director Emeritus/ Editor
Cheryl Cobb, Editor, College of Engineering

A SHORT COURSE IN ASPHALT TECHNOLOGY

This training course has been developed by NCAT for practicing engineers who are involved with hot mix asphalt (HMA). The purpose of this one-week intensive course, which will be held on Jan. 28-Feb. 1, 2008 and Feb. 25-29, 2008, is to provide a general understanding of all phases of HMA technology. Upon completion, the participant will be able to make knowledgeable decisions related to HMA pavements and communicate effectively with asphalt specialists when the need arises. NCAT will accept applications from practicing engineers from both private and public sectors in the United States and abroad. This includes personnel from the FHWA, state DOTs, FAA, Corps of Engineers, Air Force, Navy, county engineers, city engineers, consulting engineers, and contractors. Please call 334.844.6228 ext. 110 or visit our Web site at ncat.us (Click on "Education" at the top of the page, then click on "Upcoming Training Courses") for a brochure or information. On-line registration is now available.

Several mixture characteristics obtained during the Superpave gyratory compaction process were evaluated to see if they are related to HMA compactability in the field.

The second part of this study included the determination of a field compactability indicator based on the rolling operation. This indicator was termed accumulated compaction pressure (ACP) in this study. The ACP is a simple way to quantify the total applied compactive effort to the HMA mat by summing the force applied by each pass of each roller in the field compaction process. Compaction operations at the track were well documented and provide good information about the compactability of the mixtures in the field. These data were used to determine the total compaction energy applied by the rollers during construction. Regressions between the laboratory compaction parameters and the field compaction energy were analyzed. The laboratory compaction parameters, which yielded the best correlations, were analyzed further by performing multiple regression analysis with basic mixture properties.

The third part of this project included laboratory compaction of specimens using the SGC at the field lift thickness. The specimens were compacted to determine the number of gyrations required to reach 92 percent of G_{mm} (N@92%G_{mm}). The N@92%G_{mm} for the field lift thickness specimens were compared to the N@92%G_{mm} of normal height (115 ± 5 mm) specimens.

The fourth part of this study involved eleven mixtures placed on the test track in 2006 and twelve mixes placed in 2003. These mixes were used to evaluate the field compactability indicator by conducting nuclear density tests and surface temperature measurements after each roller pass. Surface temperatures were obtained with an infrared temperature gun. The goal was to obtain the field compaction energy required to reach 92 percent of G_{mm} and correlate that energy with the laboratory compaction parameters.

Several aggregate types were used on the track including limestone, granite, Florida limestone, gravel and slag. Reclaimed asphalt pavement (RAP) was also used in a few sections. Mix types included fine-graded, coarse-graded, intermediate-graded, and stone matrix asphalt (SMA). Nominal maximum aggregate sizes (NMAS) of the HMA mixtures were 9.5 mm, 12.5 mm and 19.0 mm. PG asphalt binders included PG 67, PG 70, and PG 76. Each section on the test track had the same structural pavement foundation and used the same rollers and operator within each cycle. Weather conditions were also similar at the time each section within each cycle was laid.

In order to obtain the target density, each section was rolled with different number of roller passes with a combination of rollers. Each roller type applies a specific compactive effort – vibratory force, static force and pneumatic tire kneading action. All of these were considered in calculating the ACP value.

The following conclusions were drawn from this study:

- Coarse-graded mixtures with low CA ratios require stronger fine aggregate structure (higher FA_C ratio) and higher asphalt content to meet the target volumetric properties. Mixtures with these characteristics tend to be difficult to compact in the laboratory.
- Overall, finer gradations and gradations with Primary Control Sieve Index (PCSI) values close to

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zero tended to increase mixture compactability in the laboratory. The PCSI is defined as the difference of percentage passing from the mixture's gradation to the primary control sieve. It represents the relative coarseness or fineness of the gradation. Fine-graded and intermediate-graded mixes tended to be easier to compact in the SGC. CEI, N@92%G_{mm}, Slope and Locking Point can be used to represent the applied energy to reach a density level in the SGC. PCSI and FA_C ratio, which describe gradation properties and how particles are packed together, can also be used as laboratory compactability parameters. This points out that from the selection of an optimum gradation, compactability of a mixture in the SGC can be predicted.

• A suitable simple linear correlation was not found to describe the relationship between laboratory compaction and field compaction. The use of multiple regression analysis was necessary to incorporate the wide variety of mix properties and factors affecting field compactability. Results showed that field compaction is more affected by t/NMAS ratio (HMA lift thickness/nominal maximum aggregate size) and mat temperature. Density of SGC specimen is also significantly affected by thickness of the sample, which is consistent with the results obtained in the field.

• In general, it was found that mixes placed in 2003 required more compactive effort than mixes placed in 2000. Thinner layers were placed in 2003 (< 50 mm), which led to a reduction in mat temperature and the time available for compaction and thus an increase in required field compactive effort.

• The interaction between temperature and t/NMAS ratio showed that for high t/NMAS ratios (above 4:1) the temperature has minimum effect on the compaction energy, but as the t/NMAS ratio decreases, lower temperatures require substantially higher compaction energy.

• The relationship between compaction effort and thickness or t/NMAS ratio for specimens compacted in the SGC to reach lift thickness showed a similar trend to the relationship between ACP and thickness or t/NMAS ratio. In other words, specimens compacted in the SGC are significantly affected by thickness, which is consistent with the results observed in the field.

• This study can be used to develop procedures and criteria to evaluate compactability of mixtures and identify field compaction equipment characteristics and rolling patterns appropriate for good compaction. It also confirms the importance of appropriate lift thicknesses and mat temperatures in achieving target density levels.

The total applied compactive effort to the HMA mat by different rollers was quantified and termed Accumulated Compactive Pressure (ACP) in this study.

RAY BROWN, NCAT DIRECTOR, RETIRES

At a retirement event in July, 2007, Ray Brown was honored by Auburn University, the NCAT board of directors, state departments of transportation, the National Asphalt Pavement Association, industry groups, and contractors with whom he had worked during his years at the National Center for Asphalt Technology (NCAT). Auburn Engineering dean Larry Benefield officiated at the event, which included comments from Alabama DOT officials; Chuck Van Deusen, chairman of the NCAT board of directors; and Jack Weigel, NCAT applications steering committee chairman. Brown was honored with the title of Professor Emeritus by the Civil Engineering Department, and received a commendation from the Alabama Governor Bob Riley, which was presented to him by Mike Harper, Alabama DOT assistant chief engineer.

Ray Brown addressed the people present at the retirement event.

Many past and current NCAT board members and former graduate students spoke at the event, expressing their thanks for Ray's influence in their lives. NAPA president Mike Acott told the group of the importance of Brown's leadership. "The industry has been able to get a direct return on its investments at NCAT because of Ray's leadership. He bridged the gap between industry, highway departments, DOTs, and the FHWA. He fully understood the need for products, processes, and knowledge that helped us specify and build long-lasting pavements."

Mike Harper, Alabama DOT assistant chief engineer, presented to Ray Brown a commendation from the Honorable Governor of the State of Alabama.

Brown retired from Auburn August 1, 2007 after 17 years as the director of NCAT to accept a position with the U.S. Army Corps of Engineers Waterways Experiment Station in Vicksburg, Miss.

Larry Benefield, dean of engineering, honored Ray Brown with the title of professor emeritus. Mrs. Shirley Brown is in the center.

ASPHALT FORUM

NCAT invites your comments and questions. Questions and responses are published in each issue of **Asphalt Technology News**. Some are edited for consistency and space limitations.

Connecticut (Keith Lane, Connecticut Department of Transportation)

Has any other state considered minimizing the number and use of some of the Superpave design levels and/or NMAS (nominal maximum aggregate size) classes to reduce the large number of mixes currently available to be specified by contract?

National Center for Asphalt Technology (Prithvi "Ken" Kandhal, NCAT)

NCAT has conducted extensive field research in the area of HMA longitudinal joint construction over the years, which has been reported from time to time in the Asphalt Technology News and has been published in various technical journals. Many state highway agencies such as Kentucky and Wisconsin have also conducted field experiments using different techniques of longitudinal joint construction. Various techniques such as rubberized joint adhesive, notched wedge joint, cutting wheel, joint maker, and infrared joint heaters have been evaluated in the field by NCAT and other states. We would like to know how severe the longitudinal joint problem is in your state and what are you doing about it in terms of specifications and/or research.

EDITOR'S FAREWELL

I have been editing the *Asphalt Technology News* since its inception in January 1989. I still remember that time when NCAT had just been established with a skeleton staff: Freddie Roberts as director and Ray Brown and myself as two assistant directors. Besides conducting research, I was given the responsibility of developing and editing a practical asphalt newsletter. Having worked as the state bituminous engineer for the Pennsylvania Department of Transportation for 17 years, I did not have any experience in the area of editing. Fortunately, readers throughout the world liked the *Asphalt Technology News* and it was acclaimed as a useful, practical newsletter.

I have enjoyed editing this newsletter for the last 19 years. Now it's time to hand over this responsibility to younger staff. Don Watson will assume the role of editor for the next issue. I am sure he will do an excellent job. I take this opportunity to thank all those who over the years contributed to the success of the *Asphalt Technology News*.

Prithvi "Ken" Kandhal
Editor/Associate Director Emeritus
National Center for Asphalt Technology

A group of 15 Chinese engineers from Liaoning Province, PRC, visited NCAT in May 2007.

ASPHALT FORUM RESPONSES

The following responses have been received to questions raised in the Spring 2007 Asphalt Forum.

Several important findings have resulted from the first and second cycles of experiments conducted from 2000 to 2005 on the test track, which has been subjected to 20 million ESALs of traffic. We would like to have your comments on three of these findings.
(Prithvi "Ken" Kandhal, NCAT)

1. The amount of rutting in coarse-graded and fine-graded Superpave mixes was approximately the same.

Connecticut (Keith Lane, Connecticut DOT)

With the implementation of Superpave in 1998, we observed that the coarse-graded mixes were more difficult to compact, had a noticeably more open texture, and took much longer to dry out after rain. This concerned us due to the anticipated higher levels of oxidation, permeability, and black ice potential during the winter. In 2002-03, the Connecticut DOT requested that all Superpave mixes (Design levels 1 through 3) be designed above the primary control sieve (PCS) point for the respective nominal maximum aggregate size (NMAS). As a result, we have had great success in producing and placing most of our fine-graded Superpave mixes.

Kansas (Cliff Hobson, Kansas DOT)

In the early days of Superpave pavements in Kansas, coarse-graded mixes were often used on high-traffic volume routes to take advantage of the potential stone-on-stone contact provided by these mixes. However, rutting occurred early in the life of these mixes, primarily from stripping due to their higher permeability. In an attempt to quantify the difference in performance between the coarse- and fine-graded mixes, the Kansas DOT contracted with Kansas State University to test both the coarse-graded and fine-graded mixes in the Hamburg Wheel Rut Tester. The results of this study indicated that the fine-graded mixes had less rutting potential than the coarse-graded mixes. In April 2003, due to the on-going permeability concerns with coarse-graded mixes, the Kansas DOT changed to fine-graded mixes for most Superpave mix designs.

Kentucky (Allen Myers, Kentucky Transportation Cabinet)

Early in the implementation of Superpave, the Kentucky Transportation Cabinet (KYTC) held to the notion that coarse-graded mixes were more rut-resistant than fine-graded. Therefore, we required coarser mixes on facilities with higher ESAL counts. Our native materials very readily produced coarse gradations, so this arrangement worked well. In later years, due to permeability concerns, Kentucky has increasingly utilized finer gradations. Many of these mixes have been placed on heavily-loaded facilities. The performance of these fine-graded mixes has been good to date. To summarize, KYTC has noted similar levels of rut resistance for both coarse- and fine-graded HMA.

Ontario (Kai Tam, Ontario Ministry of Transportation)

This statement is too general, it should be qualified by stating "for the same aggregates used and meeting mix requirements for the given traffic category."

2. Although only crushed stone is recommended in stone matrix asphalt (SMA), the SMA containing only crushed gravel aggregate gave satisfactory performance in terms of permanent deformation.

Kansas (Cliff Hobson, Kansas DOT)

Kansas has only two recently constructed projects using the current SMA design. Both of those projects used limestone aggregates. The Kansas DOT plans to construct six SMA projects in 2008. At least half of those projects have the potential of using crushed gravel as the aggregate. The NCAT test track results indicating that SMA using crushed gravel gave satisfactory results are encouraging.

Kentucky (Allen Myers, Kentucky Transportation Cabinet)

In 2004, approximately 7,500 tons of an SMA mixture containing crushed gravel coarse aggregate was placed in northeastern Kentucky. The rut resistance of this pavement has been good to date.

Mississippi (James Williams, Mississippi Department of Transportation)

Mississippi has successfully used crushed gravel Superpave mixes since the inception of Superpave. We have several SMA projects scheduled using a crushed gravel-limestone blend.

Nebraska (Laird Weishahn, Nebraska Department of Roads)

I don't recall specifics, but years ago Nebraska placed an SMA mixture with a significant percentage of crushed gravel and found it to resist permanent deformation.

3. It is possible to blend some limestone aggregate with crushed gravel aggregate in the wearing course mix without compromising the skid resistance.

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SPECIFICATION CORNER

Arizona – The Arizona DOT has made several HMA specification changes including:

- Gap-graded asphalt rubber mixtures have been changed from a recipe type specification to a percent-within-limits (PWL) type end-product specification that is similar to existing dense-graded mixture specifications. Pay factors are based on mix properties (gradation, binder content, laboratory voids); compaction (based on in-place air voids); and spread. The Arizona DOT has also turned the responsibility for designing these mixes over to the contractor (most HMA is already contractor designed). This change was in process, but was accelerated after numerous, significant moisture damage related failures occurred in these mixtures (after less than one year in service). These failures were attributed, in part, to poor mix compaction. This new specification will likely undergo some adjustments based on the experience during the first year.
- The use of a minimum one percent lime or cement has been made mandatory in all HMA mixes. Immersion compression testing is still required to ensure acceptable resistance to moisture-induced damage. Prior to this change, approximately 95 percent of mixes already met this requirement. However, there was a concern that the mixtures, which did not use lime or cement, were typically marginal with respect to moisture sensitivity. This requirement should eliminate marginal mixes and the risk of failures associated with them.
- The allowable percentage of carbonates was decreased from 25 to 20 in all mixes used in the final wearing surface.
- In-place density requirements were made consistent for all dense-graded, end-product mixtures. The density target is now based on in-place air voids in the mat, instead of laboratory density, for all mix types. An in-place air void requirement was already being used on some mixtures. The specification requirements for other mixtures were changed because when the pay factor was based on a target determined from the laboratory density, the DOT sometimes, paid bonuses for mixtures with in-place air voids in excess of 10 percent or imposed penalties for mixtures with in-place air voids in the five to six percent range.
- A critical review of Arizona DOT's HMA specification has begun. As a part of this work, a consultant was retained to hold a series of meetings with the industry and DOT staff to review issues and concerns. The outcome will likely include many changes to the specifications.

Colorado – The Colorado DOT (CDOT) piloted a temperature segregation specification in 2007 that will likely become a standard specification in 2008. The specification allows CDOT to check for temperature differences across the width of the mat behind the paver. If there is a difference of more than 25° F, CDOT may do non-random density testing on the cooler areas. The cool areas must achieve the minimum mat density of 92 percent of the theoretical maximum density or they will be subject to a disincentive. This specification was written to reduce temperature segregation in an effort to get uniform mat densities. At this time, projects piloting the specification have not reported their findings.

Connecticut – The Connecticut DOT has introduced a modified 9.5 mm mix with 97 to 100 percent passing the 9.5-mm sieve. This mix will be used for thin lift applications but should offer many of the desirable characteristics in friction that the Superpave 4.75 mm mix does not.

Kansas – The Kansas DOT is increasing the option for contractors to use a higher percentage of reclaimed asphalt pavement (RAP) material in overlay mixes. Up to 40 percent RAP will be permitted in the surface mix of four projects. The contractor will have the opportunity to put a maximum of 25 percent RAP in the surface mix without having to change from a neat asphalt binder to a modified binder on several other projects. These changes are primarily driven by contractors' concern over the rising cost of HMA.

Kentucky – The Kentucky Transportation Cabinet plans to publish an updated Standard Specifications manual in early 2008. Some significant changes are under consideration for the asphalt area, including the following:

- Add SMA base course and SMA surface course as standard items
- Statistically compare the contractor's and department's test data using the F-test, t-test, and paired t-test
- Modify the pay adjustment schedules for selected properties from "step" functions (same pay value for a range of test results) to linear equations (different pay value for each corresponding test-result increment).

Ontario, Canada – The Ontario Provincial Standard Specification for Hot Mix Construction, Hot Mix

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PUTTING RESEARCH INTO PRACTICE

The following papers were presented at the annual meeting of the Association of Asphalt Paving Technologists (AAPT) held in San Antonio, March, 2007. We are reporting observations and conclusions from them, which may be of value to field engineers. These comments are obtained from research projects with a limited scope; before applying these findings we recommend that you read the entire paper to determine its limitations.

1. Verification of the N Design Levels (Prowell and Brown)

One of the premises of hot mix asphalt (HMA) design is that the density of the laboratory compacted samples used to determine the optimum asphalt content should approximate the ultimate density of the asphalt pavement. If the ultimate density of the pavement is too low the durability of the pavement will be reduced; if the ultimate density of the pavement is too high (more than approximately 98 percent of the theoretical maximum density or G_{mm}) the pavement will tend to bleed or rut.

Similar to the number of blows used in the past in Marshall mix design, the Superpave mix design uses a number of gyrations (Ndesign) to compact the HMA specimens in the Superpave gyratory compactor (SGC) for determining the optimum asphalt content. The table of Ndesign gyrations was developed as part of the Superpave mix design system, a product of the Strategic Highway Research Program (SHRP), which was released in 1994. This is the first time a major, comprehensive field project has been conducted to reexamine and establish realistic Ndesign gyrations based on traffic levels.

The original Superpave Ndesign table of gyrations developed in SHRP was based on very limited field test data. Testing was conducted on a single core obtained from each of the 15 different selected sites. The data from the 15 cores was extrapolated to produce the original Ndesign table consisting of 28 levels representing four climatic regions and seven traffic levels.

In 1999, the Superpave Ndesign table was consolidated to four levels (See Table 1.) based on the sensitivity of mixture volumetric properties and mixture stiffness to Ndesign. The climatic regions were eliminated since differences in climate should be accounted for by the selection of the binder grade. Testing conducted on a range of mixes indicated that a difference of approximately 30 gyrations resulted in a change in voids in the mineral aggregate (VMA) of approximately 1 percent. However, the results did not indicate what the target laboratory compactive effort should be to represent the ultimate field density of pavements subject to different traffic.

TABLE 1 Recommended Superpave Gyratory Compaction Effort (1999)

Design ESALs (millions)	Number of Gyrations		
	Ninitial	Ndesign	Nmax
< 0.3	6	50	75
0.3 to < 3	7	75	115
3 to < 30	8	100	160
≥ 30	9	125	205

Therefore, there was a need to undertake a major, comprehensive field research project for establishing reasonably reliable Ndesign gyration levels based on traffic levels which could be used in the Superpave mix design system.

This research project was undertaken with three objectives: to evaluate the field densification of pavements designed using the Superpave mix design system, to verify or determine the Ndesign levels to optimize field performance, and to evaluate the locking point concept in lieu of Ndesign gyrations. Only the first two objectives are discussed in the paper.

In order to validate the Ndesign levels, an extensive field study was conducted to relate Ndesign to the in-place densification of pavements under various traffic loadings while monitoring field performance. Experimental variables for the project included: Ndesign level, lift thickness relative to nominal maximum aggregate size (NMAS), gradation, and performance grade (PG) of the binder. The experimental variables were selected based on their potential impact on initial field compaction, densification under traffic, and rutting performance. Forty projects were required to fill the experimental matrix plan. The projects were geographically distributed across the United States. All of the mixes sampled and tested were surface mixes.

For each project, the following testing and evaluation procedure was conducted:

1. Samples of loose HMA were obtained from a truck at the asphalt plant; the corresponding location where this truckload of the HMA was placed on the roadway was marked. Three replicate specimens were compacted in two different SGCs in a mobile NCAT laboratory. Samples were also tested for maximum specific gravity (Gmm), asphalt content, and gradation.
2. Three cores were taken from the right wheel path of the area marked on the roadway where the mix

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corresponding to a given sample was laid. These cores were tested for bulk specific gravity.

3. The sites were revisited at approximately 3 months, 6 months, 1 year, 2 years, and 4 years after construction. During each visit the following was conducted:
   a. Three additional cores were taken, corresponding to each sample location at each project, for determining their bulk specific gravity.
   b. The pavement condition was visually assessed.
   c. Rut-depth measurements were taken adjacent to each core location with a 6-foot string line.

The field projects reached their ultimate density after about two years of traffic, indicated by the fact that the in-place densities did not change between two- and four-years of trafficking. The majority of the densification occurred in the first three months.

The following conclusions were drawn based on the results from this research study.

- Pavements appear to reach their ultimate density after two years of traffic. The average in-place density for all of the projects was about the same (94.6 percent of Gmm) after two and four years under traffic. The majority of pavement densification, approximately 66 percent, occurs during the three months following construction. The month in which the project was constructed significantly affected the amount of densification. Projects constructed in May tended to densify the most - approximately 4 percent. Projects constructed in September or October densified the least - an average of approximately 2.3 percent.
- Both the high PG binder grade and the high temperature bumps between the climatic and specified PG were found to significantly affect pavement densification, with stiffer binders resulting in less densification. The ultimate in-place densities of the pavements evaluated in this study were approximately 1.5 percent (based on Gmm) less than the densities of the laboratory compacted samples at the agency specified Ndesign.
- The number of gyrations required to match the ultimate in-place density was calculated for each project in this study. Several analyses were conducted to evaluate the Ndesign levels. Combined, these analyses indicated that the Ndesign levels could be reduced compared to those in Table 1.
- Relationships were developed between laboratory density at 100 gyrations and as-constructed density, high PG grade, and accumulated ESALs. It was found that Ndesign could be reduced by approximately 15 gyrations when PG 76-XX was specified. This methodology was used to recommend the new Ndesign levels.
- All of the projects in this study were very rut resistant. The maximum observed rutting for the field projects was 7.4 mm with an average rut depth for all of the projects of 2.7 mm after 4 years of traffic. There were some indications of durability problems, which suggest that increased asphalt content would be beneficial.
- The requirements for Ninitial were evaluated based on the field project data. The majority of the projects which failed Ninitial were fine-graded. All of the projects are performing well in terms of rutting resistance. There is no strong evidence to keep the requirements for Ninitial.
- The requirement for Nmaximum was also evaluated based on the field project data. AASHTO M 35 specifies a density requirement of less than 98 percent at Nmaximum to guard against the potential for rutting. Thirty-six percent of the samples tested with the Pine compactor and 40 percent of the samples tested with the Troxler compactor failed the density requirements at Nmaximum. However, the projects have all been extremely rut resistant. Therefore, the density requirement at Nmaximum does not appear to be a good indicator of rutting potential and should be eliminated.

Based on the research conducted in this project, the following recommendations have been made:

- The specification for angle of gyration should be revised to only allow a dynamic internal angle (DIA) of 1.16 ± 0.02 degrees.
- The Ndesign levels shown in Table 2 should be adopted for the design of Superpave HMA.
- Consideration should be given to the use of the 2-year design traffic volume to determine Ndesign as opposed to the 20-year design traffic volume or another method of specifying rate of loading.
- The requirements for Ninitial and Nmaximum should be eliminated.

TABLE 2. Recommended Ndesign levels for Superpave gyratory compactor

20-year design traffic, ESALs	2-year design traffic, ESALs	Ndesign for binder < PG 76-XX	Ndesign for binders ≥ PG 76-XX or mixes placed > 100 mm from surface
< 300,000	< 30,000	50	NA
300,000 to 3,000,000	30,000 to 230,000	65	50
3,000,000 to 10,000,000	230,000 to 925,000	80	65
10,000,000 to 30,000,000	925,000 to 2,500,000	80	65
> 30,000,000	> 2,500,000	100	80

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2. Hot-Mix Asphalt Permeability and Porosity (Vivar and Haddock)

Prior to Superpave, permeability had not been a problem in most HMA mixtures. However, with the wide spread use of Superpave designed HMA mixtures some users began to experience HMA pavement distresses resulting from moisture intrusion. Research studies focusing on this problem concluded that Superpave designed mixtures were more permeable at lower air voids contents than were conventional HMA mixtures. This led to long-term durability problems due to moisture and air intrusion.

Permeability is the ability of a material (in this case HMA) to transmit fluids through its pores when subjected to pressure. It is expressed in units of volume of fluid per unit time per cross sectional area of material for a given hydraulic head. Percent porosity, or effective air voids, is the percent of air voids in an HMA mixture that can be accessed by water.

As air voids contents increase (or density decreases) in compacted HMA, permeability will increase. At some critical air void content value, a mixture becomes permeable to air and water. A common conclusion of many studies in the past is that 8 percent air voids appears to be a critical value dividing permeable and impermeable HMA mixtures. In addition to percent air voids, percent porosity can also be used as a factor to predict permeability. Some studies have indicated that percent porosity is a better indicator of permeability than air voids.

Several studies have evaluated the effect of aggregates on permeability. In general, it has been concluded that gradation and nominal maximum aggregate size (NMAS) do influence permeability. As NMAS increases, the sizes of the voids in the mixture also increase. After the development of the Superpave mixture design method, numerous studies have also concluded that at a given air void percentage, coarse-graded Superpave mixtures are more permeable than conventionally designed HMA mixtures.

This study was undertaken with the following objectives:

- Evaluate the influences of air void percentage, aggregate gradation, and aggregate size on the permeability and porosity of HMA mixtures.
- Develop a better understanding of the relationships among these factors.
- Suggest ways by which permeability and/or percent porosity might be used to help ensure satisfactory HMA mixture performance.

To accomplish these research objectives, four HMA mixtures were used. The test variables were NMAS (9.5 and 19.0mm), gradation (coarse- and fine-graded), and air voids content (4, 6, 8, and 10 percent). Once the mixture designs were completed, test specimens were prepared and their permeability and porosity determined. A single PG 64-22 binder was chosen for the project because of its common usage. The aggregates used were a natural sand fine aggregate and a crushed limestone coarse aggregate. Both aggregates were tested and found to be in compliance with all applicable aggregate specifications.

The Superpave mixture design method was used to determine the optimum binder content for the mixtures, selected on the basis of 4 percent air voids in HMA samples compacted with 75 gyrations of the Superpave Gyratory Compactor (SGC).

Due to its simplicity and short testing times, the Florida DOT falling head approach was selected to obtain the permeability of the samples in this project. The CoreLok device was used to measure the percent porosity in compacted HMA samples.

The following conclusions were drawn from this study:

- In general, an exponential relationship was obtained between air voids content and permeability. The critical value of permeability appears to be approximately at 7-8 percent air voids, depending on mixture type. Above this level, exponential increases in permeability can occur.
- HMA air voids content, gradation, and aggregate size, are significant to HMA permeability and percent porosity.
- HMA mixtures with higher percentages of air voids tend to have higher permeability and percent porosity.
- As HMA mixtures increase in NMAS the permeability tends to increase.
- Coarse-graded mixtures tend to have higher permeability and percent porosity compared to fine-graded mixtures.
- The in-place air voids content (density) of an HMA pavement necessary to prevent moisture and air intrusion varies depending on HMA mixture properties. Specifying one maximum percentage of air voids (minimum density) for all mixture types and sizes can result in construction of permeable HMA pavements.

The following recommendations have been made from this study:

- User agencies should consider specifying in-place HMA pavement density based on permeability measurements of the HMA mixture. This would help to ensure that impermeable HMA pavements are constructed.
- HMA mixture permeability should be controlled during pavement construction either through field permeability or density testing.
- Additional research should be done on percent

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porosity. It may be a better indicator of pavement performance and durability than either permeability or density as percent porosity accounts for not only air voids content (density), but also size of the air voids and their interconnectedness.

3. Recycled Asphalt Shingles in Hot Mix Asphalt (McGraw, Zofka, Krivit, Schroer, Olson, and Marasteanu)

Using recycled asphalt shingles in hot mix asphalt (HMA) has been a developing technology for more than two decades with growing acceptance by both construction contractors and government agencies. This paper describes a recent study, which investigated the use of both tear-off (post-consumer) shingles and manufacturer shingles combined with traditional reclaimed asphalt pavement (RAP) materials.

AASHTO has adopted a recommended practice providing guidance for designing HMA which incorporates recycled asphalt shingle (RAS). Specific considerations include: shingle aggregate gradation, performance grade (PG) of the virgin and RAS binder, and relative reduction of the virgin asphalt binder due to replacement by RAS binder.

This study was conducted to evaluate the influence of recycled asphalt shingles addition on the low- and high-temperature properties of asphalt mixtures prepared with RAP.

The same PG 58-28 binder was used to prepare three different mixtures: 20 percent RAP; 15 percent RAP plus 5 percent tear-off shingles; and 15 percent RAP plus 5 percent manufacturer's waste shingles. The mixture containing 20 percent RAP was used as the control; the Minnesota DOT allows 20 percent RAP without a change in grade of asphalt binder. Each of these recycled mixes was tested for percent asphalt binder, PG grading of recovered binder, gradation, percent glass fiber and paper content in extracted aggregate. Glass fiber and paper are considered deleterious material. The Provisional AASHTO specification allows up to 0.5 percent deleterious material.

The average percentage of binder in manufacturer's waste shingle and tear-off shingle were 19.6 and 36.4, respectively. This difference in asphalt content was adjusted in the mix design procedure. For the 5 percent allowable shingles, the contribution to total asphalt binder content for the manufacturer RAS would be about 1 percent and the tear-off RAS would be 1.8 percent. The implication of this is: the tear-off mixes have less virgin binder and therefore would be stiffer than the manufacturer's waste mixes.

The recovered binder from the three mixes was performance graded. Comparing the PG grading results to the 20 percent RAP mix, the manufacturer's waste RAS mix graded one full PG grade on the high-temperature properties while the tear-off RAS mix was 1.5 grades higher. Replacing 5 percent RAP with shingles does have an effect on the binder stiffness.

Indirect tensile tests (IDT) were performed at 0, -10, and –20°C on the eight HMA mixtures according to AASHTO TP 9: Standard Test Method for Determining the Creep Compliance and Strength of HMA.

The results from this study have indicated that the two types of shingles perform differently. The manufacturer's waste material seems to be beneficial to tear-off material, as it slightly increases the stiffness and did not affect the tensile strength of both mixtures and extracted binders. The binder critical temperature (at which low temperature cracking is expected) increased very little. The addition of tear-off shingles had a negative effect on properties, although it also increased only slightly the stiffness of the binders. It lowered the strength of the binder significantly at the higher test temperature and increased the binder critical temperature. This was not confirmed by the strength tests on mixtures, which did not indicate any significant reduction in mix strength with the addition of tear-off shingles.

NCAT HAS DOMAIN NAME

NCAT has a domain name, to make it easier to find our Web page: ncat.us. You can also reach our Web page by going to our old address, eng.auburn.edu/center/ncat/.

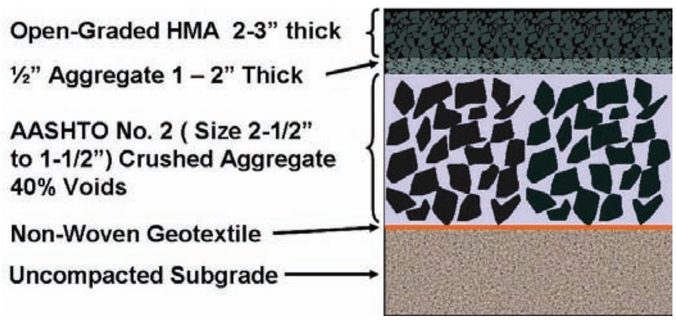
PROFESSOR TRAINING COURSE IN ASPHALT TECHNOLOGY

The NCAT professor training program for college and university civil engineering faculty provides instructors up-to-date information and materials needed to offer an undergraduate and elective courses in asphalt technology. This intensive 8-day course is conducted at NCAT in June every year. The next course will be held on June 17-26, 2008. The course has been updated to include Superpave binder and mix technology, and stone matrix asphalt (SMA). NCAT is currently revising its college textbook on asphalt technology that is used in this class. Some financial assistance for attending this course is possible. Please call NCAT at 334. 844. NCAT for a brochure or information or visit our Web site at ncat.us.

POROUS ASPHALT PAVEMENTS FOR MANAGING STORM WATER

Porous asphalt pavements are increasingly being used in parking lots. These pavements allow rainwater to rapidly drain through the asphalt pavement surface into a stone recharge bed and then infiltrate into the natural soils below the pavement. Porous asphalt parking lots have been used for:

- Providing storm-water management systems that promote water infiltration, improve water quality, and in many cases eliminate the need for a detention basin.
- Reducing demands on storm sewer systems.
- Replenishing water tables and aquifers rather than forcing rainwater runoff from impervious pavements into storm sewers.



Schematic of porous asphalt pavement.

The technology of constructing a porous asphalt parking lot is simple. It consists of the following components starting from the bottom:

- Uncompacted subgrade (compaction may reduce permeability)
- Non-woven geotextile (to prevent migration of fines from the subgrade to the overlying crushed stone layer)
- Open-graded, large-size crushed aggregate layer (since it has about 40 percent voids it temporarily stores rainwater until it can slowly infiltrate into the subgrade)
- A choke aggregate layer to level the large-stone layer and provide a stable platform for placing the asphalt layer
- Open-graded asphalt surface course that allows rain water to rapidly soak through without ponding on the surface; the water goes below into the aggregate reservoir

The technology of porous asphalt pavement was developed by the Franklin Institute of Philadelphia in the early 1970s. It was tested in pilot projects and developed further during the late1970s. The current design has been used since 1980. More than 150 projects have been built since 1980 in California alone. Porous pavement was declared an outstanding engineering project in 2006.

The procedure for designing the open-graded asphalt surface course is the same as that for designing open-graded asphalt friction course (OGFC) (See reference 1). The optimum asphalt binder content ranges from 6.0 to 6.5 percent. Use of a stiffer, modified binder should be considered to minimize binder draindown during truck transport and to increase the stability of the mix.

Porous asphalt pavements must be protected from contamination during and after construction. Properly designed and constructed pavements can last more than 20 years. The open-graded asphalt surface course can be flushed or jet washed to maintain its permeability.

Comparison of porous asphalt (foreground) with conventional dense asphalt (background) just after rain.

A complete design guide for porous asphalt pavements, describing the process from site design through maintenance, is available (See reference 2).

References

1. Kandhal, P. S. Design, Construction and Maintenance of Open-Graded Asphalt Friction Courses. National Asphalt Pavement Association Information Series IS-115, May 2002.
2. Jackson, N. Porous Asphalt Pavements. National Asphalt Pavement Association Information Series IS-131, October 2003.

THREE RESEARCH ENGINEERS JOIN NCAT

Andrea Kvasnak

Andrea Kvasnak joined NCAT in January this year. She earned her masters degree in civil engineering from the University of Vermont in 2002 and her doctoral degree from Iowa State University in 2006. Her doctoral dissertation research concentrated on moisture susceptibility of HMA and asphalt binders. Andrea was also involved in other research projects such as HMA pay factors, HMA sampling locations, non-nuclear gauges, and modeling with simple performance tests. While working on her doctorate degree, she also taught Civil Engineering Materials to undergraduate students. At NCAT she is leading several research projects on warm mix asphalt (WMA), reclaimed asphalt pavement (RAP), and cellulose fibers for stone matrix asphalt and open-graded friction course mixes.

Nam Tran

Nam Tran received both his masters and doctoral degrees in civil engineering from the University of Arkansas in 2003 and 2005, respectively. After finishing his doctorate he worked at the University of Arkansas as research associate and then as assistant research professor. During that time he served as co-principal investigator of three research projects including calibration plan for the new *Mechanistic-Empirical Pavement Design Guide* in Arkansas and evaluation of the effectiveness of different treatment methods for retarding reflective cracking in HMA overlays. Nam joined NCAT as a lead research engineer in June 2007. His principal research areas include performance testing of HMA, mechanistic empirical design of asphalt pavements, asphalt stabilized base materials, forensic studies, and bond strength between HMA layers.

Jason Nelson

Jason Nelson graduated from Auburn in 2002 with a bachelor's in Animal and Dairy Science and then again in 2007 with a bachelor's in civil engineering. He worked as a co-op student at NCAT starting in January 2004 and stayed on part-time until he started as a full-time research engineer with NCAT in September of this year. Jason is currently involved in several research projects involving WMA, foamed asphalt, and RAP.

MIKE HEITZMAN JOINS NCAT

Mike Heitzman

Mike Heitzman joined NCAT as a senior researcher in October. He will lead NCAT's research efforts related to materials inputs for mechanistic empirical pavement design, porous pavements, hot mix asphalt specifications, and modified binders.

"We are very pleased to have Mike Heitzman join our team," says Randy West, NCAT director. "Mike brings with him a great deal of experience and leadership that will help us continue to build a strong team of research engineers who are focused on providing practical solutions and information to the asphalt paving community."

Mike will also serve as special assistant to the director. For the next eight months he will work remotely from Ames, Iowa. He will relocate to the Auburn area next June.

Mike has worked as the state bituminous materials engineer for the Iowa Department of Transportation for the past nine years. Prior to Iowa DOT, he worked for 18 years with the Federal Highway Administration in a number of assignments including asphalt paving technology specialist in the Pavements Division in Washington D.C. Mike received a bachelors degree in civil engineering from the University of Missouri-Rolla in 1978, a masters degree in engineering management from UMR in 1993, and a doctorate from Iowa State in 2005. He is a registered professional engineer in Iowa and Washington.

SUPERPAVE MIX DESIGN WORKSHOP

The Superpave mix design workshop will be held at NCAT on March 24- 27, 2008. This workshop consists of three-and-a-half days of intensive lecture, demonstration, and hands-on training on Superpave volumetric mix design procedures. Upon completion the participants will be able to conduct the Superpave mix designs in their laboratories.

Please call 334.844.NCAT (6228) or visit our Web site at ncat.us (Click on "Education" at the top of the page, then click on "Upcoming Training Courses") for a brochure or information. On-line registration is now available.

RANDY WEST APPOINTED NCAT DIRECTOR

Randy West

Auburn University named Randy C. West as director of the National Center for Asphalt Technology (NCAT) effective August 1, 2007. West joined NCAT in 2003 as assistant director. With over 20 years of experience in the hot-mix asphalt industry, he brings to the table a wealth of experience in the industry, state DOT, and with NCAT. As assistant director, West led research on a broad range of pavement topics, including recycling of hot mix asphalt, mix design and materials characterization, quality assurance, pavement construction, and pavement failure investigations. Prior to joining NCAT, he worked as a research engineer for the Florida DOT and for APAC in Atlanta, where he advanced to director of materials, plants and quarry services.

West earned his bachelor's and master's degrees from Auburn in 1987 and 1989 respectively, and doctorate in civil engineering from the University of Florida in 1995. He is a registered professional engineer in Georgia and Florida and is active in the American Society for Testing and Materials, the Association of Asphalt Paving Technologists, and the National Asphalt Pavement Association – serving on a number of committees dealing with HMA research, specifications, and training.

Randy West replaced Ray Brown, NCAT director for 17 years, who joined the U.S. Army Corps of Engineers after his retirement from Auburn University on August 1, 2007. "I believe Randy's experience and leadership are what we need to build on Ray Brown's strong record of accomplishments," says Larry Benefield, dean of the Samuel Ginn College of Engineering. "NCAT is a national leader in asphalt research. I fully expect Randy to continue the success that the center has enjoyed."

—Specification Corner

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Specification for Hot Mix Construction, Hot Mix Requirements, and PG Binder has been revised to include:

- Changes to address concerns with overweight samples and other sampling issues such as:
  1. Size ranges for all mix types to replace simple minimums
  2. No single receptacle can weigh more than 30 kg
  3. The spacing of cores has been increased from 0.5 +/- 0.1 meters to 1.0 +/- 0.1 meters
  4. Sampling for PG binder has been reduced to one sample for each 10,000 tons of HMA
- The Ontario Ministry of Transportation now permits quality assurance (QA) test results to be used for payment purposes at the contractor's request.
- The contractor can now carry out repairs to a lot, in lieu of accepting a payment factor, if the payment factor for that lot is less than 0.94.
- Repairs must now be a minimum length of 250 meters and multiple repair areas must be separated by at least 100 meters.
- A reduction in the number of paving situations exempt from surface smoothness measurements.
- A modification of the special provision on smoothness is being considered for 2008, which will include requirements to take measurements by inertial profilers, in addition to the measurements taken by California profilographs for acceptance on selected contracts.

—Asphalt Forum Responses

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Kentucky (Allen Myers, Kentucky Transportation Cabinet)

The Kentucky Transportation Cabinet routinely permits the blending of limestone coarse aggregate with polish-resistant coarse aggregate (e.g., crushed gravel, slag, dolomite, etc.) in specific surface applications. The resulting HMA pavements have demonstrated satisfactory skid-resistant performance.

Nebraska (Laird Weishahn, Nebraska Department of Roads)

Nebraska limits the amount of limestone in surface mixtures to a maximum of 60 percent and has found our skid numbers remain acceptable in the following years.

Ontario (Kai Tam, Ontario Ministry of Transportation)

Ontario's experience has shown that even a small amount of limestone can affect skid resistance. However, cost considerations in some of our more remote areas of the Province have forced us to accept blending in our Superpave 9.5-mm and 12.5-mm mixes so that no more than 40 percent carbonate (limestone or dolostone) ends up in the coarse fraction of our roads with lower traffic volumes.

NCAT's Professor Training Course June, 2007

NCAT's Professor Training Program in Asphalt Technology Course, June 19-28, 2007

Back, L-R: Don Watson (Instructor), Jason Moore (Instructor)

3rd Row, L-R: Ray Brown (Instructor), Baron W. Colbert, Robert "Chad" Rogers, Hyunwook Kim, Andre Smit (Instructor), Eshan V. Dave, Andrew Braham, Robert Hamilton, Randy West (Instructor), Terrence Tadaki, Mark P. Cal

2nd Row, L-R: Alex K. Apeagyei, George Lopp, Paola Bandini, Meor Othman, Isaac L. Howard, Wilfung Martono, Sudip Bhattacharjee, Qiao Dong, Zheng Wu, Sharon A. Lewis, Cristian Druta

Front, L-R: T.Jay Cunningham, Dong-Woo Cho, Shu Wei Goh, Julian Mills-Beale, Kyoung Chul "KC" Kim, Yu Liu, Xinbao "Paul" Yu, DingXin Cheng, Eric Weaver, Thomas C. Larabel

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