

# ASPHALT TECHNOLOGY NEWS

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## NCAT COMPLETES LANDMARK RESEARCH PROJECT RELATED TO SUPERPAVE MIX DESIGN

The National Center for Asphalt Technology (NCAT) recently completed the National Cooperative Highway Research Program (NCHRP) Project 9-9 (1), "Verification of Gyration Levels in the Ndesign Table". This comprehensive field project was conducted to reexamine the Ndesign Table, a component of the Superpave mix design system originally released in 1994, to establish reliable Ndesign gyration levels based on actual field information.

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 and 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. A product of the Strategic Highway Research Program (SHRP), the Ndesign table was last updated in 1999.

### Background

The original Superpave Ndesign table of gyrations developed in SHRP  
*(continued on page 2)*



Core samples were obtained from 40 HMA paving projects in 16 states to represent a wide range of climate, traffic levels, asphalt binder grades, aggregate types and gradations

## In This Issue

NCAT Completes Landmark Project Related to Superpave Mix Design

— Page 1

Asphalt Forum — Page 7

Asphalt Forum Responses — Page 7

NCAT Projects Related to HMA — Page 8

Specification Corner — Page 11

Putting Research into Practice — Page 12



## NCAT Completes Landmark Research Project *(continued from page 1)*

was based on testing conducted on a single core from each of 15 different sites. The sites were selected to represent three climatic regions (cool, warm, and hot) and three traffic levels (low, medium and high). Two replicates were desired for each of the nine cells, but only a single replicate was identified for each of the three cells representing the hot climate. The sites had been in service for at least 12 years when they were sampled. The asphalt binder was extracted from the cores and the recovered aggregate remixed with virgin AC-20 asphalt binder. The remixed samples were compacted in a gyratory compactor and the numbers of gyrations were determined to match the densities of the cores. The density at the time of construction was assumed to be 92 percent of theoretical maximum density or  $G_{mm}$  for all of the projects. 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 was conducted on a range of mixes, which determined that a difference of



*Each HMA paving project was cored at the time of construction and at 3 months, 6 months, 1 year, 2 years and 4 years after construction to evaluate the field densification of pavements designed using the Superpave mix design concept*

approximately 30 gyrations resulted in a change in voids in the mineral aggregate (VMA) of approximately 1 percent. Similarly, a change of approximately 25 gyrations resulted in a change of 25 percent in mixture stiffness, as measured by the Superpave shear tester frequency sweep at constant-height test. However, these data were not verified for field conditions.

**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.

### Objectives

This research project was undertaken with the following three objectives: (a) to evaluate the field densification of pavements designed using the Superpave mix design system, (b) to verify or determine the Ndesign levels to optimize field performance, and (c) to evaluate the locking point concept in lieu of Ndesign gyrations.

### Research Plan

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  
*(continued on page 3)*



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**E. Ray Brown**, Director  
**Prithvi (Ken) Kandhal**, Associate Director Emeritus/ Editor  
**Cheryl Cobb**, Associate Editor, College of Engineering

### NCHRP 9-9 (1): Field Project Locations



US map showing locations of the 40 projects in 16 states evaluated by NCAT

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. Attempts were made to identify projects in the southwestern and northeastern United States. However, projects in the southwest were typically overlaid with open-graded friction course and therefore not suitable for this study. Projects could not be identified in the northeast that could be sampled during the required timeframe. In 2000, twenty-two HMA construction projects were visited and samples were obtained and tested. In 2001, the remaining eighteen HMA construction projects were visited and samples obtained and tested. 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 truck load of the HMA was placed on the roadway was marked. Three replicate specimens were compacted in SGC to two different gyrations levels, 100 and 160, without reheating, using two different SGCs in a mobile laboratory. Samples were split and boxed for determination of theoretical maximum density (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

corresponding to a given sample was laid. Gyratory specimens, cores, and loose mix (for Gmm, asphalt content, and gradation testing) were brought back to NCAT for testing.

3. The following tests were run at the NCAT laboratory:

- a. Compacted sample specific gravity (Gmb) by AASHTO T166
- b. Gmm by AASHTO T209
- c. Asphalt content determination by AASHTO T164
- d. Washed gradation analysis by AASHTO T30

4. The sites were revisited at approximately 3 months, 6 months, 1 year, and 2 years after construction. During each visit the following was conducted:

- a. Three additional cores were taken corresponding to each sample location at each project
- b. The pavement condition was visually assessed
- c. Rut depth measurements were taken adjacent to each core location with a 6-foot string line
- d. The cores were shipped back to NCAT for specific gravity determination as described above

Mix design and traffic information were also collected for each project. A mobile laboratory was sent to each site so that the SGC samples could be compacted without reheating. Previous research had indicated differences in compaction between different brands and models of SGCs. Therefore two SGCs, a Pine Model AFG1a and a Troxler Model 4141, were selected for the study. Although previous research had identified errors with the back calculation procedure, it was deemed impractical to compact samples

*(continued on page 4)*



A mobile NCAT laboratory was utilized at each paving project to test samples of HMA during construction



*Asphalt mix samples from the HMA plant were compacted in the NCAT mobile laboratory without reheating using two different Superpave gyratory compactors*

to all possible Ndesign levels. Therefore, two levels: 100 and 160 gyrations, were selected to minimize the number of gyrations for which the sample density needed to be back calculated.

### **Test Results and Observations**

There were several important hypotheses to be tested in this project:

1. Pavement densification is related to traffic
2. The laboratory design density should match the ultimate density in the field
3. In view of 1 and 2 above, the laboratory compaction effort should be related to traffic

Data from the 2000 NCAT Test Track had supported the following additional hypotheses:

1. Binder grade, particularly modified binders, affects the rate of pavement densification under traffic
2. Densification (the majority of the “rutting” which occurred at the 2000 NCAT Test Track) occurred when the air temperature exceeded approximately 28 °C

Visual assessments in the field were conducted along with the pavement coring at each coring interval. Rut depths were measured with a six-foot string line. Maximum observed rutting after four years in service was 7.4 mm. The average rutting observed for all of the projects after four years was 2.7 mm. All Superpave mixes were highly rut resistant. Noticeable raveling was observed on 14 of the 40 total projects; 13 projects exhibited cracking; 13 projects had popouts; and 7 projects exhibited moisture damage in either the test layer or the underlying layer.

The field projects reached their ultimate density after

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 month in which the project was constructed significantly affected the amount of densification which occurred. Projects constructed in the month of May tended to densify the most (approximately 4.0 percent). Projects constructed in April or June on average densified approximately 0.5 percent less than those constructed in May. Projects constructed in July or August densified slightly less than the average of all of the projects, approximately 3.0 percent. Projects constructed in September or October densified the least, an average of approximately 2.3 percent. High temperature Performance Grade (PG) of the asphalt binder or the number of high temperature PG bumps as compared to the climatic PG significantly affected pavement densification. Mixes containing PG 76-22 or with two high temperature PG bumps densified less than softer binders did.

The majority of the core samples from the field projects did not achieve the laboratory air void content at the agency specified Ndesign level. At a laboratory air void content of 4 percent, the average in-place air void content was 5.5 percent after two-years of traffic. This indicates that the laboratory compaction effort was higher than the combined compaction during construction and from traffic.

The NCAT Test Track data supported the NCHRP 9-9 (2) recommendation to lower Ndesign when the layer is deeper than 100 mm from the surface. The 2000 NCAT Test Track data indicated a reduction in Ndesign of 37 gyrations between the surface lift and a lift 50 mm from the pavement surface.

The general goal of previous studies to determine the appropriate laboratory compaction effort has been to determine the laboratory compaction effort that matches the ultimate density of the pavement after the application of traffic. Previous studies to determine or confirm laboratory compaction efforts have indicated a great deal of variability between field and laboratory compaction; therefore, variability was expected in this study. The variability in this study may have been exacerbated by the following three factors:

1. Field and traffic compaction are generally constant stress while the SGC is a constant strain device
2. The mixes sampled in this study contained a wide range of binder grades, not typical of previous studies
3. The mixes in this study were designed under a tiered system of aggregate properties and Ndesign levels

*(continued on page 5)*

## 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 January 29-February 2, 2007 and February 26-March 2, 2007, 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 **www.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.

### Conclusions

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

1. Pavements appear to reach their ultimate density after two years of traffic. The average in-place density for all of the projects was the same at 2- and 4-years (94.6 percent of Gmm). A fair relationship was determined between the as-constructed density and the density after two years of traffic. The majority of pavement densification, approximately 66 percent, occurs during the first three months after construction. 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.

2. The number of gyrations to match the ultimate in-place density was calculated for each project in this study. The calculated values for the two compactors used in this study differed by approximately 20 gyrations. This was attributed to differences in their dynamic internal angle (DIA).

The predicted gyrations, adjusted to a DIA of 1.16 degrees showed good agreement between the two machines.

3. Several analyses were conducted to evaluate the Ndesign levels. Combined, these analyses indicated that the Ndesign levels could be reduced.

4. 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.

5. The locking point concept was evaluated as an alternative to Ndesign. The locking point values determined for the Pine and Troxler compactors were almost identical, however densities at the locking point value (without adjustment to account for differing DIA's) were different. The density at the 3-2-2 locking point is weakly correlated to the ultimate density of the pavement. The locking point appears to be related to aggregate type, with softer aggregate producing higher locking point values.

6. 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 contents would be beneficial.

7. The requirements for Ninitial were evaluated based on the field project data. The majority of the projects, which failed Ninitial were fine-graded.

*(continued on page 6)*

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**TABLE 2. Recommended Ndesign Levels for Superpave gyratory compactor with a dynamic internal angle of  $1.16 \pm 0.02$  degrees**

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

All of the projects are performing well in terms of rutting resistance. Only one project failed Ninitial and was tender in the field. There is no strong evidence to keep the requirements for Ninitial.

8. The requirement for Nmaximum was 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.

### Recommendations

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  $1.16 \pm 0.02$  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.

The completion of this major project by NCAT is a significant milestone in the development of the Superpave mix design system, which will have an impact on all HMA designs in the future.



*Five highway engineers from New Zealand visited NCAT in March this year. They are seen here with NCAT staff.*

## 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.

### **Kentucky (Allen Myers, Kentucky Transportation Cabinet)**

Have any states experienced inconsistent mixture characteristics, namely erratic volumetric properties, in SMA containing fly ash as the mineral filler component? What type of asphalt mixing plant (e.g., counter-flow drum, parallel-flow drum, double-barrel drum, batch, etc.) was involved, and how was the fly ash introduced? How were the quality and consistency of the fly ash verified?

### **Virginia (Bill Maupin, Virginia DOT)**

Two trial sections of warm mix asphalt (WMA) produced using Sasobit were placed in Virginia during early August to evaluate performance and potential benefits of the technology. The first section included almost 1000 tons of WMA produced at a temperature of approximately 50 degrees F below typical temperatures. The second section included approximately 320 tons of WMA produced using a 30-degree F temperature

reduction; this trial involved a 1 hour and 45 minute haul time from the plant to the site. Evaluation of these sections (and future additional sites and technologies) is ongoing as part of research to determine how the DOT should proceed with specifying and accepting warm mix.

### **NCAT (Prithvi “Ken” Kandhal, Editor, Asphalt Technology News)**

Please read the cover story in this issue concerning the completion of NCHRP Project 9-9 (1), “Verification of Gyration Levels in the Ndesign Table”. Based on this major NCAT national study, a revised table of Ndesign gyrations used in the Superpave mix design system has been recommended. Recommendations have also been made to eliminate both Ninitial and Nmaximum requirements. Please share your comments on these proposed major revisions to the Superpave mix design system.

## ASPHALT FORUM RESPONSES

The following responses have been received to questions raised in the Spring 2006 **Asphalt Forum**.

*Has any agency observed that a modified asphalt binder could potentially mask the results of moisture susceptibility test in terms of tensile strength ratio (TSR)? For example, could a modified asphalt binder PG 76-22 give a higher, passing TSR value than a PG 64-22 in the same mix that is prone to stripping?*

**(Gary Head, Tennessee DOT)**

### **Kentucky (Allen Myers, Kentucky Transportation Cabinet)**

The Kentucky Transportation Cabinet routinely finds that, for a given aggregate blend, mixes containing a polymer-modified PG 76-22 binder produce higher TSR values than mixes with an unmodified PG 64-22 binder. Due to the enhanced properties of the binder, we in fact believe that asphalt mixtures containing a polymer-modified binder are less susceptible to stripping than the corresponding mix containing an unmodified binder. For laboratory mix designs, we do not require TSR testing of a given aggregate blend containing PG 76-22 when the same aggregate blend containing PG 64-22 satisfies the TSR specification.

### **Louisiana (Chris Abadie, Louisiana Transportation Research Center)**

We should expect improved TSR when we add polymers (the difference between PG 64-22 and PG 76-22 in Louisiana is about 3 percent SBS polymer). Does that mean that all asphalt binders that meet PG 76-22 mask the TSR test results? I believe that these asphalt mixtures are actually less prone to stripping. I find that our Louisiana PG 76-22 binder provides both higher TSR values and more resistance to moisture damage than Louisiana PG 64-22. We require 80 percent TSR after one freeze/thaw cycle. We have seen little or no stripping since our addition of polymers (Louisiana also requires liquid antistripping). The TSR test is certainly not a panacea, but it remains a very good tool with or without the use of polymers. In my opinion, the Hamburg test will be a good “proof” test for our mixtures, but even with that, I would not recommend elimination of the Modified Lottman test.

### **Mississippi (James Williams, Mississippi DOT)**

The Mississippi DOT has not observed any difference in stripping when modified and unmodified binders are used.

*(continued on page 9)*

## NCHRP PROJECTS RELATED TO HOT MIX ASPHALT

The following National Cooperative Highway Research Program (NCHRP) projects related to hot mix asphalt (HMA) and of interest to practicing engineers have been completed in recent years or are in progress at present.

Project No.	Project Title	Researching Agency	Contract Amount	Starting Date	Completion Date	Objectives (Status of the Project)
9-9 (1)	Verification of Gyration Levels in the Ndesign Table	Auburn University	\$ 625,000	2/3/2000	9/30/2006	Verify gyration levels in Superpave Ndesign table (completed)
9-10	Superpave Protocols for Modified Asphalt Binders	Asphalt Institute	\$ 995,000	4/15/1996	2/15/2001	Title self-explanatory (completed, published in NCHRP Report 459)
9-11	Segregation in Hot-Mix Asphalt Pavements	Auburn University	\$ 300,000	6/15/1997	1/14/2000	Develop procedures for defining, locating and measuring segregation (completed, published in NCHRP Report 441)
9-12	Incorporation of Reclaimed Asphalt Pavement in Superpave System	Purdue University	\$ 464,000	4/1/1997	9/30/2000	Develop guidelines for incorporating RAP in Superpave system (completed, published in NCHRP Report 452)
9-13	Evaluation of Water Sensitivity Tests	University of Nevada – Reno	\$ 150,000	11/1/1997	8/31/1999	Evaluate AASHTO T283 to make it compatible with Superpave system (completed, published in NCHRP Report 444)
9-14	Investigation of the Restricted Zone in the Superpave Aggregate Gradation Specifications	Auburn University	\$ 502,000	5/1/1998	7/15/2001	Determine if the restricted zone is necessary in Superpave system (completed, published in NCHRP Report 464)
9-16	Relationship Between Superpave Gyration Compaction Properties and Pavement Deformation	Asphalt Institute	\$ 250,000	5/10/1999	5/15/2002	Title self-explanatory (completed, published in NCHRP Report 478)
9-17	Accelerated Laboratory Rutting Tests – Asphalt Pavement Analyzer	Auburn University	\$ 370,000	5/19/1999	4/25/2003	Evaluate Asphalt Pavement Analyzer to predict HMA rutting potential (completed, published in NCHRP Report 508)
9-19	Superpave Support and Performance Models Management	University of Maryland	\$ 2,628,000	5/10/1999	7/31/2006	Develop simple performance tests for rutting and fatigue cracking (published in NCHRP Report 465)
9-20	Performance Related Specifications for HMA Construction	Nevada Automotive Test Center	\$ 1,500,000	12/31/1998	9/30/2000	Title self-explanatory (completed, published in NCHRP Report 455)
9-25	Requirements for Voids in Mineral Aggregate for Superpave Mixtures	Advanced Asphalt Technologies	\$ 400,000	4/2/2001	7/31/2006	Develop mix design criteria for VMA, VFA or binder film thickness (completed)
9-27	Relationship of HMA In-Place Air Voids, Lift Thickness and Permeability	Auburn University	\$ 350,000	4/19/2001	5/31/2004	Determine minimum HMA lift thickness and in-place density to achieve impermeable and durable pavement (completed, published in NCHRP Report 531)
9-29	Simple Performance Tester for Superpave Mix Design	Advanced Asphalt Technologies	\$ 1,059,000	4/2/2001	12/31/2006	Design, procure, and evaluate simple performance testers for Superpave mix design (partly completed, two NCHRP Reports 513 and 530 published)
9-31	Air Void Requirement for Superpave Mix Design	Advanced Asphalt Tech.	\$ 250,000	10/15/2001	7/31/2006	Title self-explanatory (completed)
9-33	A Mix Design Manual for Hot Mix Asphalt	Advanced Asphalt Tech.	\$ 400,000	7/1/2005	12/31/2007	Title self-explanatory (research in progress)

Project No.	Project Title	Researching Agency	Contract Amount	Starting Date	Completion Date	Objectives (Status of the Project)
9-34	Improved Test Procedure for Determining Moisture Damage Susceptibility of Bituminous Pavements	Pennsylvania State University	\$ 400,000	3/26/2002	10/3/2006	Develop an improved environmental conditioning system for determining HMA moisture susceptibility (research in progress)
9-35	Critical Review of Research on Aggregate Properties and Effects on Superpave Designed Mixes	Auburn University	\$ 75,000	9/16/2002	10/31/2004	Title self-explanatory (completed, published in NCHRP Report 539)
9-36	Improved Procedure for Laboratory Aging of Asphalt Binders in Pavements	Advanced Asphalt Technologies	\$ 500,000	2/17/2003	12/31/2006	Title self-explanatory (research in progress)
9-38	Endurance Limits of HMA to Pavement Fatigue Cracking in Flexible Pavements	Auburn University	\$ 750,000	1/23/2004	6/30/2007	Title self-explanatory (research in progress)
9-39	Procedure for Determining Mixing and Compaction Temperatures of Asphalt Binders in HMA	Auburn University	\$ 400,000	7/1/2005	12/31/2007	Title self-explanatory (research in progress)
9-40	Optimization of Tack Coat for HMA Placement	Louisiana Transportation Research Council	\$ 350,000	7/1/2005	1/31/2008	Determine binder types, equipment type, application methods and rates to optimize tack coats (research in progress)
9-41	Performance and Maintenance of Permeable Friction Courses (PFC)	Burns, Dennis, Cooley Inc	\$250,000	3/8/2005	12/31/2006	Recommend design, construction and maintenance guidelines for PFC (research in progress)

## — Asphalt Forum Responses

(continued from page 7)

Which other states are using chemically modified crumb rubber asphalt binder? (**Francis Manning, Rhode Island DOT**)

### Connecticut (**Keith Lane, Connecticut DOT**)

The Connecticut DOT does not use or specify chemically modified crumb rubber asphalt binder at this time.

### Mississippi (**James Williams, Mississippi DOT**)

The Mississippi DOT does not currently use chemically modified crumb rubber asphalt binders.

### Missouri (**Joe Schroer, Missouri DOT**)

Missouri has three projects planned for placement this fall with PG 64-22 binder modified with crumb rubber and Vestenamer (DeGussa Corp.) to meet PG 70-22 and PG 76-22 binder requirements.

### Ontario (**Kai Tam, Ontario Ministry of Transportation**)

We leave the modification of binders up to the supplier. We have been told that none of them are modifying asphalt cement with crumb rubber (let alone chemically modified crumb rubber asphalt cement) due to its cost.

*The Superpave mix design system requires compaction of HMA specimens with 50, 75, 100, or 125 gyrations (Ndesign) in a Superpave gyratory compactor depending on the amount of traffic on the project. The optimum asphalt content is then selected corresponding to 4.0 percent air voids. Some highway agencies have believed that the Superpave-designed mixes are relatively deficient in asphalt content, which may affect their durability. These agencies have modified the Superpave criteria in different ways to increase the optimum asphalt content in the mix. If your agency has done so, please share your modifications with other agencies. (**Prithvi “Ken” Kandhal, National Center for Asphalt Technology**)*

### Alabama (**Randy Mountcastle, Alabama DOT**)

The Alabama DOT experimented with the “locking point” concept of mix designs and found that most of Alabama’s aggregates lock around 60 gyrations. The “locking point” is defined as the point during the compaction process when two consecutive gyrations do not produce any recorded height change (less than 0.1 mm).

Now all our Superpave mixes are designed at 60 gyrations. To prevent the voids from being filled with dust, the design  
(continued on page 10)

## — Asphalt Forum Responses

(continued from page 9)

VMA has been increased by 0.5 percent. We also use minimum asphalt contents in the specifications based upon maximum aggregate size. Alabama bases the mix on maximum aggregate size rather than the nominal maximum aggregate size. All mixes greater than 30 million ESALs are now designed as stone matrix asphalt (SMA).

### Colorado (Roy Guevara, Colorado DOT)

In Colorado, the DOT now may decide, on a case-by-case basis, to lower the air voids content from 4 to 3 percent. The contractor still must optimize the mix at 4 percent air voids during the mix design. Then we allow ourselves to target up to 1 percent less air voids during production. There is more than one way to fill voids and we want to ensure that decreases in air voids are due to an increase in liquid binder content. If you tell somebody to design a mix at 3 percent air voids instead of 4 percent, they can plug up the voids with things like rounded or dirty fines. So, we adjust the air voids target after the mix design is complete. In some mixes, a change of 1 percent air voids will result in an increase of 0.3 percent of binder, and in other mixes it might change binder content by only 0.2 or 0.1 percent. Each mix reacts differently, depending on the aggregate gradations and the aggregate source. So far, we believe this approach has helped. The natural fear is that you are moving toward the rutting line, but we believe we are a long way from that point. We are seeing improvements in terms of decreased segregation, improved compaction during construction, and improved density at our longitudinal joints. We hope to see increased durability as we monitor our roads over the next few years.

### Connecticut (Keith Lane, Connecticut DOT)

We introduced a minimum binder content requirement for our HMA mixes in 2002, which did not conflict with any Superpave specifications. Any mix design must meet all Superpave requirements but also satisfy the minimum binder content, as specified by the department. We permitted the industry to migrate to these binder minimums from previously approved mix designs that were lower in binder content. We anticipated and found that all the contractors needed to do was to develop fine-graded mixes for each traffic class in order to meet these minimum binder requirements. We have seen great success in

getting the minimum binder compliance on mixes of 50, 75 and 100 gyrations (Traffic levels 1-3) with only a few not being able to comply at the 125 gyrations (Traffic level 4).

### Kentucky (Allen Myers, Kentucky Transportation Cabinet)

The Kentucky Transportation Cabinet (KYTC) utilizes three of the four gyration levels given in AASHTO standards. For less than three million 20-year ESALs, we specify 75 gyrations. For 20-year ESALs between three and 30 million, we specify 100 gyrations. Finally, for greater than or equal to 30 million 20-year ESALs, we specify 125 gyrations. In general, the optimum asphalt binder contents for Superpave mixtures in Kentucky have not been appreciably lower than the binder contents experienced with the Marshall mix design method. Contributing to this trend is the fact that KYTC now requires a minimum of 5.0 percent asphalt binder in our 1/2-in. nominal maximum size surface mixtures and a minimum of 5.3 percent asphalt binder in our 3/8-in. nominal maximum size surface mixtures. However, improved durability of our HMA pavements is always a worthy goal. To that end, the Kentucky Transportation Center at the University of Kentucky is currently conducting an “increased durability” research project for KYTC. This study involves higher asphalt binder contents (an additional 0.3 percent), higher core-density requirements (a minimum of 93.5 percent of theoretical maximum density), and lower target air void contents (a target of 3.0 percent) in HMA pavements containing PG 76-22 binders.

### Louisiana (Chris Abadie, Louisiana Transportation Research Center)

Louisiana has two gyration design levels in the latest specification (75 gyrations and 100 gyrations). Both require 3.5 percent air voids in lieu of 4 percent air voids. This decrease in air voids has increased the asphalt content in mixtures by about 0.1 to 0.2 percent. It seems at first glance that the aggregate gradation has become a bit finer as well.

### Mississippi (James Williams, Mississippi DOT)

The Mississippi DOT currently uses design gyrations of 50, 65, and 85 for low, medium, and high traffic levels, respectively.

### Ohio (Dave Powers, Ohio DOT)

The Ohio DOT uses an Ndesign of 65 gyrations for all heavy-traffic Superpave mixes to ensure HMA durability. The minimum specified asphalt content in the surface mixes is 5.7 percent. The material passing the 2.36 mm (No. 8) sieve is limited to no less than 32 percent to ensure that very coarse (permeable) mixes are not placed. A PG 70-22M or PG 76-22M asphalt binder is used in surface courses.

### Virginia (Bill Maupin, Virginia DOT)

The Virginia DOT uses Ndesign of 65 gyrations with 4.0 air voids across the board and adjusts for traffic level by using different grades of binder (PG 64-22, PG 70-22 and PG 76-22) or stabilizers such as fibers.

## RESEARCH IN PROGRESS

We have discontinued the publication of this column in this newsletter because it can now be accessed on NCAT's homepage ([www.ncat.us](http://www.ncat.us)). Click on Information at the top of the page, then Research in Progress. It is updated frequently based on the information received from the Departments of Transportation and other sources.

## SPECIFICATION CORNER

**Kentucky** – The Kentucky Transportation Cabinet (KYTC) plans to revise the criteria for selecting HMA mixtures in 2007. In response to the continuing concern about the permeability of Kentucky's surface mixtures, all 1/2-inch nominal maximum aggregate size (NMAS) mixes will be eliminated. In the future, only 3/8-inch NMAS mixes will be used. The thickness of HMA surface course mixes with core-density requirements will be 1¼ inch. The thickness of HMA surface course mixes without density requirements will be 1 inch. Also, due to the escalating costs of performance grade (PG) binders, the traffic threshold for specifying PG 76-22 will be raised from 3.0 to 7.0 million 20-year ESALs. It is anticipated that this change will result in specifying about half as much PG 76-22 binder as before and will save KYTC approximately \$5 million per year.

**Mississippi** – The Mississippi DOT (MDOT) has implemented changes to the quality control/quality assurance (QC/QA) comparison program in January 2006. Under the original program, split samples retained by the contractor were tested by both QC and QA personnel, and the data from these samples were compared for acceptance. Changes made include MDOT personnel going to the production facility and obtaining a random and independent test sample and comparing those test results to the running average of four contractor's test results at the time the MDOT sample was taken.

**Virginia** – The Virginia DOT plans to allow increased amounts of reclaimed asphalt pavement (RAP) in some specific HMA overlay jobs next year. The specification for the binder recovered by Abson recovery has been made less stringent so that bumping down the binder (using a softer grade) will be minimized. Cost savings and material properties from these selected jobs will be analyzed and reported.

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Over 80 NCAT research reports are now available as PDF (portable document format) files, which can be easily downloaded at no cost from our web site. You will need the Adobe Acrobat Reader, which can also be downloaded free from our homepage, to open these files. Visit our web site at [www.ncat.us](http://www.ncat.us) and click on NCAT Publications. Previous editions of Asphalt Technology News are also available from our homepage.

### PROFESSOR TRAINING COURSE IN ASPHALT TECHNOLOGY

NCAT has developed a training program for college and university civil engineering faculty that will allow them to offer state-of-the-art undergraduate and elective courses in asphalt technology.

The 8-day intensive course is conducted at NCAT in June every year. It will be held on June 19-28 next year. The course has been updated to include Superpave binder and mix technology, and stone matrix asphalt (SMA). Some financial assistance in attending this course is possible. **Participants will receive a copy of our latest college textbook on asphalt technology.** Please call NCAT at **334.844.NCAT** for brochure or information or visit our web site at [www.ncat.us](http://www.ncat.us).

**Ontario, Canada** – The Ontario Ministry of Transportation has revised some special provisions as follows:

- The calculation of voids in mineral aggregate (VMA) will now be based on the specific gravity of the blended coarse and the blended fine aggregates (instead of mathematically combining the specific gravity values of the individual coarse and fine aggregates).
- For the aggregate specific gravity testing, if the difference between the QA and QC testing is less than or equal to 0.010, the QC value will be used for calculating VMA. However, when that difference is between 0.011 and 0.020, the value used will be the mean of the two. Referee testing will only be invoked when the difference between QA and QC is greater than 0.020.
- A new clause has been added to the HMA smoothness requirements stating that the contractor should (it is not a requirement) either pad, diamond-grind, or micro-mill any surface underlying a surface course, in order to meet the smoothness requirements of the surface course (as long as the pavement is not reduced by more than 5 mm in thickness).

## PUTTING RESEARCH INTO PRACTICE

**The following papers were presented at the annual meeting of the Association of Asphalt Paving Technologists (AAPT) held in Savannah, Georgia in March, 2006. We are reporting observations and conclusions from them which may be of value to field engineers. These comments are obtained mostly from research projects with a limited scope; before application to practice we recommend that you read the entire paper to determine its limitations. Titles of the paper are given, with names of authors in parentheses, followed by a brief summary.**

### **1. Evaluation of Potential Processes for Warm Mix Asphalt (Hurley and Prowell)**

Three potential warm mix asphalt processes were evaluated in this study. They were Aspha-min®, Sasobit®, and Evotherm®. The objective of this study was to perform a laboratory study to determine the applicability of these processes in warm mix asphalt applications including typical paving operations and environmental conditions commonly found in the United States. The processes were evaluated with respect to compactability, quick turnover to traffic, stiffness, rutting potential, and moisture susceptibility.

Recently, several new processes have been developed to reduce the mixing and compaction temperatures of hot mix asphalt (HMA) without sacrificing the quality of the resulting pavement. These processes produce warm mix asphalt (WMA), which can reduce production temperatures by as much as 40 percent. North American asphalt mixes are generally heated to 300°F (149°C) or greater, depending mainly on the grade of binder used; mixes produced with these new products are being produced at temperatures of about 250°F (121°C) or lower. Lower plant mixing temperatures mean fuel cost savings to the contractor – findings have shown that lower plant temperatures can lead to a 30 percent reduction in fuel energy consumption. Lower temperatures also mean less volatilization, reducing health or odor problems, as well as emissions of greenhouse gasses. This decrease represents a significant cost savings, considering that 30-50 percent of overhead costs at an asphalt plant can be attributed to emission control. Lower emissions may allow asphalt plants to be sited in non-attainment areas, where there are strict air pollution regulations.

The first process is known as Aspha-min which is a product of Eurovia Services GmbH, based in Bottrop, Germany. Aspha-min is a manufactured synthetic sodium aluminum silicate, better known as zeolite. Zeolites are framework silicates with

large empty spaces in their structures that allow the presence of large cation groups, such as water molecules. Most zeolites are characterized by their ability to lose and absorb water without damaging their crystal structure. Heat can drive off the water contained in the zeolite, which can then act as a delivery system for the new fluid. Eurovia's Aspha-min contains approximately 21 percent water by mass and is released in the temperature range of 185-360°F (85-182°C). When Aspha-min is added to the mix at the same time as the binder, water is released. This water release creates a volume expansion of the binder that results in asphalt foam and allows increased workability and aggregate coating at lower temperatures.

During the production of HMA, Eurovia recommends that Aspha-min be added at a rate of 0.3 percent by mass of the mix, which in previous research has shown a potential 54°F (30° C) reduction in typical HMA production temperatures. Asphamin zeolite is approximately a 50 mesh material which may be added directly to the pugmill of a batch plant, through the RAP collar, or pneumatically fed into a drum plant using a specially built feeder.

The second process is branded Sasobit, which is a product of Sasol Wax. It is a fine crystalline, long-chain aliphatic polymethylene hydrocarbon produced from the gasification of coal or natural gas feedstocks using the Fischer-Tropsch (FT) process. It is also known as FT hard wax. Sasobit is described as an "asphalt flow improver", both during the asphalt mixing process and during laydown operations, due to its ability to lower the viscosity of the asphalt binder. This decrease in viscosity allows working temperatures to be decreased by 32-97°F (18-54°C). Sasobit has a melting temperature of about 216°F (102°C) and is completely soluble in asphalt binder at temperatures higher than 248°F (120°C). At temperatures below its melting point, it reportedly forms a crystalline network structure in the binder that leads to the added stability. During the production of HMA, Sasol recommends that Sasobit be added at a rate of 0.8 percent or more by mass of the binder, but not to exceed 3 percent. It can be blended into hot binder at the blending plant without the need for high shear mixing. In commercial applications in Asia, Europe, South Africa, and the United States, Sasobit has been added directly onto the aggregate mix as solid prills (small pellets) or as molten liquid via a dosing meter.

Evotherm is a non-proprietary technology based on a chemistry package that includes additives to improve coating. The total package is typically 0.5 percent by weight of emulsion, as was the case for this study. The chemistry is delivered in an emulsion with a relatively high asphalt residue (approximately 70 percent). Unlike traditional asphalt binders, Evotherm is  
(continued on page 13)



Two different porous asphalt mixes were laid simultaneously in August by a double paver on Georgia DOT sponsored Test Section N 13 of the NCAT Test Track. The double paver provided by DYNAPAC laid 1-1/4 inches of 12.5 mm Porous European Mix (PEM) and 5/8 inches of 9.5 mm Open-Graded Friction Course (OGFC) simultaneously. The 2-layer porous mix concept has been used successfully in the Netherlands to enhance drainage and also to reduce noise levels emanating from the tire-road interface.

stored at 176°F (80°C). The water in the emulsion is liberated from it in the form of steam when it is mixed with the heated aggregate. The resulting warm mix appears like hot mix in terms of coating and color.

Two aggregate types (granite and limestone) and one asphalt binder grade (PG 64-22) were used to evaluate the three processes. However, to achieve the PG 64-22 binder used with the Sasobit, 2.5 percent Sasobit was added to a base PG 58-28 binder to produce the PG 64-22 binder. The Superpave mix design consisted of 12.5mm nominal maximum aggregate size and an Ndesign of 125 gyrations was used. Once the mix designs were verified at 300°F (149°C), each combination was then compacted at three lower temperatures: 265, 230, and 190°F (129, 110, 88°C). Volumetric properties for each of the 32 mix design combinations (one binder grade, two aggregates,

### SUPERPAVE MIX DESIGN WORKSHOP

Superpave mix design workshop will be held at NCAT on March 27-30, 2007. 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 [www.ncat.us](http://www.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.

three processes and one control mix type, and four compaction temperatures) was determined.

The following conclusions were drawn from this laboratory study:

- The Superpave gyratory compactor (SGC) was not sensitive to the reduction in compaction temperature. Therefore, all test samples were compacted in a vibratory compactor to simulate field compactability.
- The addition of any warm mix processes lowers the measured air voids in the gyratory compactor. While this may indicate a reduction in the optimum asphalt content, at this time it is believed that additional research is required and that the optimum asphalt content of the mixture determined without any additives should be used. It should be noted that the optimum asphalt content of the mixture without the addition of any additive was used for all of the testing completed in this study. All processes improved the compactability of the mixtures in both the SGC and vibratory compactor. Statistical analyses indicated an average reduction in air voids up to 0.77 percent for the Aspha-min zeolite, 0.89 percent for the Sasobit, and up to 1.53 percent for the Evotherm in the vibratory compactor. Improved compaction was noted at temperatures as low as 190°F (88°C) for all three additives.
- The use of any warm mix process evaluated in this study does not affect the resilient modulus of an asphalt mix compared to mixtures having the same PG binder. Increased density improves the measured resilient modulus. Therefore, there would not be any effect on pavement thickness design when using warm asphalt mixes.

*(continued on page 14)*



A driving rain one day after the placement of the 2-layer porous asphalt pavement on NCAT Test Track Test Section N 13 showed the pavement was draining properly. There was no accumulation of rain water on the surface of the pavement.

- The addition of Sasobit, zeolite, or Evotherm does not increase the rutting potential of an asphalt mix. The rutting potential increased with decreasing mixing and compaction temperatures and this may be related more to the decreased aging of the binder. However, the mixes containing Sasobit were less sensitive (in terms of rutting) to the decreased production temperatures than were the control mixes.
- The indirect tensile strengths for mixes containing Sasobit were lower, in some cases, as compared to the control mixes. This reduction in tensile strength is believed to be related to the anti-aging properties of Sasobit observed in the binder testing. Other laboratory tests (APA and Hamburg) indicated good rutting resistance for the mixes containing Sasobit.
- There was no evidence of differing strength gain with time for the mixes containing any additives as compared to the control mixes. The addition of Aspha-min or Evotherm may not require a cure time for the asphalt mixture prior to opening to traffic. Field data from Europe supports the fact that the addition of Sasobit does not require a cure time for the asphalt mixture prior to opening to traffic, as well.
- The lower compaction temperature used when producing warm mix asphalt with any such warm mix additive may increase the potential for moisture damage. The lower mixing and compaction temperatures can result in incomplete drying of the aggregate. The resulting water trapped in the coated aggregate may cause moisture damage. Reduced tensile strength and visual stripping were observed in both the control and warm asphalt mixes produced at 250°F (121°C).
- Various anti-stripping agents were evaluated to mitigate the potential for moisture damage. Hydrated lime used with zeolite appeared to be effective with the granite aggregate. The addition of 1.5 percent hydrated lime resulted in improved cohesion and moisture resistance over the warm mixtures without hydrated lime. The addition of AKZO Nobel Magnabond (Kling Beta 2912) improved the tensile strength ratio (TSR) values to acceptable levels for the Sasobit.
- Hamburg wheel-tracking tests indicated good performance in terms of moisture susceptibility and rutting for the mixtures containing Sasobit and Magnabond. Hamburg results also suggested that lime will also assist in the rutting resistance of warm mixtures,

with Aspha-min compacted at lower temperatures due to the lime stiffening the asphalt binder.

Based on the research conducted to date, the following is recommended when using any warm mix additive to reduce hot mix asphalt production temperatures:

- The modified binder including Sasobit needs to be engineered to meet the desired Performance Grade. As an example in this study, a PG 58-28 was used as the base asphalt with the addition of 2.5 percent Sasobit to produce a PG 64-22.
- The optimum asphalt content should be determined without the addition of any warm mix additive. Additional samples should then be produced so the field target density can be adjusted (e.g. If the laboratory air void content with any additive included was decreased in the laboratory by 0.5 percent, then the field target density should be increased by 0.5 percent).
- Based on the compaction and rutting results, a minimum field mixing temperature of 275°F (135°C) and a minimum field compaction temperature of 250°F (121°C) is recommended. If the mixing temperature is below 275°F (135°C), then the high temperature grade should be bumped by one grade. Performance testing can be conducted to predict field performance. Field compaction will dictate the true minimum compaction temperature depending on a number of factors.
- Tensile strength ratio (TSR) testing should be conducted at the anticipated field production temperatures. If test results determined are not favorable, anti-stripping agents should be added to the mix to increase the tensile strength ratio.
- More research is needed to further evaluate field performance, the selection of the optimum asphalt content, and the selection of binder grades for lower production temperatures.

## **2. Development and Refinement of the Florida Department of Transportation's Percent Within Limits Hot Mix Asphalt Specification (Sholar, Musselman, Page and Moseley)**

The Florida Department of Transportation (FDOT) implemented a statistically based, percent within limits (PWL) specification for the acceptance and payment of hot mix asphalt in July 2002. The specification also addressed small quantities as well as single test pass/fail criteria. The same year FDOT also adopted a Contractor Quality Control (CQC) system where acceptance was based on the contractor's quality control data. The PWL specification criteria were developed based on data collected from FDOT construction projects built under the previous Quality Assurance (QA) System, where acceptance and payment were based on tests conducted by FDOT personnel.

*(continued on page 15)*

## **NCAT HAS DOMAIN NAME**

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In 2004, FDOT conducted a study to assess the PWL specifications after two years of use. The study was conducted to compare the variances generated under the old QA system to variances generated under the new CQC system. Data was collected from 79 CQC projects and analyzed. The analysis examined variances of various mixture characteristics, including roadway density, percent air voids, asphalt binder content, percent passing the No. 8 (2.36 mm) sieve, and percent passing the No. 200 (0.075 mm) sieve. The analysis also examined individual mixture characteristic pay factors and composite pay factors generated under the CQC System.

This paper presents a brief background of the original analysis conducted in 2001 and explains in detail the results of the second analysis and modifications made to FDOT specifications.

### Summary of 2001 Analysis

Data for the following hot mix asphalt properties was analyzed: 1) roadway density, 2) percent air voids, 3) asphalt content, 4) percent passing the No. 8 sieve, and 5) percent passing the No. 200 sieve. A total of 4,377 cores were used in the analysis of roadway density and 1920 test results were used in the analysis for each of the other four properties. Data from a wide range of contractors and mixture types was included. Median lot standard deviations were calculated for each material property. A typical lot is defined as four 1000-ton sublots and contains one test result per subplot for percent air voids, asphalt content, percent passing the No. 8 sieve, and percent passing the No. 200 sieve. For roadway density, five cores are obtained per subplot and are averaged to obtain one density value per subplot. FDOT used the method presented in the AASHTO Quality Assurance Guide Specification and NCHRP Report 447 to develop the specification limits for each asphalt material property. In this method, a contractor can receive 100 percent payment if 90 percent of the estimated population (as determined by the contractor's test results) is within the upper and lower specification test limits. The median standard deviations are multiplied by 1.645 to obtain the specification limits for each material property.

**TABLE 1**

HMA Property	Target Value	Specification Limits
Roadway density, %Gmm (coarse mixtures)	94.50	+/- 1.30
Roadway density, %Gmm (fine mixtures)	93.00	+ 2.00, -1.00
Percent Air voids	4.00	+/- 1.40
Percent Asphalt Content	Mix Design	+/- 0.40
Percent Passing No. 8	Mix Design	+/- 3.10
Percent Passing No. 200	Mix Design	+/- 1.00

Table 1 gives the target values and implemented specification limits for various HMA properties based on the 2001 analysis. In the FDOT acceptance and payment system, a pay factor is

calculated for each material property and then a composite pay factor is calculated by multiplying each individual pay factor by a weighting factor as shown in Table 2.

**TABLE 2**

HMA Property	Weight
Roadway density	35
Percent Air voids	25
Asphalt Content	25
Percent Passing No. 8	5
Percent Passing No. 200	10
Total	100

### 2004 Analysis Plan

Approximately two years after the implementation of the new PWL specification, FDOT conducted a follow-up study to compare the variability of the material properties resulting from the old QA system to the variability resulting from the new PWL System based on contractor quality control test results. The purpose of the study was to assess the functionality and performance of the new system and make modifications as necessary. The analysis plan consisted of compiling and analyzing test result and pay factor data from projects constructed under the new PWL specification. The data included all mix design types utilized in Florida, large and small tonnage projects and included data from a wide range of asphalt contractors. Data was collected throughout Florida from 18 contractors and represented 79 projects, 152 mix designs, 480 lots and 1848 sublots. For each project and mix design, the within-lot variance was determined.

After discussions were held between FDOT, industry and the FHWA, two primary changes were made to the PWL portion of the specification: (1) the lower specification limit for roadway density of fine graded mixtures was increased from 1.00 to 1.20 percent Gmm, and (2) air voids for coarse and fine graded mixtures were separated and the specification limit for fine graded mixtures was narrowed to +/- 1.20 % from a target of 4.00 percent. The specification limits for coarse graded mixtures and all of the other material properties were left unchanged. Therefore, the results of the 2004 material property variability analysis indicated that the specification limits established from the 2001 analysis were reasonable with only slight adjustments needed for roadway density and air voids, both for fine graded mixtures.

It has been recommended that the FDOT continue to periodically examine the material property variability and pay factor distribution and make modifications to the specification as necessary. Analysis and assessment of the FDOT's and contractor's risk is also needed.

## NCAT's Professor Training Course June 20-29, 2006



**Back, L-R:** Ray Brown (Instructor), Don Watson (Instructor), Paul McMullin, Chuck Mills, Jayhyun Kwon, Greg Morris, Syed Haider, Mohan Devgun, Bryce Cole, Jianlin Wang, Bryan Keas, Andre Smit (Instructor). **Middle, L-R:** Shaojing Wu, Xingwei Chen, Monte Symons (Instructor), Xiong (Bill) Yu, Hector Garcia, Parisa Shokouhi, Nader Amer, Hassan Salama, Sanjeev Adhikari, Webert Lovencin, John Bartoszek, Jie Zhang. **Front, L-R:** Fen Ye, Randy West (Instructor), Qingli (Barbara) Dai, Jie Huang, Corey Enderby, Minkwan Kim, Elizabeth Pastuszka, Runhua Guo. *Not Pictured: Jason Selvage.*



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