

# Transportation Literature Search



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## In-Place Permeability of HMA Pavements

Prepared for  
Bureau of Highway Construction  
WHRP Flexible Pavements Technical Oversight Committee

November 30, 2004

*Transportation Literature Searches are prepared for WisDOT technical staff in highway development, construction and operations. The bibliography below is representative, rather than exhaustive, of available studies on the topic. Primary online resources for the literature searches are the Transportation Libraries Catalog ([TLCat](#)), the Transportation Research Information Service ([TRIS Online](#)), and various academic and scientific databases. Online copies of publications are noted when available. Hard copies of all cited literature may be obtained through the WisDOT Library.*

### **KEYWORDS**

Terms used in Web-based searches were: HMA pavements; permeability; in-place permeability; pavement density; in-place HMA pavements; air voids; target in-place permeability values; in-place air void content; t/NMAS (minimum thickness to nominal maximum aggregate size ratio); pavement mixture; Superpave pavements; mixture layer; lift; NMAS (nominal maximum aggregate size); lift thickness; bulk specific gravity.

### **LIBRARY OF CONGRESS DESCRIPTORS**

Library of Congress descriptors identified were: Bulk density; Specific gravity; Water; Saturation flow; Air Voids; Dimensional Analysis; Compaction; void ratios; hot mix paving mixtures; permeability; field permeator(s); Asphalt emulsion mixtures; Asphalt concrete—Density; Asphalt emulsion mixtures—Testing; Pavements; Asphalt concrete—Permeability; Compressive strength; Overlays (pavements); Base course (Pavements); porosity; air voids reduction; creep.

### **CITATIONS**

#### **BOOKS/TECHNICAL REPORTS**

##### **Title: Relationships of HMA In-Place Air Voids, Lift Thickness, and Permeability – Volume 1**

Author(s): National Cooperative Highway Research Program, Transportation Research Board. Submitted by: E. Ray Brown, M. Rosli Hainin, Allen Cooley, Graham Hurley, National Center for Asphalt Technology, Auburn University, Auburn, Alabama

Date: September 2004

Doc ID/URL: NCHRP Web Document 68 (Project 9-27), [http://trb.org/publications/nchrp/nchrp\\_w68v1.pdf](http://trb.org/publications/nchrp/nchrp_w68v1.pdf)

Description: 144 pages.

Conclusions: Based upon the results of this study, the following conclusions can be drawn. The density that can be obtained under normal rolling conditions is clearly related to the t/NMAS. For improved compactibility it is recommended that the t/NMAS be at least 3 for fine graded mixes and at least 4 for coarse graded mixes. The data for SMA indicates that the ratio should also be at least 4. Ratios less than these suggested numbers could be used but it would generally require more compactive effort to obtain the desired density. In most cases a t/NMAS of 5 does not result in the need for more compactive effort to obtain maximum density. However, care must be exercised when the thickness gets too large to ensure that adequate density is obtained.

The results of the evaluation of the effect of mix temperature on the relationship between density and t/NMAS indicate that one of the reasons for low density at thinner sections (lower t/NMAS) is the more rapid cooling of the mixture. Hence, for thinner layers it is even more important that rollers stay very close to the paver so that rolling can be accomplished prior to excessive cooling. For the conditions of this study the mixes placed at 25mm thickness

cooled twice as fast as mixes placed at 37.5mm thickness. For thicker sections (larger t/NMAS) rate of cooling is typically not a problem. The in-place void content is the most significant factor impacting permeability of Superpave pavements. This is followed by coarse aggregate ratio and VMA. As the values of coarse aggregate ratio increases, permeability increases. Permeability decreases as VMA increases. The variability of permeability between various mixtures is very high. Some mixtures are permeable at the 8 to 10 percent void range and others do not seem to be permeable at these higher voids. However, to ensure that permeability is not a problem the in-place air voids should be between 6 and 7 percent or lower. This appears to be true for a wide range of mixtures regardless of NMAS and grading.

**Title: Relationships of HMA In-Place Air Voids, Lift Thickness, and Permeability – Volume 2**

Author(s): National Cooperative Highway Research Program, Transportation Research Board. Submitted by: E. Ray Brown, M. Rosli Hainin, Allen Cooley, Graham Hurley, National Center for Asphalt Technology, Auburn University, Auburn, Alabama

Date: September 2004

Doc ID/URL: NCHRP Web Document 68 (Project 9-27), [http://trb.org/publications/nchrp/nchrp\\_w68v2.pdf](http://trb.org/publications/nchrp/nchrp_w68v2.pdf)

Description: 83 pages.

Conclusions and recommendations: The objectives of Task 3, Part 3 were to: (1) compare AASHTO T166 with other methods of measuring bulk specific gravity to determine under what conditions AASHTO T166 is accurate; (2) identify potential improvements to AASHTO T166 to achieve a more accurate measure of bulk specific gravity (if needed); and (3) recommend alternate methods of measuring bulk specific gravity (if needed). Separate sets of data for laboratory prepared samples and field compacted samples were evaluated to accomplish these objectives. Based upon these results the following conclusions are made:

- When laboratory prepared samples having low levels of water absorption were evaluated, the dimensional method resulted in the highest air void contents followed by the gamma ray method. The vacuum-sealing and water displacement (AASHTO T166) methods resulted in similar air void contents when the water absorption level was low.
- At low levels of water absorption, the water displacement method is an accurate measure for bulk specific gravity. The error develops when removing the sample from water to determine the SSD weight. If water flows out of the sample an error occurs. The allowable absorption level to use the displacement test method is 2% in AASHTO T166 but this level of absorption can create accuracy problems as shown in this report. This number should be reduced to 1% or lower for better accuracy. If the allowable water absorption is reduced much below 1%, many field compacted mixes will exceed this absorption resulting in a need for an alternate test method. It is recommended that the absorption limit for the displacement test method be reduced to 1%. If the vacuum-seal method is adopted on a project the contractor should realize that the compactive effort may now have to be increased over what has been used in the past since the voids measured with the vacuum-seal method will be higher than that measured with the AASHTO T166 method in the 7-10 percent void range or higher.
- The water displacement method was accurate for all water absorption levels encountered for mixes that were fine-graded (ARZ gradations). For mixes having gradations near the maximum density line (TRZ) or coarser (BRZ and SMA), the level of water absorption at which AASHTO T166 was no longer accurate was between 0.2 and 0.4 percent.
- For mix design samples and other laboratory samples that are compacted to relatively low voids, the displacement method will provide reasonable accurate answers. However, for field samples where the void levels will typically be 6% or higher it is important to evaluate absorption to determine if the vacuum-seal method needs to be used.
- Care must be used when using the vacuum sealing method to measure density. Many times the plastic bag developed a leak during the test, leading to an error in the result. Weighing the sample in air after measuring the submerged weight will indicate if a leak has developed. If a leak is identified the test must be repeated until an acceptable test is achieved.
- There appears to be a need for a correction factor for the vacuum-sealing and water displacement methods to provide equal measured air void contents even when the air void level is low. The correction factor for the mixtures evaluated in this report should be approximately 0.2% air voids. A better determination of the correction factor can be made for specific dense graded mixes by compacting samples in the Superpave gyratory compactor to approximately 4% air voids (design air void content) and testing using the two test methods. The difference between these two tests will be the correction factor for the mix.

**Title: Relationships of HMA In-Place Air Voids, Lift Thickness, and Permeability – Volume 3**

Author(s): National Cooperative Highway Research Program, Transportation Research Board. Submitted by: E. Ray Brown, M. Rosli Hainin, Allen Cooley, Graham Hurley, National Center for Asphalt Technology, Auburn University, Auburn, Alabama

Date: September 2004

Doc ID/URL: NCHRP Web Document 68 (Project 9-27), [http://trb.org/publications/nchrp/nchrp\\_w68v3.pdf](http://trb.org/publications/nchrp/nchrp_w68v3.pdf)

Description: 47 pages.

Conclusions: The primary purpose for the field study was to validate the findings in the earlier part of the study and to validate the relationships between voids, lift thickness, and permeability. Based on the field study of the twenty pavement sections the following conclusions were made:

- The in-place air voids of the twenty projects were high. Fourteen of the twenty mixes tested had average in-place air voids above 8% and seven of the mixes had average air voids over 10% (based on test results with the vacuum-seal method). Five of the seven projects with more than 10% air voids were coarse-graded mixes. This low density on a high percentage of random projects is disturbing since this lower density will most certainly lead to significant loss in pavement life. The poor density obtained on most of these projects makes it very difficult to determine the effect of t/NMAS, grading, and other factors on permeability. In general, much of the loss in pavement life is a direct result of low density. This study along with other recent studies clearly shows that inadequate density is a significant problem on a high percentage of paving projects.
- Some of the twenty projects did not have poor density results. For example, five of the twenty projects had less than 7% average air voids. Three of these projects with less than 7% air voids were coarse-graded mixes. These successful projects show that adequate density can be obtained.
- Even though there is a lot of scatter in the data (within and between projects), most of the results for these twenty projects support the finding that higher t/NMAS ratios generally provide lower void levels.
- Based on these twenty projects coarse-graded mixtures generally have higher permeability values than the fine-graded mixtures for a given air void level.
- Air voids were clearly shown to be a key determinant of permeability. However, many times the air voids were reasonably low (5-7%) and the permeability was still high. Permeability testing needs to be conducted on local materials to develop an understanding of the effect of air voids, NMAS, and grading on permeability. Consideration should be given to making permeability a part of the specification requirements.

**Title: Relationships of HMA In-Place Air Voids, Lift Thickness, and Permeability – Volume 4 (Appendices)**

Author(s): National Cooperative Highway Research Program, Transportation Research Board. Submitted by: E. Ray Brown, M. Rosli Hainin, Allen Cooley, Graham Hurley, National Center for Asphalt Technology, Auburn University, Auburn, Alabama

Date: September 2004

Doc ID/URL: NCHRP Web Document 68 (Project 9-27), [http://trb.org/publications/nchrp/nchrp\\_w68v4.pdf](http://trb.org/publications/nchrp/nchrp_w68v4.pdf)

Description: 333 pages

Contents: TASK 3 – PART 1 AND 2. APPENDIX A - MIX DESIGN SUMMARY INFORMATION FOR PART 1. TASK 3 – PART 3 - APPENDIX A - INFORMATION ON 40 SAMPLES FOR SATURATION TIME EXPERIMENT. TASK 5 - Appendix A and B - FIELD PROJECT REPORTS, TEST RESULTS AND DISCUSSION.

**Title: Density Measurements of Hot Mix Asphalt (HMA) Pavements**

Author(s): David Andrewski, Materials Engineer, Materials and Tests Division, Indiana Department of Transportation

Date: December 2003

Doc ID/URL: Joint Transportation Research Program, SPR-2327,

[http://rebar.ecn.purdue.edu/JTRP\\_Completed\\_Project\\_Documents/SPR\\_2327/FinalReport/SPR-2327%20Final%20Report.pdf](http://rebar.ecn.purdue.edu/JTRP_Completed_Project_Documents/SPR_2327/FinalReport/SPR-2327%20Final%20Report.pdf)

Description: 5 pages.

Contents: It was found that the most accurate method to determine the field density of HMA mixtures was by testing cores taken from the pavement and determining their density; however, the PQI gauge was found to be a good QC tool. During Phase 2 it was found that greater densities could be achieved in most case by decreasing the speed of the rollers. Although one might suspect that this would increase the number of rollers required on a project it was found that decreasing the speed of the rollers would also decrease the number of passes required.

**Title: Correlation between the Laboratory and Field Permeability Values for the Superpave Pavements**

Author(s): Aneel Gogula, Mustaque Hossain, Stefan Romanoschi, Department of Civil Engineering Kansas State University and Glenn A. Fager, P.E. Materials & Research Center Kansas Department of Transportation

Date: August 2003

Doc ID/URL: In Proceedings of the 2003 Mid-Continent Transportation Research Symposium,

<http://www.ctre.iastate.edu/pubs/midcon2003/GogulaSuperpave.pdf>

Description: 11 pages.

Contents: Permeability affects the performance of Superpave pavements. Percolation of water, through the interconnected voids of an asphalt pavement, causes stripping of the asphalt-bound layer as well as deterioration of the foundation layers of the roads. In this study, laboratory and field permeability tests, based on the principles of falling head, were conducted on different Superpave mixes with 19 mm and 12.5 mm nominal maximum aggregate sizes and coarse and fine gradations, to study the correlation between the laboratory and the field permeability values. The objective was to assess whether the field permeability values could be estimated during the mixture

design process so that mix design can be adjusted depending upon the degree of permeability desired. The results show that there was a significant difference between the laboratory- measured and the field permeability values. The field permeability values were very high compared to the laboratory-permeability values. The reason behind this discrepancy was further investigated and explained in this paper. Nevertheless, the field permeability values were found valuable in assessing compaction quality of the Superpave pavements.

**Title: DEVELOPMENT OF CRITICAL FIELD PERMEABILITY AND PAVEMENT DENSITY VALUES FOR COARSE-GRADED SUPERPAVE PAVEMENTS**

Author(s): Cooley, LA, Jr; Brown, ER; Maghsoodloo, S - National Center for Asphalt Technology, Auburn University

Date: 2001

Doc ID/URL: NCAT Report No. 01-03, <http://www.eng.auburn.edu/center/ncat/reports/rep01-03.pdf>

Description: 24 pages

Contents: Within the hot mix asphalt (HMA) community, it is generally accepted that the proper compaction of HMA is vital for a stable and durable pavement. Low in-place air voids have been shown to lead to rutting and shoving while high in-place air voids have been shown to reduce a pavement's durability through moisture damage and excessive oxidation of the asphalt binder. Recent research has suggested that coarse-graded Superpave designed mixes are more permeable than conventionally designed pavements at a given air void content. This higher permeability can lead to durability problems. This study was conducted to evaluate at what pavement density coarse-graded Superpave mixes become permeable using a field permeability device. Based upon the data collected, 9.5 and 12.5 mm nominal maximum size mixtures (NMA) become excessively permeable at approximately 7.7% in-place air voids, which corresponded to a field permeability value of 100x(10 to the -5th) cm/sec. Mixtures having a 19.0 mm NMA became permeable at an in-place air void content of 5.5% air voids which provided a field permeability value of 120x(10 to the -5th) cm/sec. Coarse-graded mixes having an NMA of 25.0 became permeable at 4.4% air voids, which corresponded to a field permeability value of 150x(10 to the -5th) cm/sec

**Title: Evaluation of Permeability of Superpave Mixes in Maine**

Author(s): Mallick, R.B., L.A.Cooley, Jr., and M.Teto, Maine Department of Transportation

Date: 1999

Doc ID/URL: Technical Report ME-001, <http://ntl.bts.gov/lib/15000/15900/15954/PB2000101827.pdf>

Description: 54 pages.

Contents: This study was carried out to evaluate the permeability of Superpave mixes used by the Maine Department of Transportation, and determine the effect of voids, gradation and lift thickness on permeability. A field permeameter was developed on the basis of the National Center for Asphalt Technology field permeameter, and was used for testing projects with 9.5 mm, fine and coarse, 12.5 mm coarse, 19 mm coarse, and 25 mm coarse graded mixes. Testing of cores taken from location of field testing were also conducted in the laboratory according to Florida Department of Transportation method. Samples of loose mix obtained during construction were also compacted to different thickness in the laboratory, prior to permeability testing. Results from permeability tests indicated that mixes with different gradations and nominal maximum aggregate size have significant increase in permeability at different voids in total mix content. All of the mixes tested in this project showed permeability below critical permeability at or below 5% in place construction voids. Hence, the average specified 5% construction voids in total mix or 95% of theoretical maximum density seems to be justified for Superpave coarse graded mixes used by the Maine Department of Transportation.

**Title: EVALUATION OF PAVEMENT PERMEABILITY IN MISSISSIPPI**

Author(s): L. Allen Cooley, Jr. National Center for Asphalt Technology

Date: July 2003

Doc ID/URL: <http://www.gomdot.com/research/pdf/EvalPPMs.pdf>

Description: 51 pages.

Contents: The primary objective of this study was to evaluate the permeability characteristics of HMA pavements constructed in Mississippi. A secondary objective was to compare the AASHTO T166 and vacuum-sealing methods for determining bulk specific gravity of field compacted samples. Based upon the research results and analyses, the following are concluded:

1. There is a significant relationship between the permeability and pavement density (air voids). This relationship is dependent on both nominal maximum aggregate size and gradation.
2. Mixes having a nominal maximum aggregate size of 9.5 mm became excessively permeable at in-place air voids of 8.8 percent based upon the Corelok data and 7.6 percent for the AASHTO T166 data. Mixes having a 12.5 mm nominal maximum aggregate size became excessively permeable at 9.3 percent air voids based upon Corelok testing and 8.5 percent for the AASHTO T166 data. Mixes having a nominal maximum aggregate size of 19.0 mm became excessively permeable at 6.2 percent based upon Corelok testing, while the AASHTO T166 data indicated 4.8 percent in-place air voids. Of the mix types tested during this study, only the fine-graded 12.5 mm nominal maximum aggregate size mixes would be expected to be impermeable (assuming a critical

permeability level of  $125 \times 10^{-5}$  cm/sec) at typical density specifications (8 percent in-place using AASHTO T166 results).

3. There is a significant relationship between permeability and water absorption as measured by AASHTO T166 on cores cut from a roadway. The relationship appears to be more related to gradation shape than nominal maximum aggregate size. For coarse-graded mixes, a water absorption value of approximately 1 percent would define a point where a pavement becomes excessively permeable.
4. Air void contents resulting from the testing of core samples using Corelok and AASHTO T166 bulk specific gravity methods were significantly different. The Corelok method resulted in significantly higher air void contents. On the basis of the conclusions of this study, it is recommended that field permeability testing be used as a quality control for pavement density on selected HMA projects. This testing should initially shadow current density specifications to determine the usefulness of the field permeability device to control construction practices. It is also recommended that the Department further evaluate the use of the Corelok vacuumsealing device for measuring the bulk specific gravity of field compacted samples.

**Title: BULK SPECIFIC GRAVITY ROUND-ROBIN USING THE CORELOK VACUUM SEALING DEVICE**

Author(s): Prowell, BD; Cooley, LA, Jr; Hainin, MR; Buchanan, MS; Harrington, J - National Center for Asphalt Technology and Federal Highway Administration (corporate author)

Date: 2002

Doc ID/URL: FHWA Report No. FHWA-IF-02-044.

Description: 122 pages.

Contents: This project conducted an evaluation of the Corelok device for the determination of the bulk specific gravity of compacted hot mix asphalt samples. The project consisted of the bulk specific gravity determination for compacted HMA mixes using the Corelok vacuum-sealing device and the SSD method (AASHTO T166). All samples were prepared by the National Center for Asphalt Technology (NCAT) and were provided to each participating laboratory for testing. Participating laboratories conducted the bulk specific gravity testing using both the Corelok device and SSD method. Test results were returned to NCAT for statistical analysis and determination of repeatability and reproducibility parameters for both methods. A total of 21 laboratories participated in this study. 18 of which returned test results. Each laboratory was provided a Corelok vacuum sealing device through the pooled-fund effort.

**Title: Relationship of Air Voids, Lift Thickness, and Permeability in Hot Mix Asphalt Pavements**

Author(s): E. Ray Brown, M. Rosli Hainin, Allen Cooley, Graham Hurley, National Center for Asphalt Technology, Auburn University, Auburn, Alabama

Date: 2004

Doc ID/URL: NCHRP Report 531, [http://trb.org/publications/nchrp/nchrp\\_rpt\\_531.pdf](http://trb.org/publications/nchrp/nchrp_rpt_531.pdf)

Description: 48 pages

Contents: This report presents recommended guidelines for hot mix asphalt pavement construction to achieve satisfactory levels of in-place air voids and permeability. These guidelines were developed from the findings of a research project that examined the relationship of air voids content to permeability and hot mix asphalt lift thickness. The report will be of particular interest to materials and construction engineers in state highway agencies, as well as to materials supplier and paving contractor personnel responsible for the production and placement of hot mix asphalt. The full findings of the research were published as NCHRP Web Document 68.

**Title: Permeability of Pavement Base Course**

Author(s): SAM I. THORNTON, CHIN LEONG TOH - Civil Engineering Department, University of Arkansas.

Submitted to Arkansas Highway and Transportation Department, Little Rock, Arkansas and Mack-Blackwell National Rural Transportation Study Center, University of Arkansas, Fayetteville

Date: May 1995

Doc ID/URL: <http://www.mackblackwell.org/research/finals/MBTColdFinals/MBTC1010.pdf>

Description: 59 pages

Contents: Base course permeability plays an important role in many pavement failures which are subjected to moisture-related problems. The Mack-Blackwell National Rural Transportation Study Center and the Arkansas Highway and Transportation Department (AHTD) sponsored the 'Permeability of Pavement Base Course' research to measure the permeability of some granular base course materials. Limestone, sandstone, igneous rock, and Razorrock chert were the materials tested. The permeameter, which was obtained from the U.S. Bureau of Reclamation, was used during the permeability test to contain a 19" diameter by 9" thick base course specimen. A laboratory procedure was developed to build the specimen in 3 layers by using a mechanical compactor. The AHTD Class-7 base course gradation was used to construct the base course specimens. Specimens with 3%, 6.5%, and 10% fines were tested to identify the change in permeability due to the variation of fines. Limestone is the most permeable aggregate tested for all gradations. The permeability of limestone ranges from  $5.52 \times 10^{-3}$  cm/sec at 3% fines to  $2.49 \times 10^{-3}$  cm/sec at 10% fines. The least permeable aggregate at 3% fines content is Razorrock chert

which has a permeability of  $2.91 \times 10^{-3}$  cm/sec. At 10% fines, sandstone has the lowest permeability of  $1.86 \times 10^{-4}$  cm/sec. Samples with 3% fines has an average decrease of 74% in permeability when fines were increased to 10%. For all gradations, permeability results obtained from the DRAINIT spreadsheet program are approximately 100 times less permeable than the results obtained from the permeability tests.

**Title: Relationships between air voids, lift thickness, and permeability of hot mix asphalt (HMA) mixtures**

Author(s): Mohd Rosli Hainin

Date: 2004

Doc ID/URL: Dissertation: Thesis (Ph. D.)--Auburn University

Description: 321 leaves

**Title: Evaluation of HMA laboratory permeability using the Karol-Warner Flexible Wall Permeameter**

Author(s): Justis, Thomas D.

Date: 2001

Doc ID/URL: Dissertation: Thesis (M.S.)--University of Tennessee, Knoxville

Description: 118 leaves

**Title: Evaluation of the field permeability of HMA using the NCAT tiered permeameter**

Author(s): Oliver, Daniel K

Date: 2001

Doc ID/URL: Dissertation: Thesis (M.S.)--University of Tennessee, Knoxville

Description: 170 leaves

**Title: Final report, TRC-9901, permeability of Superpave**

Author(s): Hall, Kevin D. ; Cruz, Josue. ; Gin, Hooi.

Date: 2004

Doc ID/URL: University of Arkansas State Highway and Transportation Dept report

Description: 1 CD-ROM

Contents: In 1998 all asphalt concrete hot mix (ACHM) used for federal-aid projects in Arkansas was designed using Superpave volumetric mix design system. ... This project generally sought to find methods for accurately determining the permeability of Superpave mixes.

**Title: Effect of void size, arrangement and interconnectivity on permeability of hot-mix asphalt concrete: void pathway test**

Author(s): Ng, Hooi Gin.

Date: 2000

Doc ID/URL: Dissertation: Thesis (M.S.C.E.)--University of Arkansas, Fayetteville

Description: 144 leaves

**Title: Permeability of hot-mix asphalt concrete**

Author(s): Cruz, Josue Sebastian

Date: 2000

Doc ID/URL: Dissertation: Thesis (M.S.C.E.)--University of Arkansas, Fayetteville

Description: 115 leaves

**Title: Wet-dry indirect tensile test for evaluating moisture susceptibility of asphalt mixtures**

Author(s): Kennedy, Thomas William ; Anagnos, James N

Date: 1984

Doc ID/URL: Center for Transportation Research, Bureau of Engineering Research, University of Texas at Austin, Research report no. 253-8

Description: 46 p

Contents: This report contains a description of the development and use of the Wet-Dry Indirect Tensile Test to evaluate stripping or moisture susceptibility of asphalt mixtures. Tests were performed on eight mixtures of which five had stripped in the field and three had not. Each mixture was tested to determine whether the results could be used to differentiate between stripping and nonstripping mixtures. Based on these tests and other field testing it was tentatively concluded that mixtures with less than 70 percent retained strength are moisture susceptible and require treatment. Test results indicate the valuable information is provided by the Wet-Dry Indirect Tensile Test. The test can be performed either in the laboratory during mixture design or on the field-mixed materials. In general, the Wet-Dry Indirect Tensile Test offers good potential for use in detecting moisture susceptible mixtures before they are placed in the field.

**Title: Comparison of air void content measurements in fresh versus hardened concretes**

Author(s): Ozyildirim, H. Celik (Hamdi Celik)

Date: 1990

Doc ID/URL: Virginia Transportation Research Council, 90-R23

Description: 26 pages.

Contents: This study compares the air content of freshly mixed and hardened concretes. At the fresh stage, pressure meters (Types A and B) and a volumetric meter were used to determine the air content. At the hardened stage, the air content was calculated using the linear traverse method described in ASTM C 457, which is a microscopical procedure. The unit weight and compressive strength of the concretes were also determined. The results show that, at the ranges commonly used in the construction of pavements and bridges, the air content of fresh concrete measured by pressure meters and that determined by the microscopical method for essentially the same concrete after hardening are, for practical purposes, the same. The air content obtained by a volumetric meter as normally run in the field is generally lower than that obtained for the same hardened concretes by the microscopical method. The unit weight and compressive strength correlate well with the air content. It was also shown that adding water to concrete can significantly increase the air content, as well as the slump. Thus, a higher air content in hardened concretes than that indicated by initial measurements with a pressure meter is likely to be present if water is added during placement.

**Title: Investigation of low compressive strengths of concrete paving, precast and structural concrete**

Author(s): Cross, William.

Date: 2000

Doc ID/URL: South Dakota Dept. of Transportation, Report No: SD98-03-F,

<http://ntl.bts.gov/reports/SD98-03FINAL.pdf>

Description: 78 p

Contents: This research examines the causes for a high incidence of catastrophically low compressive strengths, primarily on structural concrete, during the 1997 construction season. The source for the low strengths was poor aggregate/paste bond associated with air void clusters and poorly formed cement paste in the interfacial region adjacent to the aggregate. An interaction between the 3synthetic4 air entraining admixtures, used as substitutes for vinsol resin, and low alkali cements was directly tied the problem with high summertime temperatures also contributing to the problem. The 3synthetics4 appear to be more hydrophobic, form thinner-walled air bubbles and develop rapid draining bubble flocculations more readily than vinsol resin, all of which can lead to significant reductions in strength. As an interim measure, the Department specified the sole use of vinsol resin air entraining agents along with water reducers, as needed, in April, 1998 and these measures have minimized the incidence of low strengths. Petrographic analysis of cores taken from low strength concretes failed to reveal the causes of the low strength problem but SEM microscopy clearly showed the failure mechanism. Laboratory testing of concrete mixes with various air entraining admixtures demonstrated an interaction was taking place with one cement and petrographic and chemical analysis of the cements used in the testing implicated alkali sulfates as a potential source of the interaction. Testing of the 3synthetic4 air entraining admixtures showed they have substantially different properties compared to vinsol resins. Mixtures of the 3synthetics4 and vinsol resin with 50 % or more vinsol resin behaved similarly to vinsol alone.

**Title: QUANTITATIVE AND RAPID MEASUREMENT OF THE AIR-VOID SYSTEM IN FRESH CONCRETE**

Author(s): Hansen, W

Date: 1991

Doc ID/URL: Strategic Highway Research Program, SHRP-ID/UFR-91-519

Description: 29 pages

Contents: This paper evaluates a new method for determining air void characteristics in fresh concrete. The method uses a laser counting device to evaluate the number and distribution of air voids. The measurements are made on a core extracted from a sample of fresh concrete frozen with liquid nitrogen.

**Title: DETERMINATION OF THE OPTIMUM BASE CHARACTERISTICS FOR PAVEMENTS**

Author(s): White, DJ; Vennapusa, P; Jahren, CT - Center for Transportation Research and Education, Iowa State University

Date: 2004

Doc ID/URL: Iowa DOT Project TR-482, <http://www.ctre.iastate.edu/reports/tr482.pdf>

Description: 270p

Contents: In recent years, it has become apparent that the design and maintenance of pavement drainage extends the service life of pavements. Most pavement structures now incorporate subsurface layers. Part of the function of these subsurface layers is to drain away excess water, which can be extremely deleterious to the life of the pavement. To assure the effectiveness of such drainage layers after they have been spread and compacted, simple, rapid, in-situ permeability and stability testing and end-result specification are needed. This report includes conclusions and recommendations related to four main study objectives: (1) Determine the optimal range for in-place stability and

in-place permeability based on Iowa aggregate sources; (2) Evaluate the feasibility of an air permeameter for determining the permeability of open and well-graded drainage layers in situ; (3) Develop reliable end-result quality control/quality assurance specifications for stability and permeability; and (4) Refine aggregate placement and construction methods to optimize uniformity.

**Title: Evaluation of Permeability of Superpave Mixes**

Author(s): Walaa S. Mogawer, Rajib B. Mallick, Matthew R. Teto and William C. Crockford

Date: July 3, 2002

Doc ID/URL: Prepared for The New England Transportation Consortium, Project No. NETC 00-2,

<http://docs.trb.org/00932402.pdf>

Description: 87 pages

Contents: The objectives of this study were to evaluate permeability of Superpave mixes and develop procedure for permeability testing. The scope included testing of mixes in the laboratory and in the field, determination of relationships between mix properties and permeability, and development and recommendation of new mix design and in-place testing methods. Results from this study indicate that air voids, gradation and nominal maximum aggregate size have significant effects on permeability of HMA mixes. Amounts of interconnected air voids were found to be significantly higher for coarse graded mixes. A critical permeability of 10-3 cm/s is suggested for designing HMA mixes. Porosity test by the vacuum sealing method was found to be a good indicator of mix permeability. Porosity was found to be significantly affected by mix gradation, specifically the percent passing the 2.36 mm sieve. Charts were developed to help mix designers avoid mixes with excessive permeability, by selecting appropriate gradation and in-place air voids. Results of field tests indicated that in-place permeability is significantly affected by air voids and aggregate gradation and nominal maximum aggregate size. Permeabilities of coarse graded mixes with larger nominal maximum aggregate size are more sensitive to change in air voids than relatively fine mixes with smaller nominal maximum aggregate size. A laboratory-field permeameter was developed for testing "true" in-place permeability and also for use as a field quality control tool.

**Title: 4.75 MM NMAS STONE MATRIX ASPHALT (SMA) MIXTURES**

Author(s): Hongbin Xie, L. Allen Cooley, Jr., Michael H. Huner

Date: December 2003

Doc ID/URL: NCAT Report 03-05, National Center for Asphalt Technology,

<http://www.eng.auburn.edu/center/ncat/reports/rep03-05.pdf>

Description: 23 pages

Contents: The use of 4.75 mm nominal maximum aggregate size (NMAS) hot mix asphalt has recently become a more attractive alternative to highway engineers because these mixes have the potential to be used within a preventative maintenance program. The primary reason for this attractiveness is that these mixes can be placed in thin lifts. Because of the recent research and experiences in developing 4.75 mm NMAS SMA mixes, a study was needed to further refine the design of 4.75 mm NMAS SMA mixes. Specifically, the fraction passing the 0.075 mm sieve and the currently specified draindown basket were evaluated.

Based upon the test results and analyses, SMA mixes having a 4.75 mm NMAS can sometimes be successfully designed having gradations with aggregate fractions passing the 0.075 mm sieve less than the currently specified 12 percent. Gradations with aggregate fractions passing the 0.075 mm sieve of 9 percent can be utilized as long as all other requirements are met.

Draindown tests conducted using a wire mesh basket with 2.36 mm openings produced test results with less draindown than tests conducted with a wire mesh basket having 6.3 mm openings. It was concluded that the difference in draindown results between the two basket types was related to the amount of mix that could fall through the different mesh size openings.

**Title: AN EVALUATION OF FACTORS AFFECTING PERMEABILITY OF SUPERPAVE DESIGNED PAVEMENTS**

Author(s): Rajib B. Mallick, L. Allen Cooley, Jr., Matthew R. Teto, Richard L. Bradbury, Dale Peabody

Date: June 2003

Doc ID/URL: Auburn University, NCAT Report 03-02, <http://www.eng.auburn.edu/center/ncat/reports/rep03-02.pdf>

Description: 34 pages.

Contents: It can be expected that the life of a permeable pavement would be shorter than that of an impermeable pavement, due to deterioration of mix through water and air infiltration, and subsequent stripping and oxidation and hardening of binder. Recent work has indicated that coarse graded Superpave mixes can be excessively permeable to water at air void levels around 6 percent. The objectives of this study were to evaluate the permeability of Superpave designed mixes used by Maine Department of Transportation and determine the effect of gradation, lift thickness, and in-place density on the permeability of these mixes. Five Superpave projects were selected for this study. These

projects included coarse-graded 9.5 mm, 12.5 mm, 19.0 mm, and 25.0 mm nominal maximum aggregate size (NMAS) mixes and one fine-graded 9.5 mm NMAS mix. Based on the National Center for Asphalt Technology permeameter, a field permeameter was developed at the Worcester Polytechnic Institute (WPI) laboratory. This permeameter was used for testing at ten locations per project. One core was obtained at each of these test locations. The cores were used to determine in-place density at each of the test locations. Field testing was done at random locations, immediately behind the finish roller. Loose mixes were also obtained from each project. The loose mixes were compacted to 5 percent air voids, and to different thickness to evaluate the effect of thickness on permeability. On the basis of results obtained in this study, the following conclusions can be made:

1. Air void content (as measured by voids in total mix) of dense graded HMA has a significant effect on in-place permeability of pavements,
2. There is a significant effect of NMAS on the permeability of coarse-graded Superpavedesigned mixes. It was shown that at a given in-place air void content the permeability increased by one order of magnitude as the NMAS increased,
3. Samples with different thicknesses showed that there is a decrease in permeability with an increase in thickness. It is recommended that State DOTs consider designing mixes to be placed 100 mm below the pavement surface on the fine side of the maximum density line. By designing base mixes on the fine side of the maximum density line, these mixes could be made less permeable than coarse graded mixes at similar void levels and thus less susceptible to allowing moisture or moisture vapor to propagate upward through the pavement structure. This in turn should reduce the potential for moisture damage within pavement structures.

**Title: Development of Simplified Asphalt Concrete Stiffness/Fatigue Testing Device**

Author(s): Nam H. Tran, Kevin D. Hall

Date: March 2004

Doc ID/URL: MBTC-2014, Mack-Blackwell National Rural Transportation Study Center, University of Arkansas, Department of Civil Engineering, Fayetteville, AR,

<http://www.mackblackwell.org/research/finals/arc2014/MBTC%202014%20-%20FINAL%20REPORT.pdf>

Description: 170 pages.

Contents: Mechanistic-empirical flexible pavement design procedures proposed for use within the 2002 Design Guide require the input of the dynamic modulus ( $E^*$ ) of hot-mix asphalt concrete. In addition, the  $E^*$  test has been proposed as a "simple performance test" for use in mixture design and construction quality control. The objective of this study included conducting the dynamic modulus test, evaluating the accuracy/variability of test results, and constructing master curves for the mixtures tested. The hotmix asphalt mixes tested in this research are typically used for pavement construction in Arkansas, and binder content and air voids were varied to simulate typical construction variability. The analysis showed that the variability of the average dynamic modulus for each set of four replicates was acceptable. Since the dynamic modulus tests were run at intermediate temperatures in this study, a modified procedure, using Arrhenius and power functions, was employed to construct the master curves. Based on the master curves, the effects of aggregate size, binder content, and air voids on the tested asphalt mixtures were evaluated and determined to be consistent and reasonable. The testing procedure and results of this study were recommended for use in a new project to characterize the stiffness of Arkansas mixtures to prepare input data for the proposed 2002 Design Guide.

**Title: IMPACT OF FINES ON ASPHALT MIX DESIGN**

Author(s): Tayebali, AA; Khosla, NP; Malpass, GA

Date: 1996

Doc ID/URL: North Carolina State University, <http://itre.ncsu.edu/cte/tayebali-khosla-malpass1996.pdf>

Contents: Pavement engineers have known for some time that the particle shape and surface texture of aggregates play a significant role in the constructability, drivability, strength, and durability of asphalt concrete pavements. Superpave recommends use of a variety of aggregate tests to ensure minimum desirable aggregate characteristics or "consensus properties" in order to assure an acceptable level of performance. For fine aggregates, the recommended method is AASHTO TP33 (ASTM C1252) - Test Method for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading). In this investigation, three methods for classifying aggregate particle shape and texture - AASHTO TP33 (ASTM C1252), ASTM D3398 (Index of Particle Shape and Texture), and the flow rate method - were evaluated. These methods were used to rank four natural river sands and a crushed granite from good to poor performance based on the criteria established in each method. Test results indicate that all methods easily distinguished the crushed aggregate from the natural river sands. The AASTHO TP33 (ASTM C1252) and the flow rate methods were found to be somewhat less sensitive to slight differences in particle shape and texture than ASTM D3398. The flow rate test was also found to be dependent on the gradation of the aggregate while the index values determined by ASTM D3398 and AASHTO TP33 (ASTM C1252) seemed to be less dependent on grading. All the test methods were found to be repeatable, each having low coefficients of variation for all the aggregates tested. One of the objectives of this study was to show that increased amount of mineral fillers can be accommodated in asphalt mixtures without adversely affecting its rutting (permanent deformation performance). Results of this study clearly indicate that within the range of mineral filler content and

type used in this study, increasing the amount of mineral filler has a beneficial effect on the rutting performance. However, although the rutting performance is enhanced, it should be noted that at a higher mineral filler content, the asphalt content is reduced, which may have a detrimental effect on other mixture properties, such as fatigue, thermal cracking, and raveling.

## **JOURNAL ARTICLES**

### **Title: An Evaluation of Selected Methods for Measuring the Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Mixes**

Author: M. S. Buchanan

Source: Journal of the Association of Asphalt Paving Technologists

Date/Pages: Vol. 69, 2000, pp. 608-634.

Abstract: The measurement of the bulk specific gravity of compacted hot mix asphalt (HMA) mixes is the basis for volumetric mix design and quality process control procedures. Among the items, which are dependent upon the measured mix bulk specific gravity, are air voids and voids in mineral aggregate. In this study, four methods of mix bulk specific gravity are evaluated. The methods include the water displacement, dimensional analysis, parafilm, and the vacuum sealing method. The evaluation consisted of measuring samples of the four mix types (fine and coarse Superpave, Stone Matrix Asphalt, and Open Graded Friction Course), three compactive efforts (low, medium, and high), and two aggregate types (limestone and granite). Additionally, all samples were cut into cubical shaped samples and the mix bulk specific gravity determination was repeated with all the methods. The results indicated that the vacuum sealing method appeared to provide the best measurement of the specific gravity of the samples in all instances. The ability of the other methods to accurately measure the specific gravity was found to be dependent upon the parameters (type, compactive effort, and sample state) of the mix being tested.

### **Title: Development of A Simple Test for Evaluation of In-Place Permeability of Asphalt Mixes**

Author: Mallick, R.B., Cooley, A.L., Teto, M.R., and R.L. Bradbury

Source: International Journal of Pavement Engineering

Date/Pages: v.2, n. 2, 2001, pp. 67-83

Abstract: Dense graded hot mix asphalt mixtures are designed to have low permeability to resist excessive penetration of water and avoid durability problems. With the introduction of Superpave mixes, there is concern that the coarse graded mixes are more permeable, at similar void levels, compared to fine graded mixes. Presently, however, there is a lack of a simple tool for measuring the in-place permeability of asphalt mixes. This paper describes a simple permeability test developed to determine the effect of voids and gradation on permeability. The field permeameter was used for testing projects with 9.5 mm fine and coarse, 12.5 mm coarse, 19 mm coarse, and 25 mm coarse graded mixes. Testing of cores taken from location of field testing were also conducted in the laboratory. Results from the in-place permeability tests were found to be consistent with experience with fine and coarse graded mixes. These results indicate that mixes with different gradations and nominal maximum aggregate size have significant increase in permeability at different voids in total mix content. Additional results are reported and recommendations are provided.

### **Title: Selection and Evaluation of a Field Permeability Device for Asphalt Pavements**

Author: Cooley, L.A., and E.R. Brown

Source: Transportation Research Record 1723

Date/Pages: 2000, pp. 73-82

Abstract: Results of a study conducted to select, standardize, and evaluate a device to estimate the in-place permeability of hot-mix asphalt (HMA) pavements are presented. The study consisted of evaluating four different field permeameters in order to select and standardize a device that was correlated with laboratory permeability results, would provide repeatable results, and was easy to use. Additional testing on five HMA pavements was conducted with the selected device in order to evaluate the relationship between in-place pavement density and field permeability. The study entailed visiting three ongoing construction projects and conducting field permeability tests on newly compacted HMA pavements with each device. Also at each project, cores were obtained from which the laboratory permeability was determined. The data from each project were analyzed to determine which field permeameter correlated best with laboratory permeability, provided the most repeatable results, and was easy to use. Results of this study indicated that two permeameters did not show significant differences in results when compared with laboratory permeability results and had approximately the same amount of repeatability. For this reason, a field permeameter was selected on the basis of ease of use. This selected device was then taken to five additional HMA construction projects. At each project, field permeability testing was conducted, and the in-place density of pavements was obtained from cores. Relationships between in-place air voids and field permeability for all five projects were good: R-squared values ranged from 0.63 to 0.82.

**Title: USE OF OPEN-GRADED, FREE-DRAINING LAYERS IN PAVEMENT SYSTEMS: A NATIONAL SYNTHESIS REPORT**

Author: Baldwin, JS

Source: Transportation Research Record 1121

Date/Pages: 1987 - pp.86-89

Abstract: The effects of excessive and uncontrolled water entrapped in the various components of a paving system are known or suspected to have been responsible for unsatisfactory performance and outright failures of both portland cement concrete and asphaltic concrete pavements. To eliminate or at least reduce the detriment, almost half of the highway and transportation agencies across the nation have been addressing the problem by designing and constructing free-draining pavement systems. In an effort to ascertain just how much and what kind of attention is being given free-draining pavements on a national scale and to gain some insight into the performance characteristics of such systems designed to date, the Transportation Research Board's Committee on Subsurface Drainage prepared a questionnaire for national distribution in the fall of 1985. This paper is an attempt to summarize the responses to that questionnaire.

**Title: ECONOMIC IMPACT OF PAVEMENT SUBSURFACE DRAINAGE**

Author: Forsyth, RA; Wells, GK; Woodstrom, JH

Source: Transportation Research Record 1121

Date/Pages: 1987 pp 77-85

Abstract: Even though road builders have recognized the role of water in pavement deterioration since the last century, with the development of the "rational" methods of pavement design evolved a strong reliance on the ability to build pavements stout enough to resist damage without the benefits of good drainage. Even today, most designers attempt to improve the strength and "quality" of the pavement and base layers used in road construction and neglect rapid drainage. Much of the water that falls on pavements penetrates the structural section through cracks, joints, and porous surfaces. Conventional slow-draining pavements are deteriorating more rapidly than is necessary because of the impacts of heavy vehicles on flooded structural sections. The most positive pavement drainage systems use an open-graded drainage layer under the full width of a roadbed with adequate collector pipes and outlet pipes. However, the California Department of Transportation has found that retrofit edge drains are greatly reducing the rate of step faulting of existing portland cement concrete pavements. The impact of positive rapid drainage features on the performance of a number of pavements is reviewed, with particular emphasis on the establishment of a cost-benefit relationship. The results of this evaluation indicate that the increased cost of effective pavement drainage is almost incidental to the savings realized through improved performance.

**Title: DRAINABILITY OF GRANULAR BASES FOR HIGHWAY PAVEMENTS**

Author: McEnroe, BM

Source: Transportation Research Record 1434

Date/Pages: 1994 pp 23-28

Abstract: The best measure of the drainability of a granular base is the minimum degree of saturation that can be achieved through gravity drainage in the field. The amount of water that can drain from a base course depends not only on the physical properties of the material, but also on the cross-sectional geometry of the pavement system. A fine-grained base may remain fully saturated under the largest suction that can be developed through gravity drainage. A formula for the minimum degree of saturation in the granular base is developed from Brooks and Corey's formula for water retention in unsaturated porous media. The relationship for drainable porosity in the FHWA subdrainage design manual tends to overestimate the amount of drainage from fine-grained bases and greatly underestimate the amount of drainage from coarse-grained bases. If the minimum degree of saturation for a granular base is sufficiently low, it will drain fairly quickly. The recommended method for the estimation of drainage times is a one-dimensional analysis of the saturated flow below the phreatic surface. This analysis accounts for the nonuniform spatial distribution of drainable porosity. Casagrande and Shannon's procedure, which is recommended by FHWA, tends to underestimate drainage times, particularly for base courses that are relatively thin. The recommended procedures for subdrainage analysis have been implemented in the SUBDRAIN computer program of the Kansas Department of Transportation.

**Title: INVESTIGATION OF PERMEABILITY ON INDIANA SR-38**

Author: Haddock, JE; Prather, M

Source: Journal of Performance of Constructed Facilities (ASCE)

Date/Pages: 2004 - Volume: 18 Issue: 3, pp 136-141

Abstract: In 1999, a 9.5 mm nominal maximum size hot-mix asphalt mixture, designed according to the Superpave mixture design method, was placed as an overlay on Indiana State Road 38. Within 1 year of construction, the pavement showed signs of significant distress, including aggregate pop-outs and degradation, the presence of free water (weeping) on the driving surface, and longitudinal and fatigue cracking. At the District's request, an investigation was undertaken to determine the cause of the pavement distress. As part of the investigation, core samples were taken from the road surface and tested for compliance with material properties and volumetrics, and to

determine the mixture permeability. The mixture met all relevant materials and volumetric specifications, but had a low in-place density and was permeable. Results show that the mixture was too coarsely graded to achieve compaction in the relatively thin lift specified by the Department of Transportation. It was recommended that the mixture be removed and replaced, and that mixture specifications be revised to more closely control gradation and increase mixture lift thickness.

**Title: An Alternative Approach for the Determination of Bulk Specific Gravity and Permeability of Hot Mix Asphalt (HMA)**

Author: Bhattacharjee S.; Mallick R.B.

Source: International Journal of Pavement Engineering

Date/Pages: 1 January 2002, vol. 3, no. 3, pp. 143-152

Abstract: The objective of this study was to investigate the use of an alternative method for determination of bulk specific gravity and estimation of water permeable voids of dense graded HMA mixes. As a part of an ongoing study on evaluation of permeability of HMA, several dense graded mixes with coarse and fine gradations from three New England states were compacted to produce mixes at different air voids. The bulk specific gravities of these mixes were determined using both the saturated surface dry method and the vacuum seal method. Theoretical maximum densities of these mixes were also determined. Air voids of the different compacted mixes were estimated from the bulk specific gravity and theoretical maximum density values. Porosity and permeability tests were also conducted on the mixes. The results showed that for coarse graded mixes and fine graded mixes with high air voids, the vacuum seal method provided a better estimation of air voids in a compacted HMA mix. For coarse graded mixes, porosity can provide a good indication of inter-connectivity of air voids in a compacted HMA mix. Analysis of the data showed that porosity could provide an excellent indication of permeability of HMA. A porosity of 7% seemed to be critical--mixes with porosity greater than 7% showed significantly higher permeability than mixes with porosity lower than 7%. Charts have been provided for selection of proper gradation and air voids to avoid mixes with excessive permeability.

**Title: Water-cement ratio gradients in mortars and corresponding effective elastic properties**

Author: Nadeau J.C

Source: Cement and Concrete Research

Date/Pages: March 2002, vol. 32, no. 3, pp. 481-490

**Title: Permeability and bleeding of asphalt concrete using mixture theory**

Author: Murali Krishnan J.; Lakshmana Rao C.

Source: International Journal of Engineering Science

Date/Pages: April 2001, vol. 39, no. 6, pp. 611-627

**Title: Mechanics of air voids reduction of asphalt concrete using mixture theory**

Author: Murali Krishnan J.; Lakshmana Rao C.

Source: International Journal of Engineering Science

Date/Pages: August 2001, vol. 38, no. 12, pp. 1331-1354

**Title:**

**Air voids reduction phenomena of asphalt concrete – A continuum approach**

Author: Krishnan J.M.; Rengaraju V.R

Source: International Journal of Fracture

Date/Pages: 1999, vol. 97, no. 1-4, pp. 337-354

Abstract: Asphalt concrete used in flexible highway pavement construction has 5–8 percent air voids immediately after laying of the roadway. Constitutive laws for asphalt concrete developed till now have modelled the mix as a linear elastic or viscoelastic material and have not taken into account the effect of void concentration on the mechanical behaviour of the material. In this paper, the theory of linear elastic material with voids is used to model asphalt concrete under isothermal conditions. Two cases of void reduction behaviour are studied, one in which the void volume reduces asymptotically under a constant load and the other in which it reaches the refusal air void content. The model is used to predict the creep behaviour under constant compressive stress as well as to obtain the hysteretic stress-strain behaviour. Solutions for the case of uniaxial deformation are derived and the strains are simulated for a constant compressive stress. Use of the air voids reduction measure as a possible damage parameter is also examined.

## **PRESENTATIONS**

### **Superpave Mixture and Aggregate Expert Task Group**

Las Vegas, NV, Sep. 16-18, 2003.

<http://bridge.ecn.purdue.edu/~spave/Technical%20Info/Meetings/Mix%20ETG%20Sept03%20Las%20Vegas%20NV/mix%20etg%20NCHRP.ppt>

### **SEAUPG (Southeastern Asphalt User/Producer Group) Conference 2003**

Allen Cooley, Nov. 9, 2003.

[http://www.seaupg.org/Media/pdf%202003/Permeability\\_ACooley.pdf](http://www.seaupg.org/Media/pdf%202003/Permeability_ACooley.pdf)