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Wisconsin Mixture Characterization Using the SPT

Prepared for
Wisconsin Highway Research Program
Flexible Pavements Technical Oversight Committee

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Transportation Literature Searches are prepared for WisDOT staff and principal investigators to heighten awareness of completed research in areas of current interest. The citations below are representative, rather than exhaustive, of available English-language studies on the topic. Primary online resources for the literature searches are OCLC's WorldCat and TLCat, U.S. DOT's TRIS Online, the National Transportation Library (NTL), TRB's Research in Progress (RiP) and other academic, engineering and scientific databases as appropriate. Links to online copies of cited literature are noted when available. Hard copies may be obtained through the WisDOT Library at library@dot.state.wi.us or 608-264-8142.

SUMMARY
In our review of research databases we found nine documents pertaining to mechanistic characterization of hot-mix asphalt mixtures and performance. Four of these documents were published in 2006, three in 2005, and two in 2004. Federal sources account for four, and academic journals and conference proceedings for another four, with only the Virginia Transportation Research Council representing a state-driven effort. We also found one Research in Progress project being conducted by Mississippi DOT.

KEYWORDS
Mechanistic, HMA, characterization, performance, mixture, SPT.

CITATIONS

Title: Performance Tests for Hot Mix Asphalt (HMA) Including Fundamental and Empirical Procedures
Author(s): Multiple authors, articles
Date: 2006
Doc ID/URL: *ASTM Special Technical Publication 1469*, Proceedings of ASTM Symposium, Dec. 9-10, 2006, Tampa, Fla.
Description: 213 pp.
Contents: The proceedings contain 13 papers. The topics discussed include: an overview of fundamental and simulative performance tests for hot mix asphalt; utilization of an asphalt pavement analyzer for hot mix asphalt laboratory mix design; simulative performance test for hot mix asphalt using asphalt pavement analyzer; laboratory investigation of HMA performance using Hamburg wheel tracking and DSR torsion creep tests; use of HMA stiffness results as a referee test in Indiana; mechanistic quality management of hot mix asphalt layers with seismic methods; field validation of supersaver shear test on NCAT test track; identification of a physical model to evaluate rutting performance of asphalt mixtures; obtaining creep compliance parameters accurately from static or cyclic creep tests; dynamic modulus testing of thin pavement cores; and characterization of asphalt concrete by multi-stage true trivial testing.

Title: Evaluation of testing protocols for dynamic modulus of hot-mix asphalt
Author(s): Nam H. Tran, Kevin D. Hall
Date: 2006
Doc ID/URL: *Transportation Research Record 1970*, 2006: 126-132.
Description: 7 pp.
Contents: The dynamic modulus (|E*|) of hot-mix asphalt (HMA) is one of the fundamental inputs in the mechanistic–empirical (M-E) pavement design guide developed in NCHRP Project 1-37A. The M-E design guide provides three levels for |E*| input, which are related nominally to the reliability of pavement performance estimates generated by the guide. Level 1 |E*| inputs require laboratory-measured |E*|-values, and Level 2 and 3 |E*| inputs

are estimated by using a predictive equation. To provide the laboratory-measured |E*| inputs for implementation of the M-E design guide, a comprehensive research effort was completed in Arkansas. The research included a study evaluating different |E*| testing protocols, derived by varying combinations of the number of test replicates and the number of measurement instruments affixed on each test specimen recommended in AASHTO TP 62-03. The testing protocols were evaluated in terms of the variability of the resulting |E*| test results. The total research effort included three replicate specimens from each of four aggregate types, three nominal maximum aggregate sizes, two performance grade binder grades, and two air void levels. The |E*| tests were conducted with five test temperatures and six loading frequencies. Even though all evaluated testing protocols produced standard errors of less than 15% (which is the requirement specified in AASHTO TP 62-03), a program utilizing four measurement instruments and two replicate specimens is recommended for future |E*| testing.

Title: Permanent deformation analysis of hot-mix asphalt mixtures using simple performance tests and 2002 Mechanistic-Empirical Pavement Design software
Author(s): Louay N. Mohammad, Zhong Wu, Sandeep Obulareddy, Sam Cooper, Christopher D. Abadie
Date: 2006
Doc ID/URL: *Transportation Research Record 1970*, 2006: 133-142.
Description: 10 pp.
Contents: A complex laboratory study in characterization of permanent deformation resistance of hot-mix asphalt (HMA) mixtures is presented. Six plant-produced HMA mixtures were selected for this study. The main objective was to characterize the permanent deformation characteristics of HMA mixtures based on four laboratory tests, namely, the dynamic modulus |E*|, flow number, frequency sweep at constant height (FSCH), and Hamburg-type loaded wheel-tracking tests. The secondary objective was to evaluate the sensitivity of the dynamic modulus |E*|-test results in pavement rutting performance prediction with the 2002 mechanistic? empirical (M?E) pavement design software. Test results indicate that the |E*|-test was sensitive to the nominal maximum aggregate size in an HMA mixture. Larger aggregates combined with aged materials tend to have high |E*|-values at high temperatures. However, both the |E*|- and FSCH tests could not correctly rank the permanent deformation characteristics for the six HMA mixtures considered in this study. However, test results from the flow number and Hamburg tests correlated fairly well, and both tests were sensitive to the permanent deformation characteristics for the mixtures evaluated. The mixture ranking order obtained from the flow number tests was consistent with the use of those mixtures in the field. The predicted rut depths from the 2002 M-E pavement design software basically followed the same trend found in the |E*|-test results at high temperatures.

Title: Comparing resilient modulus and dynamic modulus of hot-mix asphalt as material properties for flexible pavement design
Author(s): Amara Loulizi, Gerardo W. Flintsch, Imad L. Al-Qadi, David W. Mokarem
Date: 2006
Doc ID/URL: *Transportation Research Record 1970*, 2006: 161-170.
Description: 10 pp.
Contents: With the current trend toward developing mechanistic flexible pavement design and the need for more reliable design procedures, accurate characterization of hot-mix asphalt (HMA) properties is needed. Resilient and dynamic modulus tests were performed at five temperatures on two typical mixes used in the Commonwealth of Virginia to compare the test results. The dynamic modulus was measured at six frequencies at each of the testing temperatures, and the resilient modulus test was performed at one loading time. The study found that the size of the specimen statistically affected the measured resilient modulus value. Resilient modulus values obtained in the 100-mm-diameter specimens were higher than those obtained in the 150-mm-diameter specimens at all testing temperatures. No statistical differences were observed in the resilient modulus of the two mixes. However, statistical differences were found in the dynamic modulus of the two mixes. A strong relation between the dynamic modulus test performed at 5 Hz and the resilient modulus was found. Three different pavement structures were analyzed to estimate the variation of their bottom-up fatigue life when different moduli were used for the HMA layer. It was found that the measured dynamic moduli resulted in the highest fatigue life estimates for the three considered pavements. It is concluded that the dynamic modulus test provides a better characterization of HMA than the resilient modulus test because it provides full characterization of the mix over temperature and loading frequencies.

Title: Laboratory investigation of HMA performance using Hamburg wheel tracking and DSR torsional creep tests
Author(s): Gerald Reinke, Stacy Glidden, Doug Herlitzka, John Jorgenson
Date: November 2005
Doc ID/URL: *Journal of ASTM International*, Vol. 2 (10), November/December 2005: 99-130.
Description: 32 pp.

Contents: Lack of existing fundamental mechanistic tests to evaluate performance potential of HMA mixtures has given rise to a number of empirical and mechanical-empirical test procedures. In an effort to understand how one of these tests, the Hamburg rutting test, was impacted by differences in HMA mixture variables, the following experimental work was conducted. Three aggregate types consisting of a crushed granite, a crushed siliceous gravel, and a crushed limestone were evaluated at four design ESAL levels. These four ESAL levels were 300 000, 1 million, 3 million, and 10 million. For each of these aggregate types and ESAL levels, 5 PG graded binders were investigated. The binders were PG 58-28, PG 64-28C (chemically modified), PG 64-28P, PG 64-34, and PG 70-28; the latter 3 binders were polymer modified. For all mixtures, Hamburg Wheel Tracking tests were performed under water at 50°C. In addition, a DSR Creep Test developed at MTE was performed on each mixture at 58°C and 34 kPa stress to determine the dry strength characteristics. The Hamburg test showed consistently better results as the ESAL level of the mix increased and as the high temperature PG grade of the binder increased for a given base asphalt. In the Hamburg test, mixes produced with PG 64-34 did not perform as well as PG 70-28 or PG 64-28P, while in the DSR Creep Test, mixes produced with PG 64-34 performed significantly better than PG 64-28P. This leads to speculation that the modulus of the base asphalt plays a more significant role in stress applied moisture resistance tests and that dry high temperature permanent deformation tests are influenced by the modified binder properties. Copyright © 2005 by ASTM International.

Title: Laboratory Tests for Hot-Mix Asphalt Characterization in Virginia
Author(s): Gerardo W. Flintsch, Imad L. Al-Qadi, Amara Loulizi, David W. Mokarem
Date: June 2005
Doc ID/URL: VTRC 05-CR22; Project No. 70984, Final Report.
http://www.virginiadot.org/vtrc/main/online_reports/pdf/05-cr22.pdf
Description: 56 pp.
Contents: This project reviewed existing laboratory methods for accurately describing the constitutive behavior of the mixes used in the Commonwealth of Virginia. Indirect tensile (IDT) strength, resilient modulus, static creep in the IDT and uniaxial modes, flexural beam fatigue, and dynamic modulus tests were conducted on two typical mixes used in Virginia: SM-9.5A (surface mix) and BM-25.0 (base mix). The tests conducted produced a wealth of data on typical values for the properties of the two mixes studied over a wide range of temperatures and loading frequencies. The results suggest that the IDT strength test is an effective test to characterize the tensile strength of hot-mix asphalt (HMA), especially for thermal cracking evaluation. The resilient modulus test and the static creep test in the IDT setup are practical and simple to perform, but the analysis of the measurements is complicated, and the variability of the results is high. The compressive uniaxial dynamic modulus and the uniaxial static creep tests were found to be simple to conduct and to analyze because of the homogeneous state of stress in the specimen during testing. The flexural fatigue test was time consuming, but the test produces valuable information about the fatigue properties of HMA. The investigation also found good correlations among the IDT strength, resilient modulus, and dynamic modulus results. A variety of tests is recommended for characterizing the mechanistic-empirical pavement analysis and design. These tests would provide the properties needed to characterize the asphalt layers for the pavement analysis and design. The recommended tests are as follows: IDT strength for characterizing HMA susceptibility to thermal cracking, dynamic modulus for characterization of the constitutive behavior of the HMA, uniaxial creep for characterizing permanent deformation characteristics, and flexural fatigue tests to characterize fatigue properties. Materials characterization testing can be a valuable tool in pavement design. The use of mechanistic-empirical modeling can be used to predict the performance of a pavement. With this type of testing and modeling, the materials used in pavements will be of better quality and more resistant to environmental and structural deterioration. A more durable pavement will aid in reducing the frequency and costs associated with maintenance.

Title: A practical look at the simple performance tests: Louisiana's experience
Author(s): Louay N. Mohammad, Zhong Wu, Leslie Myers, Sam Cooper, Christopher Abadie, Ghassan Chehab, Richard Davis
Date: 2005
Doc ID/URL: *Asphalt Paving Technology: 2005 Meeting of the Association of Asphalt Paving Technologists, Proceedings of the Technical Sessions,* Vol. 74, 2005: 557-600.
Description: 44 pp.
Contents: The Superpave volumetric mix design procedure developed during the Asphalt Research Program of the Strategic Highway Research Program did not include a mechanical "proof" test similar to the ones commonly used in the Marshall mix design or Hveem mix design such as the Marshall stability and flow tests or the Hveem stabilometer method, respectively. The Superpave mix design method, however, did use strict requirement to material specifications and volumetric mix criteria to ensure satisfactory performance of mix designs that were intended for low volume traffic. In addition, the original Superpave mix design protocol required mix verification

for intermediate and high volume traffic through advanced materials characterizations tests utilizing the Superpave Shear Tester test protocols. It was quickly recognized the complexity of those test protocols for routine mix design application and that a simple performance test is needed to complement the Superpave volumetric mix design procedure. In response to this need, NCHRP Project 9-19, Superpave Support and Performance Models Management, recently recommended three candidate Simple Performance Tests (SPTs) to complement the Superpave volumetric mixture design method. These are flow time (F_T), flow number (F_N), and dynamic modulus |E*| tests. In addition, the dynamic modulus test was selected for the HMA materials characterization input utilized in the 2002 Empirical and Mechanistic Guide for Design of New and Rehabilitated Pavement Structures, developed under NCHRP Project 1-37A. This paper presents a practical look at the results of a cooperative evaluation of similar Superpave mixtures utilizing two tests of the SPTs: the Dynamic Modulus and Flow Number. Two different dynamic modulus predictive models, Witczak and Hirsch, were also evaluated.

Title: Potential applications of the hollow cylinder tensile tester as a simple performance test
Author(s): W.G. Buttlar, G.G. Al-Khateeb, D.S. Sherman
Date: September 2004
Doc ID/URL: *Transportation Research E-Circular E-C068*, September 2004: 69-84.
Description: 6 pp.
Contents: A hollow cylinder tensile tester (HCT) was developed that can be used to obtain fundamental properties of asphaltic paving mixtures, such as creep compliance, tensile strength, and dynamic modulus, at low and intermediate temperatures. The device was originally developed to be a compact, portable, and operationally simple surrogate test to obtain properties similar to the Superpave Indirect Tensile Tester (IDT) (e.g., creep compliance and tensile strength). However, a recent study has shown that the HCT also can be used to obtain the dynamic complex modulus (E*) of hot-mix asphalt in tension. By applying pressure to the inner cylinder wall of the specimen, a tensile or "hoop" response is induced. The load system also can be used to measure specimen deformation, which makes specimen preparation and device operation free of mounted sensors and, hence, simple and rapid. A production version of this device would resemble a portable gyratory compactor in size, simplicity, and portability. The possibility of using the HCT as a simple performance test in the asphalt industry was explored. The results of several recent studies are summarized; these indicate that the HCT produces accurate measures of creep compliance and dynamic complex modulus of HMA compared with the IDT. Very reasonable values of tensile strength also were obtained with the HCT, because strength variations followed logical trends with changes in aggregate type and polymer modification level. It appears that the HCT is compatible with the requirements of the NCHRP 1-37A software models (used in the AASHTO Mechanistic-Empirical Design Guide) for thermal cracking performance prediction (e.g., a suitable surrogate test for the IDT). Because it also can measure E* at low to intermediate temperatures, the HCT appears to be able to collect the necessary inputs for running the fatigue cracking performance prediction models used in NCHRP 1-37A software. The HCT device is currently configured to apply tensile loads to asphalt mixture specimens at low and intermediate temperatures and is therefore not currently applicable to the study of permanent deformation (rutting). In addition, testing to date has been limited to mixtures with nominal maximum aggregate size no greater than 19 mm.

Title: Comparison of aggregate gradation and mixture physical properties to performance tests of coarse-graded Superpave mixtures in Louisiana
Author(s): Louay N. Mohammad, Zhong Wu, Amar Raghavendra, Christopher Abadie
Date: 2004
Doc ID/URL: *Asphalt Paving Technology: 2004 Meeting of the Association of Asphalt Paving Technologists, Proceedings of the Technical Sessions*, Vol. 73, 2004: 261-285.
Description: 25 pp.
Contents: This paper presents the comparison of laboratory performance tests of coarse-graded Superpave HMA mixtures in Louisiana with physical properties of mixtures including volumetrics, aggregate gradation analysis, and field performance. Eight Superpave HMA mixtures were evaluated. Six of the eight mixtures were designed for high-volume traffic (greater than 30 million ESALs), while the other two mixtures were designed for low-volume traffic (less than 3 million ESALs). Theses mixtures includes two aggregate types: limestone and sandstone, and two binder types: PG 70-22M and PG 76-22M. Laboratory mechanistic tests conducted include indirect tensile (IT) strength, IT and axial creep, frequency sweep at constant height (FSCH) and repeated shear at constant height (RSCH). The aggregate gradation analysis was characterized using a Power-law to evaluate the effects of gradation on mixture mechanistic properties. Laboratory test results showed that high-volume mixtures appeared to have higher IT strengths, lower IT and axial creep slope and higher shear stiffness when compared to those of low-volume mixtures. This indicates that high volume mixtures generally possessed better rut-resistance than low volume mixtures considered. All four Power-law gradation parameters (a_{CA}, n_{CA}, a_{PA} and n_{FA}) were sensitive to the mixture mechanistic properties evaluated.

RESEARCH IN PROGRESS

Title: Hot Mix Asphalt (HMA) Characterization for the 2002 AASHTO Design Guide
Principal Investigator(s): Shane Buchanan, Mississippi State University, shaneb@engr.msstate.edu.
Start Date: 10/1/2002
RIP URL: http://rip.trb.org/browse/dproject.asp?n=7522
Sponsor Organization: Mississippi Department of Transportation
Contents: MDOT currently uses the AASHTO Guide for the Design of Pavement Structures for structural pavement design. This guide is empirically based and utilizes the concept of structural numbers (SN) to determine the overall required thickness of varying pavement layers. These structural numbers were determined from the AASHTO road test in the 1950's. Currently the AASHTO 2002 Guide for Design of New and Rehabilitated Pavement Structures is being developed. This guide will have three design levels (Level 1,2 and 3) all based on mechanistic-empirical design principles and will potentially replace the existing guide as the structural design guide for MDOT. The researchers working on the flexible pavement component of the 2002 guide have evaluated many test methods to determine the best relationship between observed HMA mix lab performance and field performance with respect to rutting, fatigue cracking, etc. Currently, the dynamic modulus test will be used to characterize HMA mixes for input into the 2002 design guide. The test is run in accordance with ASTM D 3497 Standard Test Method for Dynamic Modulus of Asphalt Concrete Mixtures. Mississippi HMA mixes need to be characterized using dynamic modulus testing in preparation for the future implementation of the 2002 design guide. In this study a range of HMA mixes will be characterized using the dynamic modulus testing. Any proposed evaluation will initially be focused on materials and mixes that are currently being used in the state. Selected mixes will also be evaluated using the asphalt pavement analyzer (APA) and confined repeated deformation testing for comparison purposes. MDOT has performed APA testing on many mixes and a side-by-side comparison of the dynamic modulus and the APA would be very useful.