TechBrief

The Asphalt Pavement Technology Program is an integrated, national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, Industry and academia the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement guidelines, methods, procedures and other tools for use in asphalt pavement materials selection, mixture design, testing, construction and quality control.

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Asphalt Material Characterization for AASHTOWare® Pavement ME Design Using an Asphalt Mixture Performance Tester (AMPT)

This Technical Brief provides an overview of the asphalt materials input requirements in AASHTOWare® Pavement ME Design and how the Asphalt Mixture Performance Tester can be used to characterize asphalt mixtures for flexible pavement ME designs.

Background

The Asphalt Mixture Performance Tester (AMPT) is a servo-hydraulic testing device developed to test asphalt mixtures over a range of temperatures and frequencies (see Figure 1). It was developed and known as the Simple Performance Tester (SPT) under National Cooperative Highway Research Program (NCHRP) Project 9-29 to conduct three mixture performance tests, including dynamic modulus (E*), flow number (F_n) and flow time (F_t), in accordance with AASHTO TP 79 (*1*). These performance tests were selected at the conclusion of NCHRP Project 9-19 for evaluating the resistance of asphalt mixtures to permanent deformation in conjunction with the Superpave volumetric mix design procedure (*2*). The dynamic modulus test was also selected in NCHRP Project 1-37A to determine the viscoelastic properties of asphalt mixtures over a range of temperatures and frequencies (*3*). The dynamic modulus results are used as primary inputs for asphalt mixtures in the AASHTOWare® Pavement ME Design software (formerly Mechanistic Empirical Pavement Design Guide (MEPDG) and DARWin-ME™). Thus, it makes the implementation of the AMPT a high priority.

Figure 1. Photograph of AMPT Equipment by IPC Global

AASHTOWare® Pavement ME Design

Pavement ME Design encompasses two parts: mechanistic and empirical. The mechanistic part includes models to determine pavement responses, such as stresses, strains and deflections. The pavement responses are then used as inputs in empirical distress prediction models, also known as "transfer functions," to predict cumulative pavement distresses over time. Each design is an iterative process that includes the following steps (*3*):

1. The pavement engineer provides traffic, climate, and material inputs and a trial pavement design. The engineer also sets the design reliability level and critical criterion for each pavement performance indicator. For each input, the Pavement ME Design software allows three levels based on the philosophy that the level of engineering effort exerted in the pavement design process should be consistent with the relative importance, size, and cost of the project.
2. The pavement engineer then runs the software, which executes both the mechanistic and empirical parts, to predict pavement performance indicators for the trial pavement design. These performance indicators include pavement roughness, quantified according to the International Roughness Index (IRI), rutting, fatigue (bottom-up) cracking, longitudinal (surface-down) cracking, and transverse (thermal) cracking. For each pavement performance indicator, the user-specified design reliability level set in Step 1 is applied to account for the variability of the corresponding distress prediction model when it was calibrated with the field data.

3. After the Pavement ME Design analysis of the trial pavement design is complete, the pavement performance indicators are compared with the corresponding critical criteria set in Step 1.

Material Inputs Required for Asphalt Layers

In the Pavement ME Design software, the material inputs for individual asphalt layers are divided into three groups—asphalt mixture, asphalt binder and asphalt general. The information required in each group varies according to the level of analysis to be conducted. More details of the required inputs for individual asphalt layers follow.

Level 1 Inputs

Asphalt Mixture

Laboratory dynamic modulus testing results at different temperatures and frequencies are required to develop the master curve and shift factors. The master curve and shift factors for the Level 1 analysis are determined through a numerical optimization process in the Pavement ME Design software.

The following AASHTO standards describe procedures for measuring dynamic modulus for the Level 1 analysis using the AMPT:

- PP 60, *Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)*
- TP 79, *Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)*
- PP 61, *Developing Dynamic Modulus Master Curves for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT)*

If a universal testing system capable of controlling the temperature of the specimen over a temperature range from -10 to 60^{o}C (14 to 140^{o}F) is used, dynamic modulus testing for the Level 1 analysis can be conducted in accordance with T 342, *Determining Dynamic Modulus of Hot Mix Asphalt (HMA)*.

Asphalt Binder

Laboratory testing results for short-term aged binder over a range of temperatures are required. The results are used in the Global Aging System (GAS) embedded in the Pavement ME Design software to account for the long-term aging effect on the mixture dynamic modulus. While the results from several tests can be input in the Pavement ME Design software, the Dynamic Shear Rheometer (DSR) complex modulus and phase angle data at 10 rad/sec and Brookfield viscosity results are often used. The same information is required for Level 2 “Asphalt Binder” inputs.

Asphalt General

The information required in this section is obtained from as built mixture volumetric properties, including effective binder content, air voids and total unit weight. For other properties, such as thermal conductivity and heat capacity, default values provided in the Pavement ME Design software are used. The same information is required for Level 2 and 3 “Asphalt General” inputs.

Level 2 Inputs

Asphalt Mixture

Instead of laboratory dynamic modulus data, the Witczak prediction model (Equation 1) embedded in the Pavement ME Design software is used. However, the pavement engineer needs to provide the inputs for this predictive model.

$$\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a - 0.802208\left(\frac{V_{eff}}{V_{eff}+V_a}\right) + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{(-0.603313 - 0.313351\log(f) - 0.393532\log(\eta))}} \quad (1)$$

Where:

E*	= Dynamic Modulus, psi
η	= Bitumen viscosity, 10^6 poise
f	= Loading frequency, Hz
V_a	= Air voids content, %
V_{eff}	= Effective bitumen content, % by volume
ρ_{34}	= Cumulative % retained on the 3/4-in sieve
ρ_{38}	= Cumulative % retained on the 3/8-in sieve
ρ_4	= Cumulative % retained on the #4 sieve
ρ_{200}	= % passing the #200 sieve

Level 3 Inputs

Asphalt Mixture

The Witczak prediction model (Equation 1) is used to estimate the dynamic modulus of asphalt mixture, and the aggregate gradation, V_a and V_{eff} are the only information required. After the pavement designer selects an asphalt binder (described below) for the design, the default viscosity properties corresponding to the selected binder will be used as inputs for the Witczak prediction model.

Asphalt Binder

The pavement designer is required to select either the performance grade (PG), viscosity grade or penetration grade of the asphalt binder. Then, the corresponding default values for the selected binder grade embedded in the Pavement ME Design software are used for the design.

Sensitivity of Pavement ME Design Predicted Performance to Asphalt Material Inputs

Several analyses of the sensitivity of the performance predictions to variability of the design input values for flexible pavements have been conducted, and a complete list of published sensitivity analyses is provided in the NCHRP Project 1-47 final report (*4*). Among the published sensitivity analyses, the analysis conducted under NCHRP Project 1-47 is the most comprehensive. This study evaluated the degree of sensitivity of the design inputs on the performance predicted using version 1.1 of the MEPDG software. The input categories included: HMA properties such as dynamic modulus, thickness, air voids, effective binder content; base and subgrade properties such as resilient modulus and other properties such as traffic volume and operating speed. Four levels of sensitivity for the design inputs were used: hypersensitive, very sensitive, sensitive and insensitive.

The NCHRP 1-47 research team reported that the sensitivity of the predicted performance to variations in the design input varied by distress type, but only the HMA properties in terms of dynamic modulus data were consistently in the highest sensitivity category for all performance predictions except thermal cracking (*4*). The fact that thermal cracking is not sensitive to dynamic modulus but other mixture properties is not unexpected because this type of cracking is exclusively related to environment. The high sensitivity of the performance predictions to the E* inputs indicates a need for careful characterization of this property.

State Experience in Generating E* Inputs for AASHTOWare® Pavement ME Design Implementation

Since 2002, several states in the United States have initiated various research activities for implementing the Pavement ME Design procedure. These activities include training staff, collecting traffic information, climate and material inputs, acquiring testing equipment, selecting pavement sections for local calibration, and designing pavements using both the empirical and mechanistic-empirical approaches for comparison.

Most efforts of highway agencies toward the characterization of asphalt materials for the implementation of Pavement ME Design focus specifically with the dynamic modulus of asphalt mixtures. The general approach employed by the highway agencies is to develop a dynamic modulus database and to assess the accuracy of the Witczak and Hirsch predictions against the measured results. The Hirsch model requires only three parameters to predict dynamic modulus: binder shear modulus, voids in the mineral aggregates and voids filled with asphalt. The database includes dynamic modulus results for typical asphalt mixtures, specialty asphalt mixtures, such as stone matrix asphalt, and asphalt mixtures with high recycled material contents and/or warm mix asphalt (WMA) that were not included in the development of Level 2 and 3 default values.

Agencies will gain benefits by creating a database of typical asphalt mixes used in typical pavements that can be used for day to day design purposes. This database can be used to verify the prediction models used for Level 2 and 3 analyses and to evaluate the effect of the difference between the measured and predicted data on the performance predictions for the state materials and conditions. In addition, laboratory dynamic modulus data may be necessary for high-value projects. In those cases, since the pavement design may be done years before a mix design is submitted so that dynamic modulus testing can be conducted, the results could be used to verify the dynamic modulus values used in the design.

Use of AMPT to Characterize Asphalt Material Inputs for AASHTOWare® Pavement ME Design

As previously mentioned, all the Pavement ME Design performance predictions except thermal cracking are very sensitive to dynamic modulus inputs; hence, it is important to characterize this mixture property. If highway agencies are not able to conduct full Level 1 dynamic modulus testing for each asphalt mixture, a catalog of the E* and other material properties of typical asphalt mixtures used in each state will yield the following:

1. Provide Level 1 asphalt material inputs for designing high-value projects if it is expected that the mixes used in these projects are similar to those in the catalog.
2. Provide the laboratory and field information for evaluating the accuracy of the dynamic modulus predictions and possibly re-calibrating the prediction models for use in the Level 2 and 3 analyses in the future.
3. Provide the asphalt mixture information for future local calibration of the Pavement ME Design performance prediction models for the state materials and conditions (*5, 6, 7*).

This section provides recommendations for developing a catalog of the dynamic modulus values for typical asphalt mixtures used in each state and collecting all necessary information for evaluating the accuracy of the prediction models.

Experimental Design

It is not necessary to have a statistically designed experiment that covers all possible effects. However, it is important that the experiment include the mixtures that are commonly used across the state and cover the desired range of each important factor. The following factors have been identified as significantly affecting dynamic modulus values:

- Mix type
- Binder grade, including binder modification
- Aggregate source, including NMAS and absorption
- RAP and RAS content
- Use of WMA

Other factors that may be included in the experiment are binder source, design compaction level (N_{des}), and plant type. It is anticipated that as a minimum, mixtures that will be produced in the next construction season will be initially tested in this experiment. Then, the experimental design will be expanded to include more mixtures that are not included in the initial round of testing. Once the state has an AMPT testing program in place, it is anticipated that a number of production mixes will be selected and tested in each construction season thereafter to expand the database and characterize new mixture types as they are used in that state. To verify the prediction models, a minimum of 20-30 mixtures will need to be tested.

Laboratory Testing and Data Collection

It is desirable to determine dynamic modulus results for both laboratory-prepared and plant-produced mixes; however, if resources are limited, testing can be conducted using only plant-produced mixes. In addition to the test results for each plant-produced mix, other information should also be collected. Some information will be available from the construction and mix design reports, but the other information may require laboratory testing. For each mixture, information about the project site and construction, such as project location (county, route, mile marker, etc.), traffic level (average annual daily truck traffic in design lane, percent trucks in design lane, operational speed, etc.), roadway classification, and overall pavement structure (layer thicknesses, materials, etc.), should also be collected. In addition, a list of specific information that needs to be collected for this experiment is provided in Table 1. This information will provide all the asphalt material inputs that can be reasonably collected for Pavement ME Design analysis. Using this information, pavement designers will have a basis for selecting mixture test data that most closely relates to the actual project they are currently designing. It should be noted that in order to conduct a Level 1 design, the information about asphalt mixture and the properties of virgin binder or composite binder listed in the “For Level 1 ME Design” column will be needed.

Data Storage and Analysis

It is recommended that a database be developed to manage testing results. The database can be developed in Microsoft Office Excel, Access or other data formats that can be imported to a SQL or Oracle database for use with the ME Design, more information is available elsewhere (8). The database approach to be used should be reviewed and discussed with both materials and pavement design personnel who will update and export data from the database in the future. Before data are entered, a rigorous screening process should be conducted to ensure data quality. This screening process may include checking the repeatability of the test results with commonly accepted data quality indicators. The data should also be screened to assure that the results are reasonable based on testing conditions. This process will ensure that only reliable and realistic data are stored for future use. Information within the database needed for a future design should be searchable based on location, traffic level, classification, mix type, binder grade, etc.

Table 1. Plan for Information Collection and Laboratory Testing (*8*)

Materials	Properties		Sample Size
	For Level 1 ME Design	For Model Verification	
Virgin Binder	- G* and δ at 10 rad/sec and at 2 temperatures	- G* and δ at temperatures and frequencies used for E* testing	1 quart
RAP and RAS (if applicable)	- Specific information on RAP/RAS is not needed	- Aggregate gradation - Binder content - G* and δ at temperatures and frequencies used for E* testing	Sufficient mix to yield 100 g of extracted binder (approx. 3,000 g of RAP and 1,000 g of RAS)
Composite Binder*	- Binder content - Performance grade - G* and δ at 10 rad/sec and at 2 temperatures	- Binder content - G* and δ at temperatures and frequencies used for E* testing	Sufficient mix to yield 100 g of extracted binder (approx. 3,000 g)
Composite Aggregate*	- Gradation - Specific gravity	- Gradation - Specific gravity	Mix design report and/or QC/QA data
Volumetric Properties	- Effective asphalt content by volume (V_{beff}) - V_a and VFA - Unit Weight	- Binder content (P_b) - G_{mm} and G_{mb} - V_a, VMA, VFA, dust/binder ratio - V_{beff}	Mix design report and/or QC/QA data
Dynamic modulus	- E* at temperatures and frequencies specified in PP 61	- Measured E* according to TP 79 (AMPT) or T 342 (Universal Testing Machine)	Sufficient mix (approx. 50 kg) to prepare 6 specimens (test only 3 replicates)

*For a virgin mixture, only properties for the virgin materials are needed.

The database of general project and material testing data can be used to evaluate dynamic modulus prediction models if needed. The evaluation can be done using graphical and regression techniques. First, scatter plots can be used to compare the measured and predicted results. Then, the next step is to evaluate the appropriateness of each prediction model. As a minimum, the goodness-of-fit and residual analyses would be conducted. These analyses can be done in Microsoft Office Excel or using other statistical analysis tools.

Materials and pavement design personnel should consider how their asphalt mixture data relate to the asphalt mixtures used for development and calibration of the models within the Pavement ME Design program. Many of the mixtures used today include modified asphalt binders, warm mix asphalt technologies, high reclaimed asphalt pavement contents, and/or recycled asphalt shingles. Mixtures with these aspects were not widely represented in the mixture data sets used in the MEPDG development. When the input material properties are outside the range of the model development data sets, the resultant pavement design outputs should be evaluated for reasonableness, and caution should be used when unexpected outputs are encountered. Additional research work in this area is currently underway.

Other AMPT Tests

The AMPT can also be used to conduct other test for evaluating the rutting and cracking performance of asphalt mixtures, and the data are potentially applicable in the mechanistic empirical pavement design.

NCHRP Project 9-29 refined the Flow Number (F_n) and Flow Time (F_t) tests to evaluate the resistance of asphalt mixtures to permanent deformation (*1*), but currently, evaluation and implementation efforts are focused on the F_n test. The procedure for conducting the F_n test in the AMPT is presented in AASHTO TP 79; however, the procedure does not specify a testing condition (i.e., a deviator stress, a confining stress or a test temperature). The Federal Highway Administration (FHWA) Mix Expert Task Group (ETG) is finalizing its recommendations on a testing condition and acceptance criteria for the F_n test.

NCHRP Project 9-30A also selected a repeated-load permanent deformation test to obtain information for rutting prediction models that have been calibrated with field data and incorporated in the software program MEPDG Version NCHRP 9-30A. A proposed procedure for the repeated-load permanent deformation test is included in Appendix A of the NCHRP Project 9-30A report (*9*). The revised rutting models have been submitted to the AASHTO Joint Task Force on Pavements for consideration.

The F_n test and the repeated-load permanent deformation test differ in the testing conditions (i.e. deviator stresses, confining stresses, test temperatures) are specified differently. In addition, the F_n test was designed for use in the mix design process, and the repeated-load permanent deformation test was developed as geared more towards pavement design.

Newer AMPT units may also be sold with an AMPT Uniaxial Fatigue Kit that can be used for tension tests, including the Simplified Continuum Damage Uniaxial Fatigue (SCDUF) (*10*) and Simplified Viscoelastic Continuum Damage (S-VECD) (*11*). For older AMPT units, the kit can be purchased separately and added to the machine. The FHWA Mix ETG is reviewing a draft procedure for the S-VECD test that has been revised based on comments provided by the AASHTO Subcommittee on Materials. It is anticipated that this procedure will be adopted as an AASHTO provisional standard in the future.

The overlay test is the most recent test that can be conducted in the AMPT with an AMPT Overlay Test Kit purchased separately. The test is conducted in accordance with the Texas Department of Transportation (TxDOT) test procedure Tex-248-F (*12*). This procedure was developed for testing asphalt overlays on old concrete pavements, so a large opening or high tensile strain is applied on the specimen during testing. Research is underway to modify the testing condition of this procedure for testing asphalt mixtures used in applications other than overlays on concrete pavements.

Summary

The asphalt concrete materials input requirements in AASHTOWare ® Pavement ME Design encompasses the dynamic modulus results as the primary input, which underlines the importance of the Asphalt Mixture Performance Tester (AMPT) for characterizing asphalt mixtures. This document provides an overview of the Pavement ME Design, sensitivity of material inputs, and guidelines for developing an experimental plan for characterizing dynamic modulus and other material inputs to support the Pavement ME Design implementation. This document also discusses other tests that can be conducted in the AMPT and will be potentially implemented in the future for determining the resistance of asphalt mixtures to rutting and cracking.

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