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# USE OF AMPT FOR CHARACTERIZING ASPHALT MATERIAL INPUTS FOR AASHTOWARE® PAVEMENT ME DESIGN IMPLEMENTATION

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Final Report

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# DISCLAIMER

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# 1. INTRODUCTION

## 1.1 Problem Statement

The Asphalt Mixture Performance Tester (AMPT) is a servo-hydraulic testing device developed to test asphalt mixtures over a range of temperatures and loading frequencies. 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 procedure (formerly known as the Mechanistic Empirical Pavement Design Guide (MEPDG) and DARWin-ME™).

The current trend in the implementation of the AMPT by state highway agencies is focusing on two performance tests—dynamic modulus and flow number. The dynamic modulus test is primarily implemented for determining the dynamic moduli of asphalt mixtures for use as inputs in Pavement ME Design. The flow number test is implemented for evaluating the resistance of asphalt mixtures to permanent deformation. Even though the AMPT can be used to conduct the flow time test, this test currently is not widely used.

The focus of this synthesis is on the use of AMPT for determining the dynamic modulus inputs to support the implementation of Pavement ME Design. The information provided in this synthesis can be useful for both material and pavement design engineers in the process of implementing AMPT and Pavement ME Design for designing flexible pavements.

## 1.2 Objective

The objective of this synthesis is twofold:

- Summarize the past and current efforts in characterizing the dynamic moduli of asphalt materials for use as inputs in Pavement ME Design; and
- Provide guidelines for highway agencies that plan to setup testing plans to characterize the dynamic moduli of asphalt materials in their states using the AMPT to support the implementation of Pavement ME Design.

This synthesis includes (1) an overview of Pavement ME Design, primary inputs for asphalt materials and the sensitivity of pavement performance to the primary inputs, (2) a summary of the processes that state highway agencies have taken to implement AMPT and Pavement ME Design, (3) guidelines for developing an experimental plan for characterizing the dynamic moduli of asphalt materials to support the implementation of Pavement ME Design, and (4) an overview of other tests that can be conducted in the AMPT and potentially implemented in the future.

# 2. AASHTOWARE® PAVEMENT ME DESIGN FOR FLEXIBLE PAVEMENT

## 2.1 Background

The 1993 American Association of State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures (*4*) has been the primary procedure used to design new and rehabilitated flexible pavements (*5*). This empirical design procedure is based on the design equations developed using the 1950's AASHO Road Test data. Although the empirical design procedure has been used for many years, it has a number of limitations that diminish its efficiency as a basis for pavement design. Some of these limitations include (*3*, *6*):

- *Traffic Load Deficiencies*: Traffic loads have increased enormously since the 1950's. Currently, pavements are designed to carry up to 200 million axle loads; however, the design equations were developed based on traffic loads of less than 2 million equivalent single axle loads (ESALs). This means the current designs are extrapolated far beyond the AASHO Road Test data from which the design equations were derived.
- *Environmental Effect Deficiencies:* Because the design equations were developed based on the results of the Road Test conducted at a specific location, the equations did not take into account the effects of different climatic conditions on the pavement performance. The adjustment of subgrade resilient modulus for different seasons and the layer drainage coefficients are the only elements that take into account the environmental effects.
- *Subgrade Deficiencies:* In the Road Test, all the sections were built on the same subgrade. However, various types of subgrade exist around the US, and the type of subgrade significantly affects the pavement performance.
- *Design Life Deficiencies:* The Road Test was conducted over two years. Because of this short duration, the long term effects of climate on binder aging and materials are not taken into consideration.

The advancements in material characterization, pavement design, pavement performance evaluation, and computing capability have allowed NCHRP Project 1-37A to develop a more advanced Mechanistic-Empirical Pavement Design Guide, which is known as MEPDG. The original version of the MEPDG software (Version 0.7) was released in July 2004, and the software has been updated and refined over the years into the current AASHTOware® Pavement ME Design software (*7*).

## 2.2 Overview of AASHTOware® Pavement ME Design

Pavement ME Design includes two parts—mechanistic and empirical. The mechanistic part includes models to determine pavement responses (i.e., stress, strain and deflection). Then, the pavement responses are used as inputs in distress prediction models, also known as "transfer functions," to predict cumulative pavement distresses over time. Each design is an iterative process including the following steps (*3*):

1. The pavement engineer provides traffic, climate, and material inputs as well as a trial pavement design. The engineer also sets the design reliability level and critical criterion for each pavement performance indicator. For the individual inputs, 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.
    - *Level 1*: Inputs at this level have the highest level of accuracy (least uncertainty). Material inputs at this level require laboratory or field testing, such as the dynamic modulus testing of hot-mix asphalt or nondestructive deflection testing.
    - *Level 2*: Inputs at this level have an intermediate level of accuracy. They can be selected from an agency database, derived from a limited testing program, or estimated through correlations. This level is used when resources are not available for tests required for Level 1.
    - *Level 3*: Inputs at this level have the lowest level of accuracy (most uncertainty). They can be user-selected values or typical averages for the region. This level is used for design where there are minimal consequences of early failure.
2. The pavement engineer then runs the Pavement ME Design 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. The Pavement ME Design software allows users to set the critical limits or to use the Pavement ME Design recommended limits (Table 1) to evaluate the adequacy of each design. If the predictions do not meet the critical limits, the trial design is revised, and the evaluation is repeated. The design can be repeated until an adequate pavement design is selected.

**Table 1 Critical Limits Recommended for Flexible Pavement Design (*3*)**

| **Performance Indicator** | **Maximum Value at End of Design Life** | **Performance Indicator** | **Maximum Value at End of Design Life** |
|---|---|---|---|
| IRI (smoothness) | Interstate: 160 in/mi<br>Primary: 200 in/mi<br>Secondary: 200 in/mi | Alligator Cracking | Interstate: 10% lane area<br>Primary: 20% lane area<br>Secondary: 35% lane area |
| Rutting (in wheel paths) | Interstate: 0.40 in.<br>Primary: 0.5 in.<br>Others (< 45mph): 0.65 in. | Transverse Cracking | Interstate: 500 ft/mi<br>Primary: 700 ft/mi<br>Secondary: 700 ft/mi |

## 2.3 Material Inputs Required for Asphalt Layers

To conduct a flexible pavement design, the design engineer needs to (1) select a preliminary pavement structure, including the thickness of each structural layer, (2) provide traffic and climate inputs as well as material inputs for each layer, and (3) set the design reliability level and critical criterion for each pavement performance indicator. A detailed discussion of each step in the design process can be found elsewhere (3); the focus of this section is on the 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 are discussed in the following subsections.

### *2.3.1 Level 1 Inputs*

<u>Asphalt Mixture</u>

Laboratory E* testing results at different temperatures and frequencies are required to develop the E* master curve and shift factors. The E* 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 the E* 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 Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)*
- PP 61, *Developing Dynamic Modulus Master Curves for Hot Mix Asphalt (HMA) 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°C (14 to 140°F) is used, E* testing in accordance with T 342, *Determining Dynamic Modulus of Hot Mix Asphalt (HMA)*, can be conducted to measure the E* for the Level 1 analysis.

<u>Asphalt Binder</u>

Laboratory testing results for short-term aged binder over a range of temperatures is 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.

<u>Asphalt General</u>

The information required in this section is 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.

### *2.3.2 Level 2 Inputs*

<u>Asphalt Mixture</u>

Instead of laboratory E* testing results, the Witczak E* predictive 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.

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

Where:

| | |
|---|---|
| E* | = Dynamic Modulus, psi |
| $\eta$ | = Bitumen viscosity, $10^6$ poise |
| f | = Loading frequency, Hz |
| $V_a$ | = Air Voids Content, % |
| $V_{eff}$ | = Effective bitumen content, % by volume |
| $\rho_{34}$ | = Cumulative % retained on the 3/4-in sieve |
| $\rho_{38}$ | = Cumulative % retained on the 3/8-in sieve |
| $\rho_4$ | = Cumulative % retained on the #4 sieve |

$\rho_{200}$ = % passing the #200 sieve

### 2.3.3 Level 3 Inputs

Asphalt Mixture

The Witczak E* predictive model is used to estimate the E* 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 this project, the default viscosity properties corresponding to the selected binder will be used as inputs for the Witczak predictive 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.

## 2.4 Sensitivity of Pavement ME Design Predicted Performance to Asphalt Material Inputs

Since the release of the original version of the MEPDG software in 2004, several analyses of the sensitivity of the performance predictions to variability of the design input values for flexible pavements have been done, and a complete list of published sensitivity analyses is provided in the NCHRP Project 1-47 final report (*7*). Among the published sensitivity analyses, the analysis conducted under NCHRP Project 1-47 is the most comprehensive.

The NCHRP 1-47 research team reported that E* inputs were among the most sensitive design inputs for all performance predictions except thermal cracking (*7*). The fact that thermal cracking is not sensitive to the E* 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. However, it is not expected that highway agencies will ever conduct full Level 1 E* testing for all their projects and mixtures. Agencies will gain benefits by creating an E* database of typical asphalt mixes used in typical pavements. This E* database can be used to verify the E* predictive models used for Level 2 and 3 analyses and to evaluate the effect of the difference between the measured and predicted E* data on the performance predictions for the state materials and conditions. In addition, laboratory E* testing results 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 E* testing can be conducted, the E* results could be used to verify the E* values used in the design.

# 3. 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, 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.

This section summarizes the efforts of some highway agencies toward the characterization of asphalt materials, specifically the dynamic modulus of asphalt mixtures, for the implementation of Pavement ME Design. 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 E* predictions against the measured E* results. The database includes E* 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.

### 3.1 New Jersey

A study was sponsored by the New Jersey DOT to develop a catalog of E* values for use as inputs in the MEPDG and to assess the E* values predicted by the Witczak prediction equation and the Hirsch model (*8*). The E* catalog was developed for 21 dense-graded asphalt mixtures with NMAS ranging from 9.5 to 25 mm and with two binder grades—a unmodified PG 64-22 and a polymer-modified PG 76-22. The mixes were sampled during production, compacted and tested in accordance with the procedures recommended in NCHRP Report 614 (*1*).

The study found that the E* values predicted by the Witczak equation were closer to the measured E* results than those estimated by the Hirsch model. The average difference for the values estimated by the Witczak equation was 10.5%, compared to 12.6% average difference of those estimated by the Hirsch model. The predicted E* values were found to be better for the mixes using the PG 64-22 binder than for those using the polymer modified PG76-22 binder. This was expected since the original dynamic modulus datasets used to develop the prediction equations primarily consisted of mixtures that used unmodified asphalt binders.

### 3.2 Virginia

The Virginia Center for Transportation Innovation and Research conducted a study to evaluate and compile a comprehensive catalog of asphalt material properties that can be used as design inputs in the MEPDG (*9*). The testing plan included 18 asphalt mixtures that covered a wide range of typical mixes, including base mixes (25-mm NMAS), dense-graded surface mixes (9.5- and 12.5-mm NMAS), gap-graded surface mixes (12.5-mm NMAS) and stone-mastic asphalt mixes (12.5-mm NMAS), from 7 of the 9 Virginia districts. E* testing was conducted on each specimen at 5 temperatures (14, 40, 70, 100, and 130$^{o}$F) and 6 frequencies (25, 10, 5, 1, 0.5, and 0.1 Hz) in accordance with AASHTO TP 62. The results were presented in the same input format used in the MEPDG to enable flexibility to choose the required input Level 1, 2 or 3.

The study also compared the measured E* results with those predicted by the Witczak predictive models. For most of the mixtures, differences in the predicted and measured E* were found. In some cases, the predicted E* values were up to 190% higher than the corresponding measured results.  For some other mixtures, the E* values were under-predicted by as much as 85%. The higher differences between the corresponding measured and predicted E* values were found at low frequencies or high temperatures. It is important to mention that several tested mixes contained between 10 to 25% RAP, which is typical for mixtures currently produced in Virginia.

### 3.3 North Carolina

A library of E* inputs for commonly used asphalt mixtures in North Carolina was developed by Kim et al (*10*). The study included forty-two mixtures with different aggregate sources, aggregate gradations, asphalt sources, asphalt grades, and asphalt contents. E* testing was conducted in accordance with AASHTO TP 62-03, except that the number of test temperatures was reduced from five to four and the number of loading frequencies was increased to develop a full master curve for each mixture.

The study also evaluated the prediction accuracy of the Witczak and Hirsch E* prediction models. In general, the Witczak prediction model provided better predictions, especially at lower temperatures. In addition, the effect of mixture variables on E* was also investigated. The study found that the binder variables, including crude source, performance grade, and binder content had a greater effect on the E* than the aggregate variables, such as source and gradation.

Kim et al. (*11*) also conducted another study to calibrate the MEPDG performance prediction models for local materials and conditions using the E* data collected from the previous project and from the triaxial repeated load permanent deformation test and the direct tension cyclic test. Rutting and fatigue cracking model coefficients were developed for twelve most commonly used asphalt mixtures in North Carolina, six of these mixes included RAP.

### 3.4 Mississippi

The Mississippi DOT sponsored a study to characterize the E* of 25 asphalt mixtures with three nominal maximum aggregate sizes (NMAS)—9.5, 12.5, and 19.0 mm—and with three asphalt binder grades—PG 67-22 (unmodified), PG 76-22, and PG 82-22 (*12*). The PG 76-22 and 82-22 asphalt binders were modified with a styrene butadiene styrene (SBS) polymer. E* testing was conducted on three replicates for each mixture in accordance with AASHTO TP 62-03. Each specimen was tested at 5 temperatures (-10, 4, 21, 37, and 54$^{o}$C) and 6 frequencies (25, 10, 5, 1, 0.5, and 0.1 Hz). The results of the study provided appropriate E* input data for typical asphalt mixtures used in Mississippi.

### 3.5 Oklahoma

The Oklahoma DOT sponsored a research project to develop a catalog of the E* for laboratory-prepared asphalt mixtures and to compare the measured E* values with those predicted by the Witczak equation embedded in the MEPDG (*13*). Twenty one asphalt mixtures that were produced for ODOT projects over a two-year period were selected for this study. These mixes were composed of four predominant aggregate types (limestone, sandstone, granite/rhyolite and crushed gravel) and three binder performance grades (PG 64-22, PG 70-28 and PG 76-28) used in Oklahoma. Six of the 21 mixes contained 25% Reclaimed Asphalt Pavement (RAP), and the other mixtures contain only virgin materials. All the mixes were prepared at the optimum asphalt content.

E* testing was conducted in accordance with AASHTO TP 62-03. The study reported that the laboratory testing at -10$^{o}$C was difficult and time consuming and that testing at temperatures below 0$^{o}$C can be eliminated without affecting the MEPDG predictions.

The study found that the difference in E* varied from 1 to 47 percent with the measured values being larger than predicted values and that the use of the default or predicted values in the MEPDG would be considered conservative for ODOT mixtures. The study also found that the presence of 25% RAP in a mixture had a significant effect on the measured E* values. It appears that using 25% RAP in a mixture has the same effect on measured E* as raising the PG grade of binder in a virgin mix approximately one PG grade.

### 3.6 Washington State

Yu and Shen (*14*) conducted a study sponsored by the Washington State DOT to determine the dynamic modulus properties of seven field mixes from different regions of the state. The E* test results were assembled in a database for future local calibration of the MEPDG. E* testing was conducted at four temperatures (40, 70, 100, 130$^{o}$F) and six frequencies (25, 10, 5, 1, 0.5, 0.1Hz) in an AMPT. The measured E* results were compared with those predicted by three E* prediction models, including the 1996 Witczak model, the new Witczak model, and the Hirsch model. The Hirsch model was found to be the most suitable for the mixtures tested in the study. Using the measured E* test results, the Hirsch model was re-calibrated, and the re-calibrated model was recommended for estimating the E* of dense-graded asphalt mixtures in Washington State in the future.

## 4. USE OF AMPT TO CHARACTERIZE ASPHALT MATERIAL INPUTS FOR AASHTOWARE® PAVEMENT ME DESIGN

Since all the Pavement ME Design performance predictions except thermal cracking are very sensitive to E* inputs, it is important to carefully characterize this mixture property. It is not anticipated that highway agencies will conduct full Level 1 E* testing for each pavement design project or asphalt mixture, but 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 E* predictions and possibly re-calibrating the E* 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 (*15, 11, 16*).

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

## 4.1 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, especially in the high-value projects, and cover the desired range of each important factor. The following factors have been identified as significantly affecting E* results:

- 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 predictive models, a minimum of 20-30 mixtures will need to be tested.

### *4.1.1 Example Experimental Design*

Table 2 shows an example experimental design that considers some of the important factors and the availability of different mix designs in a state. To develop this experimental design, the bituminous material engineer divides the state into three regions--north, south and central. In each region, the contractors generally use aggregates and binders from the same quarries and asphalt suppliers. The state specification requires that Stone Matrix Asphalt (SMA) mixtures be used for the surface layer on interstate highways and Superpave mixtures be used for others. The specification also requires that the binder used in a surface mix be a PG 76-22 modified with either Styrene Butadiene Styrene (SBS) or Ground Tire Rubber (GTR). The specification allows the contractor to use either 9.5 or 12.5-mm NMAS gradation for the surface layer and either 19- or 25-mm NMAS gradation for the underlying layer. The contractor can use up to 15 percent RAP or 5 percent RAS in a surface mix and up to 25 percent RAP or 15 percent RAP and 5 percent RAS in a binder- or base-layer mix. All the contractors use some WMA technologies in the state. The state specification requires all the mixes be designed at $N_{des}$ = 65.

**Table 2 Example Experimental Design**

| Region | Type | PG | Mod. | Aggregate | NMAS | %RAP | %RAS | WMA | Ndes |
|---|---|---|---|---|---|---|---|---|---|
| North | Surface (SMA) | 76-22 | SBS | Granite | 9.5 | 0 | 5 | No | 65 |
| | Surface (Super) | 76-22 | GTR | Granite | 9.5 | 15 | 0 | Yes | 65 |
| | Binder (Super) | 67-22 | None | Limestone | 19 | 25 | 0 | Yes | 65 |
| | Base (Super) | 67-22 | None | Limestone | 19 | 15 | 5 | Yes | 65 |
| South | Surface (SMA) | 76-22 | SBS | Steel slag | 9.5 | 0 | 5 | No | 65 |
| | Surface (Super) | 76-22 | GTR | Steel slag | 9.5 | 0 | 5 | Yes | 65 |
| | Binder (Super) | 67-22 | None | Sandstone | 19 | 15 | 5 | Yes | 65 |
| | Base (Super) | 67-22 | None | Sandstone | 25 | 25 | 0 | Yes | 65 |
| Central | Surface (SMA) | 76-22 | SBS | BF slag | 9.5 | 0 | 5 | Yes | 65 |
| | Surface (Super) | 76-22 | GTR | BF slag | 9.5 | 15 | 0 | No | 65 |
| | Binder (Super) | 67-22 | None | Gravel | 25 | 15 | 5 | Yes | 65 |
| | Base (Super) | 67-22 | None | Gravel | 25 | 25 | 0 | Yes | 65 |

## 4.2 Data Collection and Laboratory Testing

It is desirable to determine E* results for both laboratory-prepared and plant-produced mixes; however, if resources are limited, E* testing can be conducted using only plant-produced mixes. In addition to the E* 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 3. This information will provide all the asphalt material inputs that can be reasonably collected for Pavement ME Design analysis. 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.

**Table 3 Plan for Information Collection and Laboratory Testing (*17*)**

| 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<br>- Binder content<br>- 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<br>- Performance grade<br>- G* and δ at 10 rad/sec and at 2 temperatures | - Binder content<br>- 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<br>- Specific gravity | - Gradation<br>- Specific gravity | Mix design report and/or QC/QA data |
| Volumetric Properties | - Effective asphalt content by volume ($V_{beff}$)<br>- $V_a$ and VFA<br>- Unit Weight | - Binder content ($P_b$)<br>- $G_{mm}$ and $G_{mb}$<br>- $V_a$, VMA, VFA, dust/binder ratio<br>- $V_{beff}$ | 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.

### 4.3 Data Storage and Analysis

Since a significant amount of data is collected for this study, it is recommended that a database be developed to manage testing results. The database can include only one table or several relational tables. It can be developed in Microsoft Office Excel or Access or other data formats. 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 will 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.

The database of general project and material testing data can be used to evaluate E* predictive 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 E* results. Then, the next step is to evaluate the appropriateness of each predictive 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 ongoing.

## 5. OTHER TESTS IN AMPT

In addition to the E* test for the structural pavement design, there are other tests that can be conducted in the AMPT. These tests include procedures for evaluating the rutting and cracking performance of asphalt mixtures, and the data are potentially applicable in the mechanistic empirical pavement design.

As part of NCHRP Project 9-29, the Flow Number ($F_n$) and Flow Time ($F_t$) tests were also refined to evaluate the resistance of asphalt mixtures to permanent deformation (*1*). Currently, evaluation and implementation efforts are focused on the $F_n$ test, and the $F_t$ test is not expected to be used widely in the near future. 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.

Another test procedure, known as the repeated-load permanent deformation test, was selected by NCHRP Project 9-30A 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 (*18*). The software program is being considered by the AASHTO Joint Task Force on Pavements for adoption.

The main difference between the $F_n$ test and the repeated-load permanent deformation test is that testing conditions, including deviator stresses, confining stresses and test temperatures, are specified differently in the two test procedures. 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.

Some 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) (*19*) and Simplified Viscoelastic Continuum Damage (S-VECD) (*20*). 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. However, implementation of this test procedure for routine use will take time because this test is more involved than the above tests for permanent deformation and requires users to have some knowledge and understanding of viscoelastic continuum damage theory for better analysis and interpretation of test results.

The most recent test that can be conducted in the AMPT is the overlay test in accordance with the Texas Department of Transportation (TxDOT) test procedure Tex-248-F (*21*). This test can be done with an AMPT Overlay Test Kit purchased separately. 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. The high tensile strain may not be applicable for asphalt mixtures used in other applications. Research is underway to modify the testing condition of this procedure for testing asphalt mixtures used in applications other than overlays on concrete pavements.

## 6. SUMMARY

The focus of this synthesis is on the use of the AMPT for determining the dynamic modulus inputs to support the implementation of AASHTOware® Pavement ME Design. The information provided in this synthesis can be useful for both material and pavement design engineers in the process of implementing AMPT and Pavement ME Design for designing flexible pavements.

This synthesis includes four parts. The first part presents an overview of Pavement ME Design and sensitive material inputs. The second part summarizes activities highway agencies have conducted to implement the AMPT and Pavement ME Design. The third part provides guidelines for developing an experimental plan for characterizing E* and other material inputs to support the Pavement ME Design implementation. The last part 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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