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.

U.S. Department of Transportation
Federal Highway Administration

Office of Pavement Technology

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Asphalt Mixture Performance Tester (AMPT)

The AMPT complements current asphalt mixture design procedures by providing engineering properties for mixture evaluation and pavement structural design. This Technical Brief summarizes the development of the AMPT and describes how the AMPT can be used in pavement structural design and mixture design.

What is the AMPT?

The AMPT is a testing machine specifically designed to measure asphalt mixture engineering properties. Shown in Figure 1, it is a compact servo-hydraulic testing machine that was developed through work completed under National Cooperative Highway Research Program (NCHRP) Projects 9-19, *Superpave Support and Performance Models Management* (*1*), and 9-29, *Simple Performance Tester for Superpave Mix Design* (*2-5*). With the AMPT, a mixture's rutting resistance can be quickly evaluated using the flow number test. The flow number has been correlated with the rutting resistance of mixtures from various full scale pavement tests (*1*). The AMPT also greatly simplifies the development of dynamic modulus master curves needed for pavement structural design using the AASHTOWare® Pavement ME Design (formerly DARWin-ME™) Pavement Design and Analysis Software or other mechanistic-empirical structural design procedures. Dynamic modulus tests at multiple temperatures and loading frequencies are used to develop the dynamic modulus master curve. In addition to the flow number and the dynamic modulus tests, which have been standardized, work is currently underway to develop and standardize a direct tension fatigue test for the AMPT that can be used to evaluate the resistance of a mixture to fatigue and top down cracking (*6,7*).

Figure 1. Photographs of AMPT Equipment by Interlaken Technology Corporation (left) and IPC Global (right).

Why Was the AMPT Developed?

The AMPT was developed in response to concerns raised by agency materials engineers that the Superpave mixture design system, as implemented, did not include a fundamental performance test of rutting resistance. The Marshall and Hveem mix design methods, that Superpave was replacing, both included tests that engineers and technicians associated with rutting resistance. Although the predictive capability of these tests was questionable, they provided mix designers with a general assessment of the rutting resistance of the design mixture that was not duplicated in the Superpave volumetric design procedure. The Federal Highway Administration (FHWA) and the NCHRP initiated several research studies to evaluate various tests as "simple performance tests" of rutting resistance that could compliment volumetric mix design (*1,8-10*). These included: (1) parameters from the gyratory compactor, (2) wheel tracking tests, (3) shear tests, (4) indirect tensile tests, and (5) triaxial tests. Concurrently, the American Association of State Highway and Transportation Officials (AASHTO) Joint Task Force on

Pavements began the development of a mechanistic-empirical pavement design procedure that ultimately became AASHTOWare® Pavement ME Design (*11*). The compatibility of triaxial tests for rutting resistance with the new mechanistic-empirical pavement design procedure led to the selection of the flow number and dynamic modulus tests as the preferred performance tests to complement mixture design and were included in the development of the AMPT equipment.

How Does the AMPT Differ From Other Asphalt Mixture Performance Test Equipment?

A number of performance tests have been developed for evaluating asphalt mixtures (*12*). The major differences between the AMPT tests and other rutting resistance tests like the Asphalt Pavement Analyzer or the Hamburg Wheel Track Test are the fundamental mechanical nature of the AMPT tests and that results can be used in AASHTOWare® Pavement ME Design to estimate the performance of a pavement constructed with the mixture. The use of the same tests for both mixture evaluation and structural design provides a link between mixture design and structural analysis that has been an underlying goal of a substantial amount of past flexible pavement research. Additionally, the AMPT tests have received national support rather than regional support during their development. This has resulted in a generic equipment specification for the AMPT, multiple vendors producing production AMPT devices, AASHTO standards for testing and data analysis, initial estimates of repeatability and reproducibility, and coordinated training and support. Figure 2 is a flow chart showing the AMPT development, which has taken approximately 10 years to complete. The need for the AMPT was established by agency materials engineers. The research and the development of draft test methods and prototype equipment was completed in NCHRP Project 9-19. Support continued through NCHRP Project 9-29 to commercialize the equipment by developing an equipment

AMPT Standards

- AASHTO TP 79, Provisional Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)
- AASHTO PP 60, Provisional Standard Practice for Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)
- AASHTO PP61, Provisional Standard Practice for Developing Dynamic Modulus Master Curves for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)

specification, evaluating first article devices, performing ruggedness testing on the first articles to improve the equipment specification and test methods, developing AASHTO Provisional standards, and conducting round robin testing to establish repeatability and reproducibility for the flow number and dynamic modulus tests. The FHWA, through Transportation Pooled Fund Project TPF-5(178), conducted training for the AMPT and is providing support to agencies as they use the AMPT.

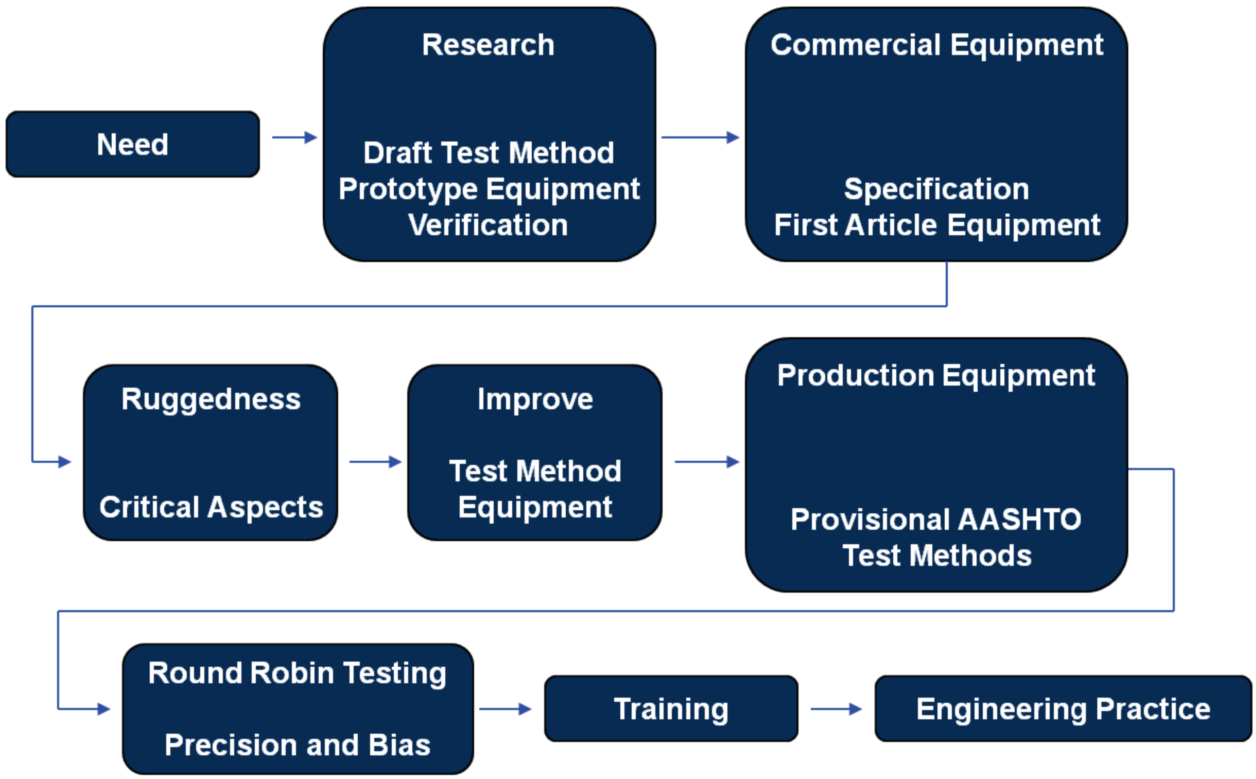

Figure 2. Flow Chart of AMPT Development.

How Are AMPT Test Specimens Prepared?

Tests in the AMPT are conducted on 100 mm (4 in) diameter by 150 mm (6 in) high test specimens that are cored and sawed from larger 150 mm (6 in) diameter by 170± mm (6.75 in) high gyratory specimens prepared in a Superpave gyratory compactor. Figure 3 illustrates the major steps in the specimen fabrication process. First the over-height gyratory specimen is prepared by compacting the mass of mixture needed to meet the target air voids to a predetermined height. Next a 100 mm diameter core is removed from the center of the larger gyratory specimen using a standard diamond coring stand. Finally the ends are trimmed smooth and parallel using a masonry saw. AMPT test specimen preparation has been standardized in AASHTO PP 60, *Provisional Standard Practice for Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)*. The size and dimensions of the AMPT test specimen were selected to ensure that fundamental engineering properties are measured in the AMPT tests. The test specimen is taken from the middle of a larger gyratory specimen to improve specimen uniformity by eliminating high air voids that occur around the circumference and at the ends of gyratory compacted specimens.

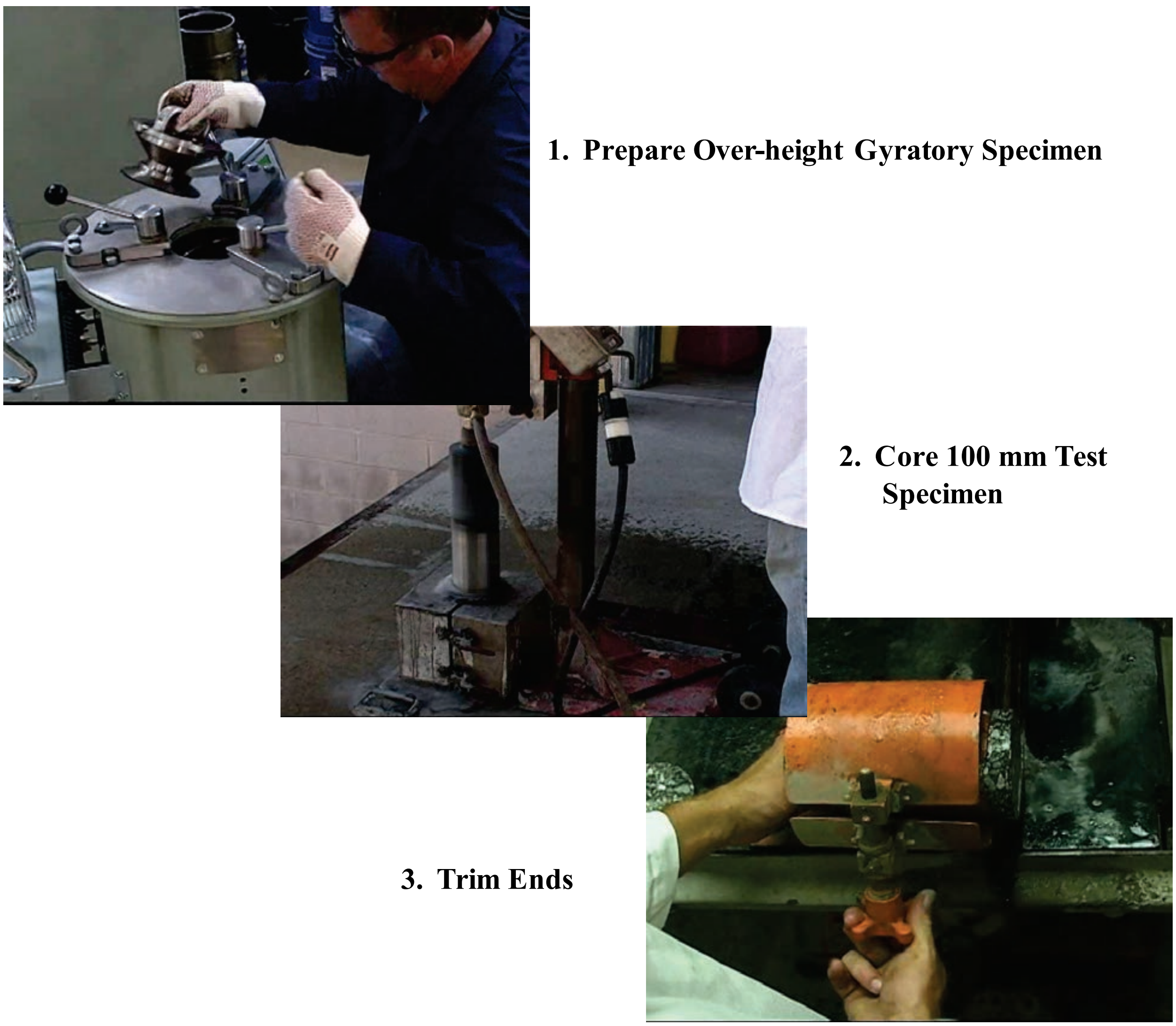

Figure 3. Major Steps in AMPT Test Specimen Preparation.

How is the AMPT Used for Pavement Structural Design?

The primary material property used to characterize asphalt mixtures for pavement structural design is a dynamic modulus master curve. During dynamic modulus testing, a specimen is subjected to continuous sinusoidal, stress-controlled loading at a specified frequency and temperature. Both the applied stress and the resulting strain are continuously recorded during testing. The dynamic modulus is defined as the peak stress divided by the peak strain and is a measure of the overall stiffness of the mixture at a particular test temperature and loading frequency.

Because the response of asphalt materials depends on both temperature and loading rate, the later relating to traffic speed, the modulus of asphalt concrete cannot be described by a single value. The dynamic modulus master curve is an equation that gives the modulus of an asphalt concrete mixture for any combination of temperature and loading rate. During structural analysis, AASHTOWare® Pavement ME Design uses the dynamic modulus master curve to assign an appropriate modulus value depending on temperature, traffic speed, and depth in the pavement structure. A dynamic modulus master curve is constructed using time-temperature superposition as shown schematically in Figure 4. Dynamic modulus measurements are made at different temperatures and frequency of loading. Then the data are shifted horizontally until the data from different temperatures align into a smooth continuous function representing the pavement response at various temperatures and loading rates. Conditions relating to cold temperature and fast traffic speeds are the high reduced frequencies on one end of the master curve and conditions relating to high temperature and slow traffic speeds are the low reduced frequencies at the other end of the master curve.

Dynamic modulus testing in the AMPT requires the use of on-specimen deformation measuring sensors to minimize errors associated with end effects. The sensors are mounted to gauge points that are glued to the specimen and are designed to be rapidly installed. Dynamic modulus testing for master curves should be performed on specimens prepared to the expected in-place air void content; typically seven percent.

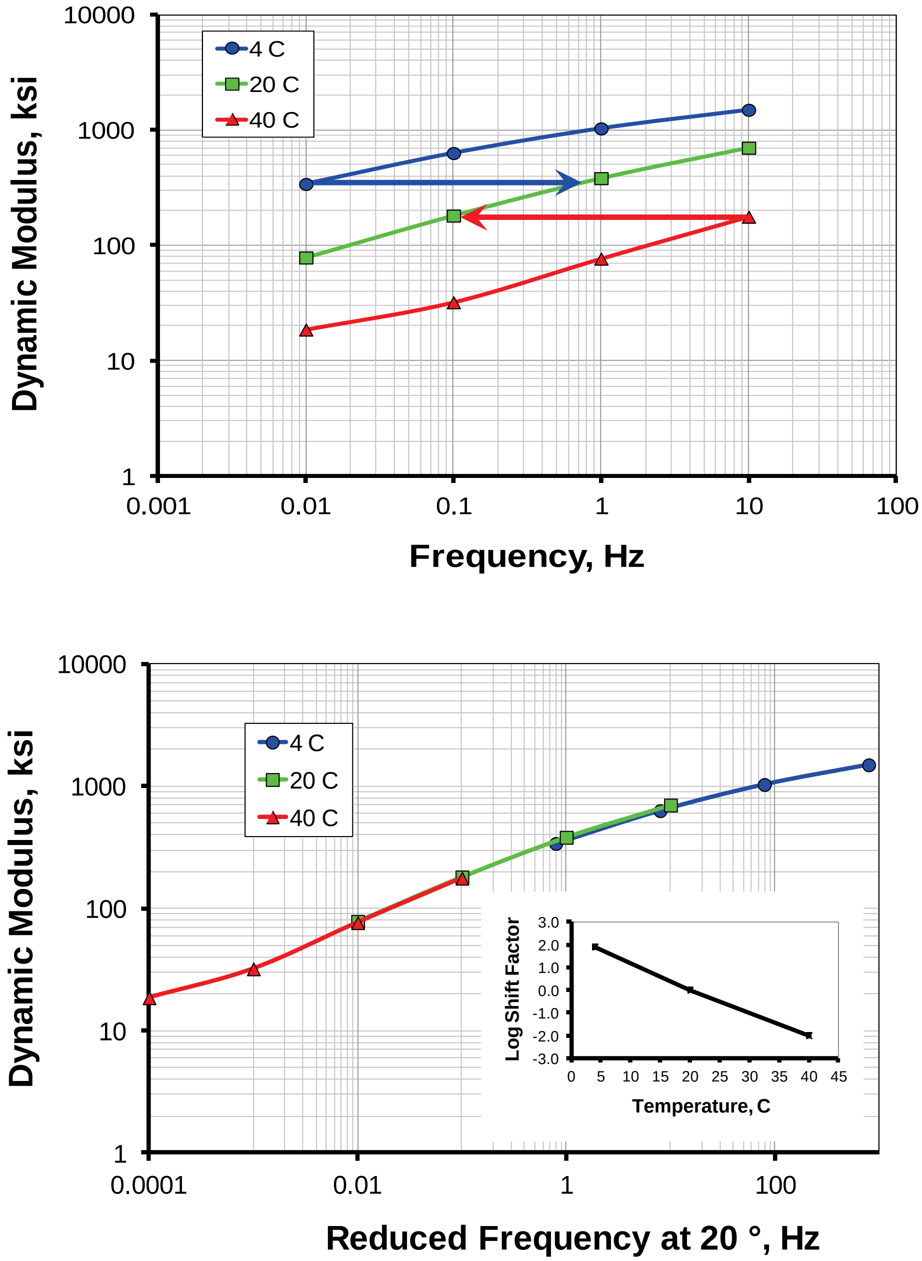

Figure 4. Schematic of Time-Temperature Superposition for Dynamic Modulus Master Curve Construction. Raw Data (top), shifted data (bottom).

The construction of dynamic modulus master curves using the AMPT has been standardized in AASHTO PP61, *Provisional Standard Practice for Developing Dynamic Modulus Master Curves for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT).* Dynamic modulus data are collected at three temperatures and four frequencies. A public domain Microsoft Excel™ application, MasterSolver[1], is used to perform the time-temperature superposition and develop the dynamic modulus master curve for input in AASHTOWare® Pavement ME Design. Figure 5 illustrates the four steps for using the AMPT and MasterSolver to obtain dynamic modulus input data for AASHTOWare® Pavement ME Design.

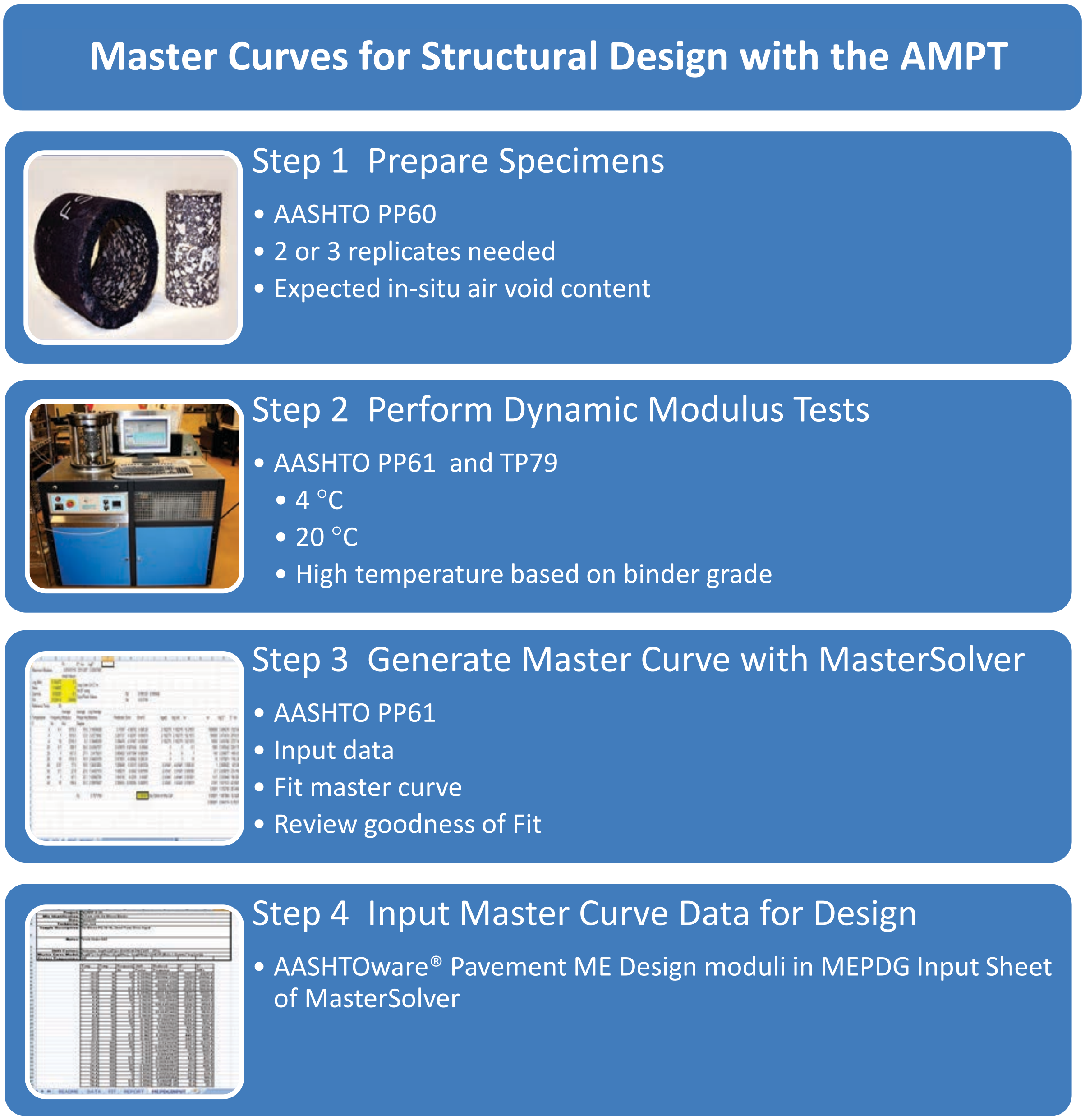

Figure 5. Generating Dynamic Modulus Master Curves for Structural Design with the AMPT and MasterSolver.

[1] MasterSolver is available from http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP09-29_mastersolver2-2.xls and includes a 'README' tab with details of the computations in the tool.

How is the AMPT Used for Mixture Evaluation?

Currently, the primary use of the AMPT for mixture evaluation is assessing the rutting resistance of a mixture using the flow number. As discussed in the next section, a fatigue cracking test for the AMPT is under development. Evaluating the rutting resistance of a mixture using the flow number is straightforward. During flow number testing, a specimen is subjected to a repeated compressive load pulse at a specific test temperature. The resulting permanent axial strains are measured for each load pulse and used to calculate the flow number, or point where the specimen exhibits uncontrolled tertiary flow. Specimen mounted instrumentation is not needed for the flow number test as the actuator displacement is used to measure the permanent deformation. To evaluate rutting resistance, an unconfined flow number test using a repeated axial stress of 600 kPa (87 psi) is conducted with the AMPT at the 50 percent reliability temperature from LTPPBind version 3.1 at a depth of 20 mm for surface courses or the top of the layer for intermediate and base courses. The specimens are prepared to target air voids of seven percent. Typically flow number testing can be conducted on the specimens after they are tested for dynamic modulus limiting the number of specimens required. The measured flow number is then compared to criteria developed in NCHRP Project 9-33 for hot mix asphalt (HMA) or NCHRP 9-43 for warm mix asphalt (WMA) (*13*). The criteria are shown in Table 1. The criteria are different for HMA and WMA because the laboratory conditioning is different. HMA specimens are short-term conditioned for 4 hours at 135 °C. WMA specimens are short-term conditioned for 2 hours at the planned field compaction temperature, which is usually around 115 °C. Figure 6 illustrates the steps for using the AMPT to evaluate rutting resistance.

Table 1. Flow Number Test Criteria.

Design Traffic, Million ESAL	HMA[1]	WMA[1]
< 3	--	--
3 to < 10	50	30
10 to < 30	190	105
> 30	740	415

[1] HMA conditioned 4 hours at 135 °C, WMA conditioned 2 hours at field compaction temperature.

Rutting Resistance with the AMPT

- 50 % reliability high pavement temperature from LTPPBind 3.1
- 20 mm for surface courses
- Top of layer for intermediate and base courses
- No adjustments for speed or traffic level

Step 2 Prepare Test Specimens AASHTO PP60

- 3 or 4 replicates needed
- Target air voids of 7 percent
- Condition HMA 4 hours at 135 °C
- Condition WMA 2 hours at field compaction temperature

Step 3 Perform Flow Number Tests

- AASHTO TP79
- Unconfined
- 600 kPa (87 psi) repeated deviatoric stress
- Test temperature from LTPPBind 3.1 as determined above

Design Traffic, Million ESAL	HMA[1]	WMA[1]
< 3	--	--
3 to < 10	50	30
10 to < 30	190	105
> 30	740	415

[1] HMA conditioned 4 hours at 135 °C, WMA conditioned 2 hours a field compaction temperature.

Step 4 Compare to Criteria

- HMA or WMA
- Traffic level

Figure 6. Evaluating Rutting Resistance with the AMPT.

Can Cracking be Evaluated with the AMPT?

With increasing amounts of recycled binders from reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) and other modifiers like crumb rubber, sulfur, and fibers being used in asphalt mixtures, the development of a cracking test for mixture evaluation is of growing interest. Current mix design procedures rely on a minimum volume of effective binder, and proper binder properties to mitigate fatigue and thermal cracking. Due to uncertainties associated with the mixing of new and recycled binders, and the effect of modifiers that cannot be accurately evaluated through binder testing, a test related to mixture cracking resistance is needed to provide confidence in mixtures designed with these materials.

A thermal cracking test is not possible in the AMPT. The temperature control in the AMPT is limited to the range from 4 °C to 70 °C and the load capacity is not high enough for low temperature testing. Tests for fatigue cracking are possible and there is ongoing work to develop an appropriate fatigue testing protocol for the AMPT (*6,7*). The fatigue methods that are being pursued are based on continuum damage principles. The testing involves performing cyclic direct tension tests and monitoring the change in the modulus of the mixture with increasing cycles. Figure 7 shows an AMPT test specimen with tension end plates needed for testing and a fixture for gluing multiple specimens. The current focus of the research is developing efficient testing and data analysis protocols for use by technicians responsible for asphalt pavement mix designs. It is anticipated that draft test methods for fatigue testing will be submitted to AASHTO in 2013.

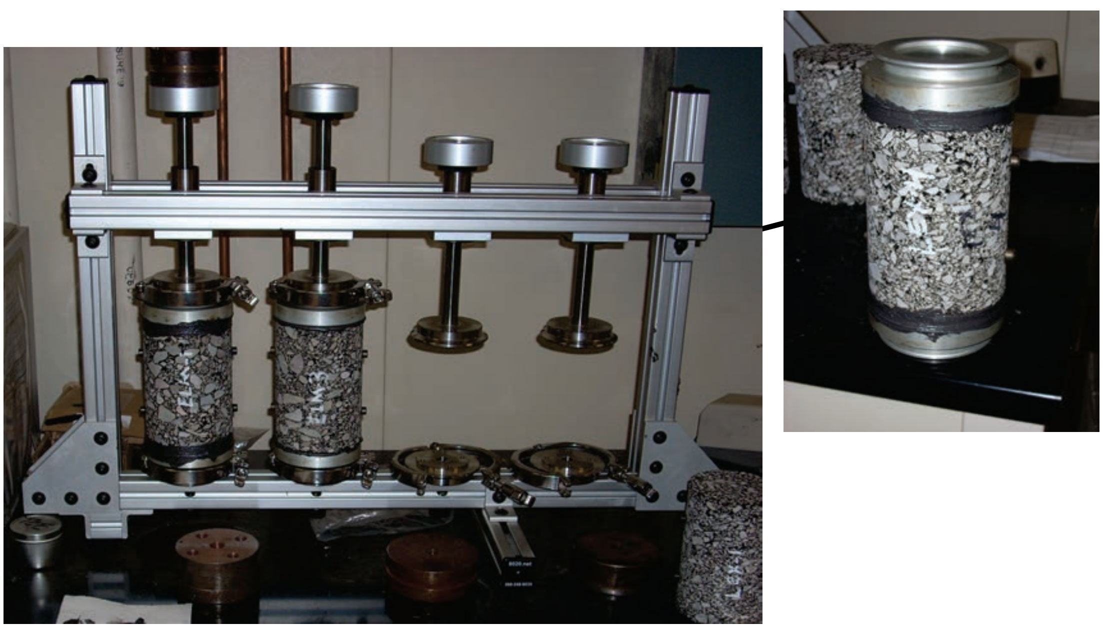

Figure 7. AMPT Fatigue Test Specimen and Gluing Fixture.

Are There Other Tests That Can be Used?

The AMPT is not the only performance testing equipment available for asphalt concrete mix design. Table 2 summarizes a number of tests that have received some level of industry acceptance. This table is organized by five major types of performance tests: modulus, permanent deformation, load associated cracking, thermal cracking and moisture sensitivity. The applicability of each test to routine mixture design is rated based on the following criteria.

1. **Standardization.** Has a standard method for the test been adopted by AASHTO or ASTM, or is there work in progress that will lead to standardization in the near future? It is critical that performance tests included in mix design methods be standardized and that estimates of within and between laboratory precision be available so that the tests can be confidently used by technicians and engineers involved in the mixture design process.

2. **Criteria.** Have criteria for using the test been developed? Past experience with attempted implementation of the Superpave Mixture Analysis System suggests that test criteria differentiating acceptable and unacceptable performance should be provided for routine mixture design. Pavement performance models may also be used by some organizations as additional assurance for critical projects.

3. **Complexity.** Are the test methods and required data analyses appropriate for technicians and engineers involved in the mixture design process? Many pavement performance tests involve the manufacture of special test specimens or the use of instrumentation that technicians are not familiar with. Data analysis often involves relatively complex theories that can be beyond the capabilities of engineers and technicians involved in mix design. Computer control and data analysis can eliminate much of the test complexity; however, the equipment and algorithms must be robust. An excellent example of proper use of computer control is the dynamic shear rheometer, which is very sophisticated equipment and uses relatively complex analysis, but because the control and data analysis are robust, dynamic shear rheometers were quickly adopted for use in the asphalt industry.

4. **Equipment.** Is the equipment for the test available from commercial sources at a reasonable cost and if the test is relatively complex, is the computer control and analysis software reliable? Preferably the equipment should be available from multiple sources so that demand and competition in the market place will lead to continuous improvement of the equipment. The Superpave gyratory compactor and the dynamic shear rheometer are excellent examples of equipment that is available from multiple vendors where there is a history of manufacturer driven improvement

Table 2. Assessment of Available Performance Tests for Use in Routine Mixture Design.

Property	Method	Standardization		Criteria		Complexity		Equipment		
		Method	Precision	Mix Design Pass/Fail	Performance Prediction Model	Method	Analysis	Availability	Reliability	Cost
Modulus	AMPT Dynamic Modulus	Yes	Yes	NA	Yes	Moderate	Moderate	Yes	High	Moderate
	Simple Shear	Yes	Yes		Yes	Moderate	Moderate	Yes	Moderate	High
	Indirect Tension Dynamic Modulus	No	No		Yes	Moderate	Moderate	No	Moderate	High
Permanent Deformation	AMPT Flow Number	Yes	Yes	Yes	Yes	Moderate	Low	Yes	High	Moderate
	Repeated Shear	Yes	Yes	Yes	Yes	Moderate	Moderate	Yes	Moderate	High
	High Temperature Indirect Tensile Strength	Draft	No	Yes	No	Low	Low	Yes	High	Low
	Asphalt Pavement Analyzer	Yes	No	Yes	No	Moderate	Low	Yes	High	Moderate
	Hamburg Wheel Tracking Device	Yes	No	Yes	No	Moderate	Low	Yes	High	Moderate
Load Associated Cracking	Flexural Fatigue	Yes	No	No	Yes	High	Moderate	Yes	High	Moderate
	AMPT Continuum Damage	No	No	No	Yes	High	High	Yes	High	Moderate
	Energy Ratio	No	No	Yes	Yes	High	High	Yes	High	High
	Fracture Energy	No	No	No	Yes	Low	Low	Yes	High	High
Thermal Cracking	IDT Creep and Strength	Yes	No	No	Yes	High	High	Yes	High	High
	Disc Shaped Compact Tension	Yes	Yes	Yes	Yes	High	Low	Yes	High	High
	Semi Circular Bend	Draft	No	Yes	No	Moderate	Low	Yes	High	High
Moisture Sensitivity	Tensile Strength Ratio	Yes	Yes	Yes	No	Moderate	Low	Yes	High	Low
	Hamburg Wheel Tracking Device	Yes	No	Yes	No	Moderate	Low	Yes	High	Moderate

Table 2 shows that substantial progress has been made developing modulus, permanent deformation, and moisture sensitivity tests for asphalt mixtures. Standards and criteria for these tests have been developed and equipment is readily available at low to moderate costs. Many of these tests lack precision statements that are needed when a test method is used to accept or reject material. In recent years, progress has been made on using fracture energy tests for low temperature cracking analysis. Much of this work has been done in Transportation Pooled Fund Study 776 (*14*). Only limited progress has been made on developing tests for load associated cracking for asphalt mixtures. Although continuum damage and fracture energy approaches appear promising, only the flexural fatigue test has been standardized.

As shown in Table 2, the AMPT is moderate cost equipment that shows promise for being able to conduct tests for modulus, permanent deformation, and load associated cracking using a specimen that can be prepared in the Superpave gyratory compactor that is available in most laboratories. The modulus and permanent deformation tests have been standardized and initial estimates of precision are available. The load associated cracking test is currently under development and is expected to be standardized in 2013. Another major benefit that the AMPT provides is the ability to link mixture design to pavement structural design. The AMPT tests provide data that can be used for both mixture evaluation and for pavement performance predictions using AASHTOWare® Pavement ME Design or other mechanistic-empirical structural design software.

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