IPC Global, 4 Wadhurst Drive, Boronia, Victoria 3155, Australia
T +61 3 9800 2200 F +61 3 9800 2813
E sales@ipcglobal.com.au www.ipcglobal.com.au
IPC Global Pty Ltd ABN 92 168 265 156 ACN 168 265 156

The science of testing **made easy**®

Moving towards end performance specifications using Asphalt Mixture Performance Tester (AMPT) to characterise standard and novel Asphalt mixtures as part of Superpave process

McGrane, K.T.
HNC Civil Engineering, Dip. Highway Traffic Engineering, MBA
Chief Executive Officer
IPC Global, Melbourne, Australia
kmcgrane@ipcglobal.com.au

Abstract

How do you know how your laboratory formulated asphalt mixtures will perform when employed in performance based pavement designs using mechanistic empirical design models? For many years pavement engineers and researches have been searching for better ways to understand and characterize the performance of Hot Mix Asphalt (HMA) in the laboratory that relates to field performance. The USA has led the way, starting with Strategic Highway Research Program (SHRP) and culminating in Superpave. Throughout this process, the missing link was a performance related laboratory tests that correlates well with field performance yet are simple to run on widely available standardized commercial equipment. This deficiency was addressed by the National Cooperative Highway Research Program (NCHRP) over the course of three projects that led to the development of the Asphalt Mix Performance Tester (AMPT). The paper presents the conception, development and uses of the AMPT in characterising asphalts for performance based pavement designs.

Superpave evolution

Since 2000 Superpave has evolved significantly. Research conducted under NCHRP (National Cooperative Highway Research Program) is evaluated by Expert Task Groups and result in AASHTO standards.

With the limitation in the volumetric-based SUPERPAVE mix design process in mind, FHWA initiated a research study through the SUPERPAVE Models Project to develop a “Simple Performance Test” that would be used in compliment to the volumetric-based SUPERPAVE mix design process.

The definition for the simple performance test, as used by the National Cooperative Highway Research Program (NCHRP), is as follows:
A test(s) method(s) that accurately and reliably measures a mixture response characteristic or parameter that is highly correlated to the occurrence of pavement distress over a diverse range of traffic and climatic conditions.

The Simple Performance Test(s)

In 1996, work sponsored by FHWA began at the University of Maryland to identify and validate simple performance tests for permanent deformation, fatigue cracking and low-temperature cracking. In 1999, this effort was transferred to Task C of National Cooperative Highway Research Program (NCHRP) Project 9-19, “Superpave Support and Performance Models Management”, with the major portion of the task conducted by a research team headed by Dr Matthew Witczak.

The research team was directed to evaluate, as potential simple performance tests, only existing test methods measuring HMA response characteristics. The principal evaluation criteria were:

1. Accuracy
2. Reliability
3. Ease of use
4. Reasonable equipment cost

The research team conducted a comprehensive laboratory testing program to statistically correlate the actual performance of HMA materials from three field test sites in North America, with the measured responses of specimens prepared from original materials for 33 promising test method-test parameter combinations.

Based on the results of this testing program, the research team recommended three test parameter combinations for further field validation as simple performance tests for permanent deformation:

1. The dynamic modulus term E*/sinΦ, determined from the triaxial dynamic modulus test.
2. The flow number, Fn, determined from the triaxial repeated load test.
3. The flow time, Ft, determined from triaxial static creep test.

All combinations exhibited a coefficient of determination, R^2, of 0.9 or greater for the combined field test sites.

Whilst the results from the project looked extremely promising, it was obvious that the tests and the equipment designed to carry them out must be capable of producing consistent results over the broadest range of suitable materials and areas of application. According to the NCHRP, the equipment developed to carry out the test of the mixture in the Superpave system should more closely resemble commercial test equipment. It should be rugged, easy to use, and based on a set of specifications which would allow it to be affordable and so designed to be suitable for purchase by State departments of transport and, very shortly thereafter, by the widest range of contractors associated and working within the industry.

In April 2001, Advanced Asphalt Technology (AAT) in the USA was assigned the task of specifying, procuring and evaluating a suitable testing machine(s) through NCHRP Project 9-29.

The objective of this project is to design, procure and evaluate Simple Performance Test (SPT) systems for use in Superpave mix design and in Hot Mix Asphalt (HMA) materials characterization for pavement structure design and possibly in field quality control. This involves:

- ✓ Development of equipment
- ✓ Equipment evaluation
- ✓ Ruggedness evaluation
- ✓ Final procedure verification

All leading towards a national procurement for the state DOTs and eventual widespread adoption and use by HMA industry.

A number of candidate design proposals were submitted of which two were selected for evaluation. One unit, manufactured by Interlaken Technology Corporation (ITC), USA and one unit, manufactured by IPC Global, Australia were delivered mid-2002 and have since been successfully evaluated. The two prototype units are shown in Figures 1 & 2, respectively.

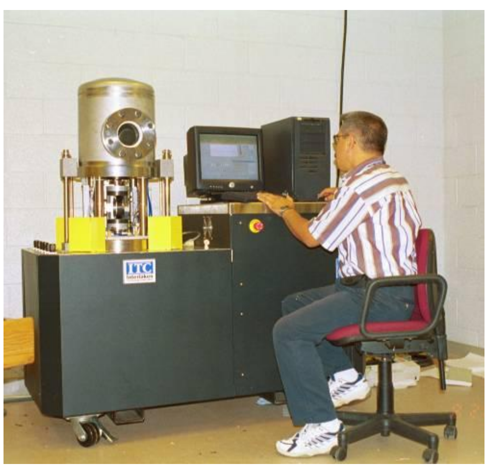


Fig. 1: ITC prototype SPT

Fig. 2: IPC early prototype SPT

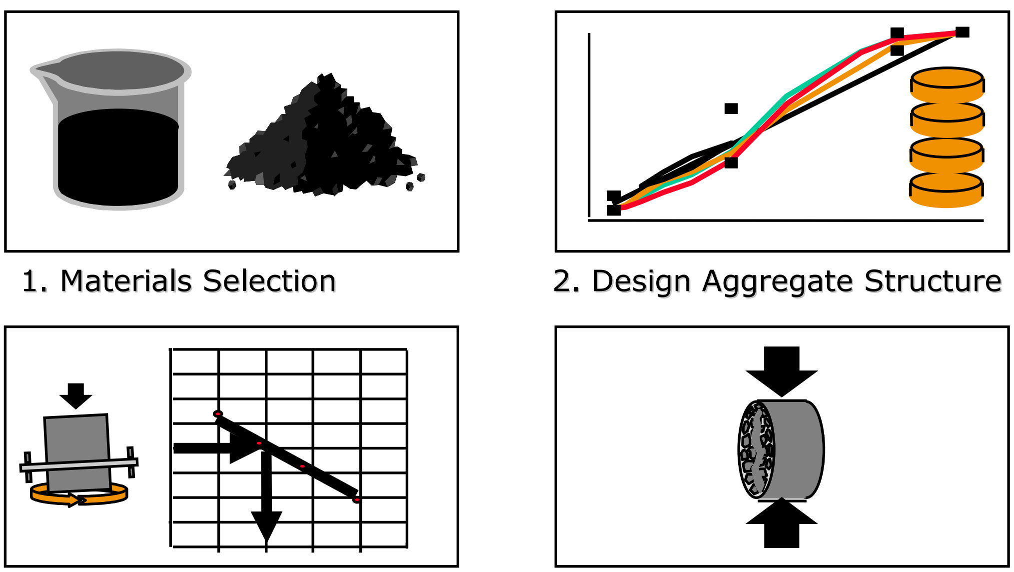
In addition, the dynamic modulus test was selected for the HMA materials characterization input utilized in the 2002 Empirical and Mechanistic Guide for Design of New and Rehabilitated Pavement Structures, developed under NCHRP Project 1-37A.

Recently the Simple Performance Tester was renamed the Asphalt Mixture Performance Tester (AMPT), with both IPC and ITC offering second generation machines.

To complete the SUPERPAVE evolutionary process, AASHTO released a Standard Test Method (AASHTO Designation TP79-09) for *Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT).*

Superpave mix design steps

The basic steps in the Superpave mix design process are: Material Selection, Design Aggregate Structure, design Binder Content and finally, Mixture Performance Testing.



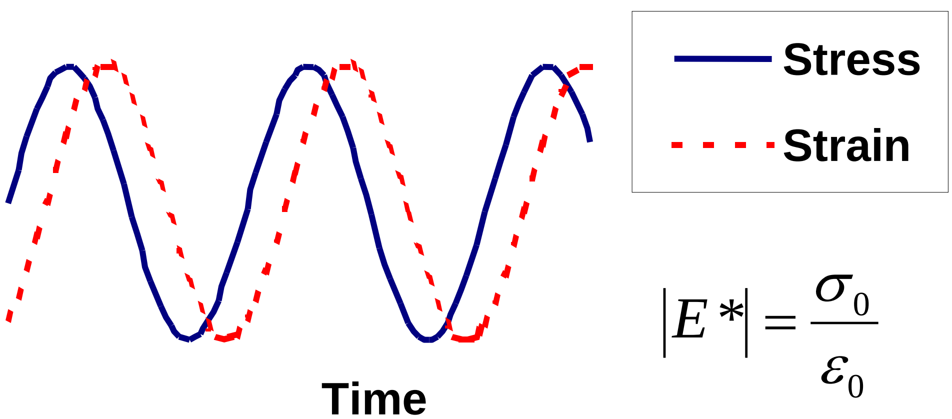
1. Materials Selection
2. Design Aggregate Structure
3. Design Binder Content
4. Mixture Performance Testing

The focus of this paper is on Mixture performance testing. Although we can test the performance/parameters of the individual constituents that make up a mixture, with will not, with any certainty, predict its performance. Key engineering parameters such as modulus are also required for pavement design.

The development of the AMPT has provided the tools required to characterize HMA accurately and seamlessly, with standardized equipment using test methods that have good correlation with performance in the field.

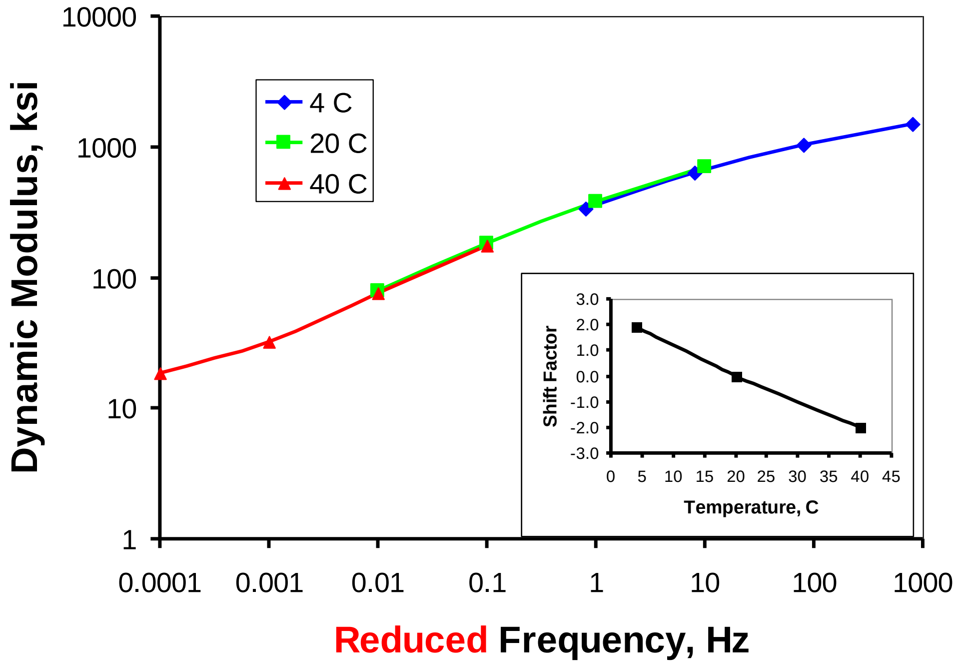
Pavement Structural Design

Dynamic modulus (|E*|) is an essential parameter for structural pavement design. More specifically, Dynamic modulus master curve of HMA is an essential input parameter in level 1 of the AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG). From an engineering point of view there is much to be desired about a mechanistic approach to pavement design. Unlike empirical approaches, the concepts are generally applicable and modular such that future enhancements can be developed and implemented. (e.g., improved rutting model, improved damage accumulation algorithm and improved laboratory testing procedures.



$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$

The recommended test(s) for developing master curves as prescribed in AASHTO Provisional Standard TP 62-03 “Standard Method of Test for Determining Dynamic Modulus of Hot-Mix Asphalt Concrete Mixtures test method” includes testing at least 2 replicate specimens at five temperatures between -10C and +54.4C and six loading frequencies between 0.1Hz and 25Hz. The master curves are then developed from this data base of 60 moduli using numeric optimization. This testing requires substantial effort and there is much overlap in the measured data, which is not needed when numerical methods are used to perform the time-temperature shifting for the master curve.



Recently, Christensen et al developed another dynamic modulus prediction (Hirsch) model for asphalt concrete modulus. Bonaquist and Christensen proposed an approach that takes advantage of the fact that, for engineering purposes, asphalt binders reach the same glassy modulus at very low temperatures. Using this binder modulus and recently developed relationships to predict mixture dynamic modulus from binder modulus and volumetric data, the maximum limiting modulus of the mixture can be made and used in the development of the dynamic modulus master curve. This alternative approach proposes testing at three temperatures (4.4C, 21.1C and 46.6C) and four loading frequencies (10Hz, 1Hz, 0.1Hz and 0.01Hz). Using this approach and software automation already incorporated into the AMPT, specimen preparation and dynamic modulus master curve testing for a mixture using three replicate specimens is estimated to require 13.5 man-hours of technician time.

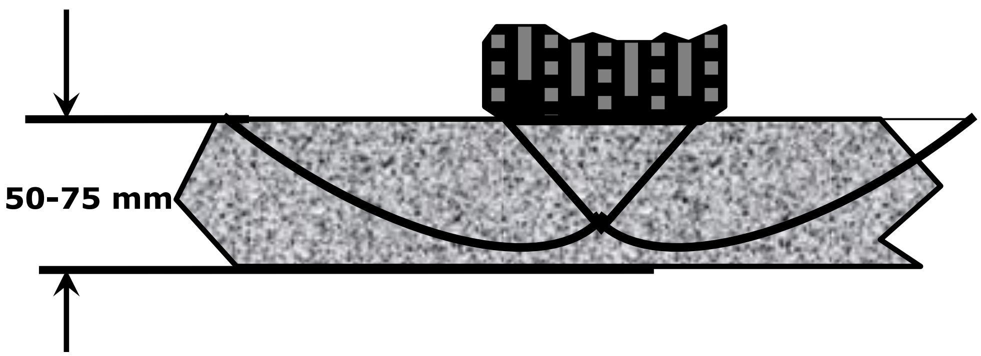
Field core specimens

The specimen geometry specified in AASHTO TP79-09 is nominally 100mm diameter specimens, 150mm tall. Whilst this is feasible for laboratory prepared specimens it's not feasible for specimens recovered from the field. Richard Kim et al undertook a study on the dynamic modulus testing of hot-mix asphalt using the indirect tension (IDT) mode. An analytical solution for the dynamic modulus in the IDT mode was developed with the use of linear viscoelasticity. A comparison of results from the axial compression and IDT test methods shows that the dynamic modulus master curves and shift factors derived from the two methods are in good agreement.

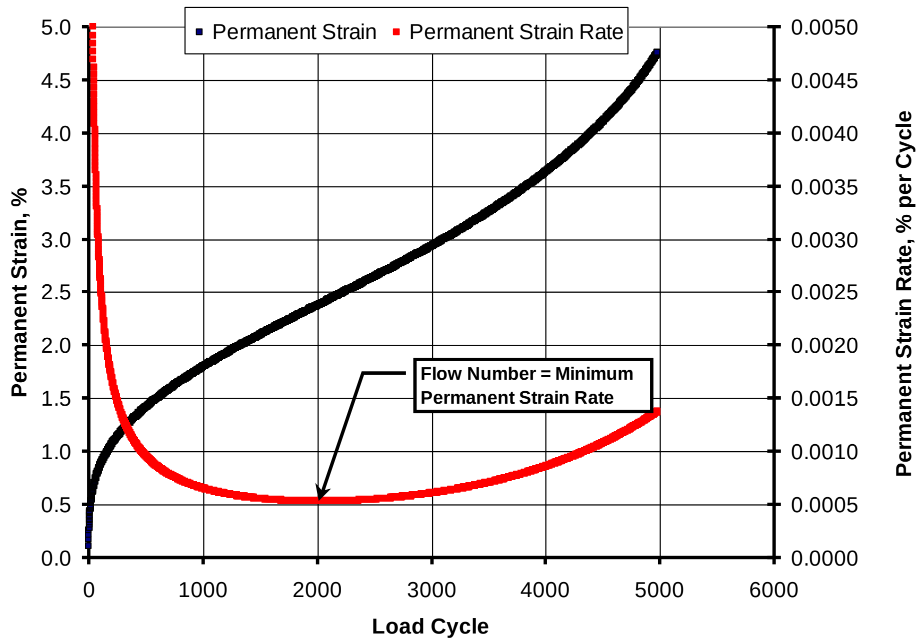
FHWA sponsored North Carolina State University (NCSU) to advance this approach and an ETG review is under way. IPC has developed hardware, instrumentation and software to perform a Dynamic modulus test in IDT mode in the AMPT.

Rutting resistance

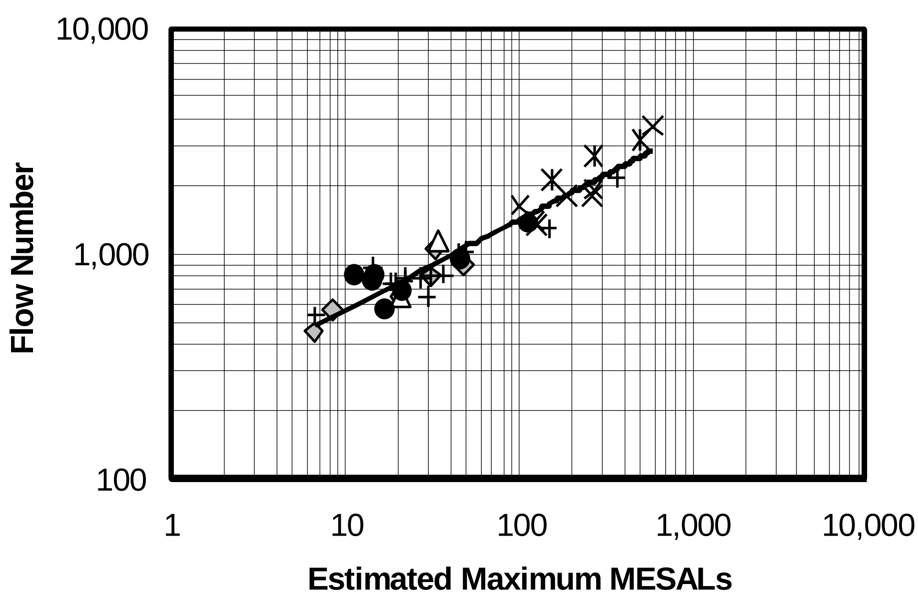
Permanent deformation in HMA is predominantly due to shear deformation and to a less extent, densification. It typically occurs at higher temperatures, early in a pavements life.



In the flow number test, a test specimen, at a specific test temperature, is subjected to a repeated haversine axial compressive load pulse of 0.1 sec every 1.0 sec. The test may be conducted with or without confining pressure. The resulting permanent axial strains are measured for each load cycle and numerically differentiated to calculate the flow number. The flow number is defined as the number of load cycles corresponding to the minimum rate of change of permanent strain. The figure below shows example data from the flow number test. In research conducted in NCHRP Project 9-19, flow number data at high temperatures correlated well with the rutting resistance of mixtures used in experimental sections at MNRoad, WesTrack, and the FHWA Pavement Testing Facility.



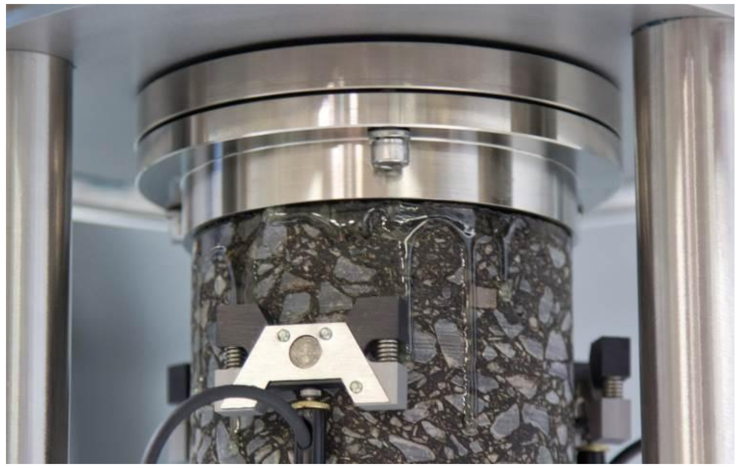
Recently, tentative criteria for the flow number test have been developed in NCHRP Project 9-33 "*A Mix Design Manual for Hot Mix Asphalt (HMA)*". The criteria are shown in the table below.



MESAL	Flow Number
3	--
3 to <10	340
10 to <30	560
≥30	890

Fatigue cracking

New developments



Full reversal ("push-pull") in a fatigue test on 100mm diameter cyclical specimens can be relatively easy to perform on the AMPT to directly monitor the modulus of the specimen as it is damaged. When combined with the known undamaged modulus (|E*|), this damage function can be used to define the effect of any loading history on the material response—essential information when predicting the response of an actual pavement structure to real-world traffic loading.

The (S-VECD) model uses data from cyclic testing to develop the damage characteristic relationship. This greatly simplifies the characterization procedure using results from fatigue data generated at a single strain level and temperature.

The Texas Overlay test developed by The Texas Transportation Institute (Texas A&M) overlay tester was designed by F.P. Germann and R.L. Lytton in the late 1970's to simulate the opening and closing of joints or cracks. The focus of many asphalt mixture design procedures over the past 10 years has led to the development of stiffer, drier mixtures. However, these mixes are more difficult to construct and are potentially more prone to reflective cracking. Due to this development the Texas overlay test Tex-248-F and the draft ASTM have become popular and included in many pavement design specifications. The overlay test can now also be performed in the AMPT.

Return on Investment Payback

By adopting best practice performance based pavement design using the Superpave process, great savings can be made. These savings will more than compensate for the cost of purchasing and operating laboratory equipment for asphalt mixture performance testing.

Without performance based pavement design, pavements may be either over engineered or under engineered. Both of which incur additional costs. For over engineered pavements these costs include additional construction time and associated traffic congestion and delays, additional materials costs, additional plant costs and additional labour costs. For under engineered roads there are costs of reconstruction, additional traffic congestion and delays, additional materials, plant and labour costs, vehicle damage and tyre wear, and road safety costs of death, injury and property damage. There is also the opportunity cost of spending more that was necessary on a highway project.

By designing for a required performance, based on the predicted traffic speed and volume and for the anticipated temperature range, it is possible to achieve optimal design and therefore avoid unnecessary costs. The saving significantly outweighs the cost of laboratory equipment and the associated running costs.

Conclusion

Simple performance tests are a quick, economical, and effective method for assessing performance of HMA mixtures designed using the Superpave system. The test methods utilized by the AMPT supplement existing test methods and performance prediction models and may replace existing, less accurate tests resulting in tremendous cost and time savings. Further, the AMPT is applicable in a variety of climates and to different materials, thus alleviating the need for extensive calibration procedures. The responses measured by the AMPT are used not only to evaluate resistance to permanent deformation during the design process, but will also play a key role in quality acceptance and control of HMA mixtures in the field. In addition, the dynamic modulus determined by the AMPT is an input in the MEPDG (NCHRP Project 1-37A) for structural design of flexible pavements. Currently the MEPDG is being implemented across the world and the acquisition of a device such as the AMPT that can more easily provide dynamic modulus data will result in long-term cost savings. As part of the long-term plan for adoption of the Superpave mix design system, the AMPT should be implemented on a worldwide basis. A cooperative effort by highway agencies to implement the AMPT will allow for communication and information dissemination among agencies and increased knowledge regarding the use of AMPT for mixture design, performance assessment, and structural design.

By incorporating the overlay test into the AMPT, IPC Global has further extended the capabilities of this machine and provides greater value for its users. Now one machine can perform the most popular and important tests –

Dynamic Modulus E*, Flow number FN, uniaxial fatigue SVECD and Overlay test.

References

Louay N. Mohammad, Zhong Wu, Leslie Myers, Sam Cooper and Christopher Abadie - *A Practical Look at the Simple Performance Tests:Louisiana's Experience (2009).*

Audrey Copland - *Improving Performance of Asphalt Mixtures: Implementation of the Asphalt Performance Mixture Tester (AMPT) (2009).*

John Bukowski - *The future of the Superpave Mixture Design System: Asphalt Mix Part II (2010).*

Simple Performance Test for Superpave Mix Design. National Cooperative Highway Research Program (NCHRP) Report 465, Transportation Research Board, National Research Council, Washington, D.C., 2002.

Simple Performance Tester for Superpave Mix Design: First-Article Development and Evaluation. National Cooperative Highway Research Program (NCHRP) Report 513, Transportation Research Board, National Research Council, Washington, D.C., 2003.

Christensen, D.W., T. Pellinen and R.F. Bonaquist - *Hirsch Model for Estimating the Modulus of Asphalt Concrete, Journal of the Association of Asphalt Paving Technologists, Vol. 72, 2003.*

Kaloush, K. E. and M.W. Witczak - *Tertiary Flow Characteristics of Asphalt Mixtures, Journal of the Association of Asphalt Paving Technologists, Volume 71, 2002.*

Y. Richard Kim, Youngguk Seo, Mark King, Mostafa Momen - *Dynamic Modulus Testing of Asphalt Concrete in Indirect Tension Mode (2004).*

Don Christensen, Y. Richard Kim, Dallas Little, Eyad Masad and Yong-Rak Kim - *Practical Approaches to Continuum Damage Fatigue Analysis (2009).*

Fujie Zhou and Tom Scullion - *Overlay tester: a rapid performance related crack resistance test, FHWA/TX-05/0-4467-2 (2005)*

F.P. Germann and R.L. Lytton - *Methodology for predicting the reflection cracking life of asphalt concrete overlays, FHWA-TX-79-09&207-5 Intrm Rpt. (1974)*