MPC-671
September 24, 2021

Project Title

Development of Dynamic Modulus Parameters from Single Point Tests

University

University of Utah

Principal Investigators

Pedro Romero, Ph.D., P.E.
Associate Professor
University of Utah
Phone: (801) 587-7725
Email: pedro.romero@utah.edu
ORCID: 0000-0002-9446-4556

Research Needs

The pavement structural design process and the asphalt materials that are used to build these pavements are currently disconnected in most highway agencies practices. Asphalt mixture properties obtained from adopted quality-control or quality-acceptance tests such as the IDEAL-CT, or Bending Beam Rheometer for mixtures that are used to evaluate cracking potential are not used as input to the pavement structural design process. While AASHTOWare Pavement ME® has been adopted in the structural design, the material inputs required in the process are not always available resulting in the use of average or default values that do not necessarily represent what is placed in the field. This practice results in the AASHTOWare Pavement ME® process over/under estimating distresses like fatigue and thermal cracking in pavement sections. Cost optimization opportunities that would allow to proactively maintain the infrastructure in a state of good repair are therefore being missed.

One of the inputs for AASHTOWare Pavement ME® is the dynamic modulus obtained from the Asphalt Mixture Pavement Tester (AMPT). However, due to the complexities of the test, the use of the AMPT to collect specific materials data has been a less than palatable solution, thus a standard-material model is being used in place of actual measured values (i.e., Level 3 in AASHTOWare Pavement ME®). Using the Level 3 pavement design does not consider the unique materials properties made recognizable by single point testing available today.

The AMPT is used on compacted asphalt cylinders to obtain the dynamic modulus, E*, of the material at three temperatures and three or four frequencies. These values of E* are direct inputs into the AASHTOWare Pavement ME® program. The program takes these values and fits the following equation developed as part of NCHRP project 9-29:

$$log|E^*| = \delta + \frac{(Max-\delta)}{1+e^{\beta+\gamma log\omega_r}}$$

Where:

$|E^*|$	= dynamic modulus, psi
ω_r	= reduced frequency, Hz
Max	= limiting maximum modulus, psi
$\delta, \beta, and\ \gamma$	= fitting parameters

This master curve is specific to a given material, therefore so are the parameters that define the curve. The master curve is used within the software to determine the E* for any loading frequency and temperature. Due to the visco-elastic behavior of asphalt materials, a portion of the master curve relates to the high temperature behavior (rutting), another portion relates to the intermediate temperature (fatigue cracking), and another relates to the low temperature behavior (thermal cracking). This means that the results from tests currently being used for materials testing can be related to that specific portion of the master curve and thus connect materials testing to the structural design process. This approach would use data that is already being collected and is specific to a given material. Using data from existing tests, will reduce the need from AMPT testing while allowing a Level 1 pavement design with the corresponding ability for cost optimization that can benefit both the quality of materials and the structural design of pavements.

Research Objectives

The overall objective of this research is to develop a relation between material tests that have been developed to control cracking (bending beam rheometer for mixtures at low temperatures, and the IDEAL CT at intermediate temperatures) and the dynamic Modulus, E*, master curve. The master curve values are used as input to the pavement design software (Level 1 in AASHTOWare Pavement ME®). This work will result in a relation between the material properties and the structural design of pavements which will allow for cost optimization and improvement of pavement mixes to minimize cracking (a major maintenance issue).

The specific objectives of this research project, based on budget constraints, are:

1. Establish a theoretical background between the CT Index from the IDEAL CT and the portion of the dynamic modulus master curve from the AMPT that corresponds to intermediate temperatures (where most of the E* data is actually collected).
2. Demonstrate experimentally that data from both tests (AMPT and IDEAL CT) relate to each other. Mixes with different CT indices should also result in different E* master curves and the relative ranking of these mixes should be similar (e.g., mixes with low CT indices will have high values of E* or high slopes).
3. Model how the different values obtain from these tests result in pavement cracking

Research Methods

This research will obtain two asphalt mixtures that are approved by the highway agency and test them using the "single-parameter" IDEAL CT test to obtain their cracking index. The same asphalt mixture will be tested using the Asphalt Mixture Pavement Tester, AMPT, to obtain the dynamic modulus of the material. Using the dynamic modulus data at different temperature and frequencies, a master curve of E* versus reduced frequency will be developed and fitted with the equation shown on the Research Needs section. The parameters corresponding to the high and low temperature portion of the curve will be held constant and the intermediate parameters will be related to the CT Index. This will allow for the selection of a given E* master curve using single-point data thus validating the proposed approach.

Expected Outcomes

The expected outcome of this work will be a relation between cracking parameter CT index and intermediate temperature portion of the dynamic modulus master curve. This relation will have a tremendous impact on the design of pavements using current software models.

Specifically, this research will provide a simplified procedure to obtain the inputs for the AASHTOWare Pavement ME® software from tests used for quality-control or quality-acceptance; a step that is critically needed to design and maintain long-lasting pavements.

Relevance to Strategic Goals

This work is directly related to the USDOT strategic goal of State of Good Repair; by having the ability to relate material properties to pavement design, highway agencies and industry partners could optimize the design of asphalt mixtures to improve its longevity and thus minimize the life-cycle cost of the system.

At a regional level, this is part of the stated activities to improve pavement mixes to minimize weather-related cracking and to the development of quality-control acceptance standards for high performance pavements.

Educational Benefits

Given the limited funding, one graduate student will assist on this project. Student will be involved in all aspects of the project including data collection, analyses, and development of limits. Beyond the obvious acquisition of knowledge, by being involved in the research the student will have to present results and write journal articles on the discoveries, thus greatly improving his/her communication skills.

At the end of his/her studies, the student will join the workforce as knowledgeable practitioners.

Technology Transfer

The main objective of this work is to relate material testing, currently done by most highway agencies and structural pavement design. Technology transfer will be an integral component of this project since this work is part of a larger project with partners both from state highway agencies (i.e., UDOT), and contractors (i.e., PEPG Material Testing). There is a UDOT advisory committee in place who would guide the process and ensure the technology will be applicable to the state department of transportation as well as the region. Furthermore, the work will include publication in the leading journals and presentation in conferences such as the Transportation Research Board Meeting that occurs every January. The PI will work with MCP staff to advertise the results so that other interested parties can benefit from the technology being developed.

A report will be provided so that agency leaders, materials engineers, and interested staff can evaluate for themselves the relation between the quality of materials as obtain from existing tests and the structural design of pavements. Using AASHTOWare Pavement ME®, the performance of the pavement can be predicted allowing for optimization purposes.

Work Plan

The specific steps to be followed include:

Task 1. Literature review and analysis of existing dynamic modulus data – the relevant literature will be summarized to ensure the proposed work is technically sound and relevant to the work being done across the world. Existing dynamic modulus data will be analyzed to develop the range of values that represent the material being produced in the field.

Task 2. Testing of selected mixtures – The experimental portion will include obtaining asphalt mixtures being produced in the field and test then using the IDEAL CT test to obtain CT index at different aging levels. The same mixtures will be tested using the AMPT Test to obtain dynamic modulus. The results from these two tests will be related to demonstrate the viability of using a QC/QA test to generate dynamic modulus master curves used as input for the structural design of pavements.

Task 3. Report results – a final report will be generated that meets the MPC requirements for distribution.

Project Cost

Total Project Cost	$90,000
MPC Funds Requested	$40,000
Matching Funds	$50,000
Source of Matching Funds	Utah Department of Transportation, financial support

References

[1] "NCHRP 9-29: Simple Performance Tester for Superpae Mix Design," National Cooperative Highway Research Program, Washington D.C., 2008.

[2] Romero, P. and Roberts, L., "Analysis of the Variability of the Dynamic Modulus of Asphalt Mixtures Obtained using the Asphalt Mixture Performance Tester," Utah Department of Transportation, Central Materials Division, Salt Lake City, 2011.

[3] Bonaquist, R., Christensen, D. W., and Stump, W., "NCHRP Report 513: Simple Performance Tester for Superpave Mix Design: First Article Development and Evaluation," National Cooperative Highway Research Program, Washington D.C., 2003.

[4] Bonaquist, R., "NCHRP Report 614: Refining the Simple Performance Tester for Use in Routine Practice," National Cooperative Highway Research Program, Washington D.C., 2008.

[5] Bonaquist, R., "Wisconsin Mixture Characterization Using the Asphalt Mixture Performance Tester (AMPT) on Historical Aggregate Structures," Wisconsin Highway Research Program, Madison, 2010.

[6] Kandhal, P.S. and Cooley, L.A., "Accelerated Laboratory Rutting Tests: Evaluation of the Asphalt Pavement Analyzer," National Cooperative Highway Research Program, Washington D.C., 2003.

[7] Romero, P., Ho, CH., and VanFrank, K., "Report No. UT-10.08: Development of Methods to Control Cold Temperature and Fatigue Cracking for Asphalt Mixtures," Salt Lake City, 2011.

[8] Romero, P. and Shenoy, A., "Standardized Procedure for Analysis of the Dynamic Modulus (E*) Data to Predict Asphalt Pavement Distress," *Transportation Research Record 1789: Journal of the Transportation Board*, pp. 173-182, 2002.

[9] Bari, J. and Witczak, M.W., "Development of a New Revised Version of the Witczak E* Predictive Model for Hot Mix Asphalt Mixtures," *Journal of the Association of Asphalt Paving Technologists*, vol. 75, 2006.

[10] Bari, J. and Witczak, M.W., "Transportation Research Record 2001: New Predictive Models for Viscosity and Complex Shear Modulus of Asphalt Binder for Use With Mechanistic-Empiracal Pavement Design Guide," Transportation Research Board, Washington D.C., 2007.

[11] Biligiri, K.P., Kaloush, K.E., Mamlouk, M.S., and Witczak, M.W., "Transportation Research Record 2001: Rational Modeling of Teriary Flow for Asphalt Mixtures," Transportation Research Board, Washington D.C., 2007.

[12] Bonaquist, R., "NCHRP Report 629: Ruggedness Testing of the Dynamic Modulus and Flow Number Tests with the Simple Performance Tester," National Cooperative Highway Research Program, Washington D.C., 2008.

[13] Christensen, D. W. and Bonaquist, R., "NCHRP Report 567: Volumetric Requirements for Superpave Mix Design," Transportation Research Board, Washington D.C., 2006.

[14] Christensen, D.W., Pellinen, T., and Bonaquist, R., "Hirsch Model for Estimating the Modulus of Asphalt Concrete," *Journal of the Association of Asphalt Paving Technologists*, vol. 72, 2003.

[15] Christensen, D.W. and Anderson, D.A., "Interpretation of Dynamic Mechanical Test Data for Paving Grade Asphalt Cements," *Journal of the Association of Asphalt Paving Technologists*, vol. 61, 1992.

[16] ARA Inc., ERES Consultants Division, "Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures," Final Report Prepared for the National Cooperative Highway Research Program, 2004.

[17] Ferrin, R., "Asphalt Mixture Performance Tester (AMPT): Compensation Springs," Utah Department of Transportation, Salt Lake City, 2010.

[18] Leiva, F. and West, R.C., "Relationships Between Laboratory Measured Characteristics of HMA Field Compactability," *Journal of the Association of Asphalt Paving Technologists*, vol. 77, 2008.

[19] Christensen, D.W. and Anderson, D.A., "Interpretation of Dynamic Mechanical Test Data for Paving Grade Asphalt Cements," *Journal of the Association of Asphalt Paving Technologists*, vol. 61, 1992.

[20] Witczak, M.W., Bonaquist, R., Von Quintus, H., and Kaloush, K., "Specimen Geometry and Aggregate Size Effects in Uniaxial Compression and Constant Height Shear Tests," *Journal of the Association of Asphalt Paving Technologists*, vol. 69, 2000.

[21] Mirza, M.W. and Witczak, M.W., "Development of a Global Aging System for Short and Long Term Aging of Asphalt Cements," *Journal of the Association of Asphalt Paving Technologists*, vol. 64, 1995.

[22] Witczak, M.W., Kaloush, K., Pellinen, T., El-Bayouny, M., and Von Quintus, H., "NCHRP Report 465: Simple Performance Test for Superpave Mix Design," National Cooperative Highway Research Program, Washington D. C., 2002.

[23] Archilla, A.R., "Developing Master Curve Predictive Equation Models for Local Conditions: A Case Study for Hawaii," University of Hawaii at Monoa, Honolulu, 2010.

[24] Archilla, A.R., de Lannoy Kobayashi, L., and Diaz, L.G., "Using Permanent Deformation Tests and the MEPDG to Quantify Permanent Deformation Improvements from Modified Binders," *Journal of the Association of Asphalt Paving Technologists*, vol. 77, 2008.

[25] Romero, P. and Shenoy, A., "Determining a Specification Parameter for Asphalt Mixtures Using Unified Frequency Sweep at Constant Height Data from the Superpave Shear Tester," *International Journal of Road Materials and Pavement Design*, vol. 1, pp. 75-96, 2000.

[26] Romero, P. and Shenoy, A., "Superpave Shear Tester as a Simple Standardized Measure to Evaluate Aggregate-Asphalt Mixture Performance," *ASTM - Journal of Testing & Evaluation*, vol. 29, no. 5, pp. 50-62, Sept. 2001.