Program Area: Technology Development

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List and descriptions of research products identified for early development and products identified for mid-term and long-term development.

ARC Asphalt Research Consortium

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PROGRAM AREA: TECHNOLOGY DEVELOPMENT

Products Identified for Early Development

Six test methods were identified as early products. The six methods were identified from prior FHWA research by ARC members. Table TD1 lists the six test methods.

Table TD1. Products identified from previous research by ARC members.

	Product	**ARC Research Program**	**Format**	**Estimated Completion Date**	**ARC Partner**
1	Simplified Continuum Damage Fatigue Analysis for the Asphalt Mixture Performance Tester	Prior	Test Method	12/31/2010	AAT
2	Wilhelmy Plate Test	Prior	Test Method	12/31/2010	TTI
3	Universal Sorption Device	Prior	Test Method	12/31/2010	TTI
4	Dynamic Mechanical Analysis	Prior	Test Method	12/31/2010	TTI
5	Automated Flocculation Titrimetric Analysis	Prior	Test Method	12/31/2010	WRI
6	Determination of Polymer in Asphalt	Prior	Test Method	Completed	WRI

Brief descriptions of the six test methods are listed below.

Technology Development Product #1

Simplified Continuum Damage Fatigue Analysis for the Asphalt Mixture Performance Tester (AMPT)

Format

Test Method

ARC Partner

Advanced Asphalt Technologies, LLC

Product Description

A test method for conducting and analyzing cyclic direct-tension fatigue tests in the Asphalt Mixture Performance Tester (AMPT) will be prepared. The test method will be based on continuum damage analysis which is a promising alternative to flexural fatigue testing. In continuum damage fatigue testing, a cylindrical specimen like that used in the AMPT is tested in cyclic direct-tension loading, while the change in stiffness with load cycles is monitored. Through continuum damage theory, a comprehensive fatigue relationship for an asphalt concrete mixture can be developed from a limited number of tests. Completed research has shown that results from continuum damage and flexural fatigue testing are very similar.

Equipment Availability and Cost

The fatigue test method would be an add-on to the currently available AMPT which costs approximately $75,000. Both current AMPT manufacturers have developed prototype hardware and software for cyclic tension fatigue testing. The additional cost for an AMPT with fatigue capability is estimated to be approximately $5,000 to $10,000.

Potential Applications

The target application is as a performance test to compliment mixture design. Once a volumetric design has been completed, its resistance to fatigue damage would be evaluated and compared to that require for the design axle load level.

Targeted Users

Engineers and experienced technicians who design asphalt concrete mixtures.

Time and Skill Requirements

Fatigue testing and analysis will require approximately 4 to 5 working days. This includes time for specimen fabrication, fatigue testing, and analysis of the data. The equipment can be operated by experienced HMA technicians. The analysis is being targeted to engineers with knowledge of pavement design and asphalt mixture characterization.

Recommended Next Steps

1. Evaluation of a wide range of mixtures with varying fatigue characteristics to further validate the procedure.
2. Ruggedness testing to refine the procedure followed by an interlaboratory study to develop precision estimates for the procedure.

Technology Development Product #2

Wilhelmy Plate Method

Format

Test Method

ARC Partner

TTI

Product Description

The Wilhelmy plate device is used to determine the three surface free energy components of the asphalt binder. Surface free energy of the asphalt binder dictates the durability of the adhesive bond between the asphalt binder and different aggregate surfaces in both wet and dry conditions.
The surface free energy components of the asphalt binder can be combined with the surface free energy components of the aggregates (either measured or available from a database of values as a part of the ARC material properties database) to determine the work of interfacial adhesion for different combinations of these materials in dry as well as wet conditions. These properties provide material properties input for micromechanical models and can also be used as a screening tool by which to select the most durable combinations of asphalt binder and aggregate during the mixture design process. In addition, the surface free energy of asphalt binders is an important material property input to model and predict the fatigue crack growth behavior of asphalt materials in wet and dry conditions. Studies related to the measurement of the surface free energy of asphalt binders and its application to characterize fatigue crack growth in asphalt mixtures and the fine aggregate matrix have been well documented in peer reviewed journals in the past few years as well in the final report for NCHRP project 9-37.

The procedure to determine the surface free energy components using the Wilhelmy plate device was developed in a recently completed NCHRP project 9-37 and the technology for its use was extended in Texas Department of Transportation (TxDOT) project 4524 into an automated system by which to evaluate the combination of aggregate and asphalt binder that would optimize resistance to moisture damage. However, this was done only for Texas materials.

Equipment Availability and Cost

The Wilhelmy plate device ($20,000) is available commercially from manufacturers such as Cahn Instruments and KSV Instruments and can be used to carry out the test procedure to determine the surface free energy components.

Potential Applications

Screening tool to identify aggregate-binder combinations that have potential for moisture damage. Material properties required to predict mixture behavior using advanced models.

Targeted Users

DOT, especially centralized labs, and other transportation agencies.

Time and Skill Requirements

One day including binder specimen preparation and testing. A trained laboratory technician can conduct the test.

Recommended Next Steps

As a part of the technology development, there is a need to evaluate the sensitivity and ruggedness of this test method and standardize procedures for its use with polymer modified asphalt binders and mastics.

Technology Development Product #3

Universal Sorption Device

Format

Test Method

ARC Partner

TTI

Product Description

The Universal Sorption Device (USD) is used to determine the three surface free energy components and specific surface area of aggregates. The surface free energy and specific surface area of the aggregate dictates the durability of the adhesive bond between the aggregate surface and different asphalt binders in both wet and dry conditions.

The surface free energy components of the aggregate can be combined with the surface free energy components of the asphalt binder to determine the work of interfacial adhesion for different combinations of these materials in dry as well as wet conditions. This methodology can be used as a screening tool by which to select the most durable combinations of asphalt binders and aggregates during the mixture design process. Studies related to the measurement of the surface free energy of aggregates and their application to the selection of material combinations that are resistant to moisture induced damage are well documented in peer reviewed journal publications.

The USD measures adsorption characteristics of aggregates in a vacuum environment and is available commercially from Rubotherm of Germany. Similar sorption test equipment that allows measurement of surface properties in an inert gas environment is also available from other manufacturers such as TA instruments.

The procedure to determine the surface free energy components and specific surface area using the USD was developed in a recently completed NCHRP project 9-37 and the technology for its use was extended in Texas Department of Transportation (TxDOT) project 4524 into an automated system by which to evaluate the combination of aggregate and asphalt binder that would optimize resistance to moisture damage. However, this was done only for Texas materials. Furthermore, Texas A&M has tested about 25 minerals to assess the mineral components that produce surface energy. This study has been highly enlightening as it identifies the major mineral sources of surface free energy as well as the impact of coating on the mineral surface that can and do impact and often compromise adhesive bond energy. Organic as well as inorganic coatings were studied. One impact of this study will be to provide a method of approximation of the surface energy based a reasonable knowledge of the mineralogical composition of the aggregate being evaluated.

Equipment Availability and Cost

Sorption device ($50,000) available from manufacturers such as Rubotherm from Germany or TA instruments.

Potential Applications

Screening tool to identify aggregate-binder combinations that have potential for moisture damage. Material properties required to predict mixture behavior using advanced models.

Targeted Users
DOT, especially centralized labs, and other transportation agencies.

Time and Skill Requirements
One day including aggregate specimen preparation and testing. A trained laboratory technician can conduct the test.

Recommended Next Steps
As a part of the technology development efforts, there is a need to evaluate the sensitivity and ruggedness of this test method.

Technology Development Product #4

Dynamic Mechanical Analysis

Format

Test Method

ARC Partner

TTI

Product Description

Aggregate particles (smaller than 1.18 mm) together with the asphalt binder constitute the fine aggregate matrix (FAM) in an asphalt mixture. The FAM can also be thought of as a combination of aggregate particles smaller than 1.18 mm and the mastic (binder and filler (particles smaller than 74 µm). The FAM holds the coarse aggregate particles together as a mixture composite. Mechanical properties of the FAM have a significant impact on the performance and durability of the full asphalt mixture. Conventional Superpave guidelines characterize asphalt binders, aggregates, and the complete asphalt mixture. These tests and specifications do not address material properties of the FAM, which represent an important intermediate length scale. The dynamic mechanical analysis (DMA) provides a tool by which to characterize the mechanical properties of the FAM.

The DMA provides rheological properties of the FAM as well as material parameters that characterize the evolution of fatigue damage. Information from the DMA can be used to design more durable asphalt mixtures as well as to provide material property inputs for constitutive models that can be used for structural design of pavements. Results from DMA testing of FAM can define the rate of crack growth damage, the potential of the FAM to heal or recover during rest periods between loads, and the potential for moisture damage within the FAM. The ability of the DMA to evaluate fracture, healing, and durability properties of the FAM is well documented in several referred (peer reviewed) journal publications during the past five years.

The analysis methodology for the DMA has been revised a number of times over the past three years in order to address the three types of damage that can be monitored during the DMA testing process. Based on these a unified methodology has been developed by which to analyze both controlled stress and controlled strain experiments and testing guidelines have been established to assure that the methodology is applicable. The evolution of the DMA testing has also produced a system that reduces the variability of the analysis to levels from which statistical inferences can be made within reasonable tolerances. Based on this approach a protocol in AASHTO format has been developed as has software that captures the testing data, analyzes the data and presents the data in the format of a crack growth index which is based on the three components of dissipated strain energy and other important materials properties of the FAM.

The test equipment is currently available in a number of laboratories in the United States.

The DMA can be carried out using equipment available from manufacturers such as Malvern Instruments, and TA Instruments, USA.

There is a need to standardize the FAM design and fabrication procedures, conduct sensitivity and ruggedness tests on the use of DMA to characterize the FAM.

Equipment Availability and Cost

1. Superpave Gyratory Compactor for preparing test samples ($20k)
2. Dynamic Mechanical Analyzer (about $70K)
3. Coring fixtures to obtain DMA specimens from gyratory specimens ($3k).

Potential Applications
This test can be used to characterize the mechanical properties of the FAM. These properties are entered into models to predict the resistance to moisture damage and fatigue cracking.

Targeted Users
1. Pavement and materials engineers/researchers;
2. State DOT technical personnel; and
3. Practitioners/lab technicians

Time and Skill Requirements
Lab technicians will be able to conduct this test. A software has been developed to help in analyzing the data. The test takes up to 2 hours and the analysis using the software takes less than 10 minutes.

Recommended Next Steps
This test method is available in AASHTO format.

Technology Development Product #5

Automated Flocculation Titrimetric (AFT) Analysis

Format

Test Method

ARC Partner

Western Research Institute

Product Description

A standard method for Automated Flocculation Titrimetry (Automated Heithaus Titrimetry) has been developed and accepted by ASTM International. The standard method is designated D6703-07. This test method describes a procedure for quantifying three Heithaus compatibility parameters that estimate the colloidal stability of asphalts, asphalt cross blends, aged asphalts, and pyrolyzed heavy oil residua. Compatibility of asphalt materials influences important physical properties such as the rheological properties of complex modulus and phase angle.

Equipment Availability and Cost

Equipment is available from Koehler Instruments, Geneq Instruments, Hoskin Scientific, PSL Systemtechnik, and others. Cost is approximately $50,000.

Potential Applications

Material compatibility may have practical importance when two different asphalt sources, even of the same grade, are mixed in a storage tank in a situation such as when a portable asphalt plant is moved from one location to another and different asphalt sources are being used. Another example may be where a contractor purchases asphalt from two different suppliers. Other variations of mixing different asphalt or crude oil sources may also have importance. The instrument and test method can also be used to calculate coking indexes in refinery operations.

Targeted Users

Refiners, State DOT's, Suppliers, Contractors, Test laboratories.

Time and Skill Requirements

The time requirement for one test is approximately 2 hours. Larger groups of samples can improve time effectiveness. A laboratory technician with minimal training can conduct the testing.

Recommended Next Steps

None.

Technology Development Product #6

Determination of Polymer in Asphalt

Format

Test Method

ARC Partner

Western Research Institute

Product Description

This method is used to determine the polymer content of an asphalt sample and is based on Gel-Permeation Chromatography (GPC), also called Size-Exclusion Chromatography. This method is applicable to any asphalt binder or asphalt cement that can be dissolved in toluene. The equipment required for this procedure is available from commercial vendors but requires a general knowledge of column chromatography and chromatography equipment. A standard method for the determination of the polymer content of an asphalt has been prepared in AASHTO format.

The draft AASHTO format method can be delivered upon FHWA request.

Equipment Availability and Cost

Equipment is available from Waters Corporation, and others. Cost is approximately $75,000.

Potential Applications

Verification of type and quantity of polymer modifier added to an asphalt binder.

Targeted Users

Refiners, State DOT's, Suppliers, Contractors, Test laboratories.

Time and Skill Requirements

The time requirement for one test is approximately 1 hour. Larger groups of samples can improve time effectiveness. A laboratory technician with minimal training can conduct the testing.

Recommended Next Steps

This method can be utilized as-is. However, with more work the method can be advanced to determine not only polymer concentration but also polymer identity and molecular weight range. This may be particularly useful if polymer-modified pavements are going to be used as RAP.

Products Identified for Mid-Term and Long-Term Development

Table TD2 lists the research products identified as mid-term products.

Table TD2. ARC Mid-term research products.

	Product	ARC Work Element	Format	Estimated Completion Date	ARC Partner
7	A Method for the Preparation of Specimens of Fine Aggregate Matrix of Asphalt Mixtures	M1c	Test Method	12/31/2010	TTI
8	Measuring intrinsic healing characteristics of asphalt binders	F1d	Test Method	12/31/2010	TTI / UT Austin
9	Lattice Micromechanical Model for Virtual Testing of Asphalt Concrete in Tension	F3b	Analysis Program	12/31/2011	NCSU
10	Cohesive Zone Modeling as an Efficient and Powerful Tool to Predict and Characterize Fracture Damage of Asphalt Mixtures Considering Mixture Microstructure, Material Inelasticity, and Moisture Damage	F3b	Performance Predicting Model	12/31/2010	University of Nebraska
11	Pavement Analysis Using Nonlinear Damage Approach (PANDA)	F3c	Test Method	12/31/2010	TTI
12	Test Methods for Determining the Parameters of Material Models in PANDA (Pavement Analysis Using Nonlinear Damage Approach)	F3c E1a	Test Method	12/31/2010	TTI
13	Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures	E1a	Test Method	12/31/2010	TTI
14	Characterization of Fatigue and Healing Properties of Asphalt Mixtures Using Repeated Direct Tension Test	E1a	Test Method & Data Analysis Program	12/31/2010	TTI
15	Nondestructive Characterization of Tensile Viscoelastic Properties of Undamaged Asphalt Mixtures	E1a	Test Method & Data Analysis Program	Completed	TTI
16	Nondestructive Characterization of Field Cores of Asphalt Pavements	E1a	Test Method & Data Analysis Program	12/31/2010	TTI
17	Self-Consistent Micromechanics Models of Asphalt Mixtures	E1a	Analytical Model & Data Analysis Program	Completed	TTI
18	Nondestructive Characterization of Anisotropic Viscoelastic Properties of Undamaged Asphalt Mixtures under Compressive Loading	E1a	Test Method	Completed	TTI
19	Mix Design for Cold-In-Place Recycling (CIR)	E1c	Practice	12/31/2011	UNR
20	Mix Design for Cold Mix Asphalt	E1c	Practice	3/31/2012	UNR
21	Evaluation of RAP Aggregates	E2b	Practice	12/31/2010	UNR

Table TD2 continued. ARC Mid-term research products.

	Product	ARC Work Element	Format	Estimated Completion Date	ARC Partner
22	Identification of Critical Conditions for HMA mixtures	E2c	Practice	12/31/2011	UNR
24	HMA Thermal Stresses in the Intermountain Region	E2d	Model	3/31/2012	UNR
25	Dynamic Model for Flexible Pavements 3D-Move	VP3a	Software	3/31/2011	UNR
26	Bitumen Bond Strength Test (BBS)	M1a	Test Method	Completed	UWM
27	Elastic Recovery – DSR	F2a	Test Method	12/31/2010	UWM
28	Linear Amplitude Sweep (DSR)	F2e	Test Method	Completed	UWM
29	Binder Yield Energy Test (BYET)	F2e	Test Method	Completed	UWM
30	Rigden Voids for fillers	F2e	Test Method	9/30/2011	UWM
31	Binder Lubricity Test – DSR	E1c	Test Method	12/31/2010	UWM
32	RAP Binder PG True Grade Determination	E2b	Test Method / Software	3/31/2011	UWM
33	Single Edge Notch Bending	E2d	Test Method	5/31/2011	UWM
34	Binder Glass Transition Test	E2d	Test Method	5/31/2011	UWM
35	Asphalt Mixture Glass Transition Test	E2d	Test Method	5/31/2011	UWM
36	Planar imaging/ Aggregate Structure	E1b	Test Method/ Software	3/31/2011	UWM
37	Gyratory Pressure Distribution Analyzer (GPDA)	E1c	Test Method	Completed	UWM
38	Improved Oxygen and Thermal Transport Model of Binder Oxidation in Pavements	F1c	Methodology, Publication		TAMU
39	Field Validation of an Improved Oxygen and Thermal Transport Model of Binder Oxidation in Pavements	F1c	Methodology, Publication		TAMU
40	Validation of an improved Pavement Temperature Transport Model for use in an Oxygen and Thermal Transport Model of Binder Oxidation in Pavements	F1c	Methodology, Publication		TAMU
41	Pavement Air Voids Size Distribution Model for use in an Oxygen and Thermal Transport Model of Binder Oxidation in Pavements	F1c	Methodology, Publication		TAMU
42	Improved Understanding of Fast-Rate, Constant-Rate Binder Oxidation Kinetics Mechanism through the Effects of Inhibitors	F1c	Publication		TAMU
43	Improved Understanding of Fatigue Resistance Decline with Binder Oxidation	F1c	Publication		TAMU
44	Micromechanical Properties of Various Structural Components in Asphalt using Atomic Force Microscopy (AFM)	F2d	Test and Analysis Method	3/2011	TAMU

Brief descriptions of the ARC Mid-term research products are listed below.

Technology Development Product #7

A Method for the Preparation of Specimens of Fine Aggregate Matrix of Asphalt Mixtures

ARC Research Program

M1c

Format

AASHTO Test Method

Estimated Completion Date

December 31, 2010

ARC Partner

Texas A&M

Product Description

A new method will be developed for preparing Fine Aggregate Matrix (FAM) specimens for the DMA testing. This method aims at preparing FAM specimens that represent the composition and structure of the fine portion of the mixture. The method involves preparing loose full asphalt mixtures and sieving them into different sizes. Then, ignition oven is used to determine the binder content associated with the small size materials (passing sieve #16). The sieve # 16 is used to separate fine aggregates from the coarse aggregates. The binder content and original mixture gradation for sizes passing sieve #16 are used to prepare gyratory specimens. The DMA samples are cored out of the gyratory specimens. The test method will also include a procedure for moisture conditioning of DMA specimens.

Equipment Availability and Cost

Superpave gyratory compactor, equipment used for mixing and compaction of asphalt mixtures, and an ignition oven ($70k).

Potential Applications

This test method will be used to prepare FAM specimens for testing in the DMA. The testing results are used to predict the resistance to fatigue and moisture damage.

Targeted Users

1. Pavement and materials engineers/researchers;
2. State DOT technical personnel; and
3. Practitioners/lab technicians

Time and Skill Requirements

Lab technicians will be able to prepare specimens and test them in the DMA. The specimen preparation takes about 5 to 6 hours.

Recommended Next Steps

Develop an AASHTO procedure for DMA specimen preparation.

Technology Development Product #8

Intrinsic healing rate of asphalt binders measured using the Dynamic Shear Rheometer (DSR)

ARC Research Program

F1d

Format

Test Method

Estimated Completion Date

12/31/2012

ARC Partner

Texas A&M

Product Description

A test method to measure the rate of intrinsic healing in asphalt binders at different temperatures will be prepared. Self-healing in asphalt binders can be regarded as the reversal of micro-damage. The fracture or crack growth process in an asphalt binder entails development of a failure process zone ahead of the crack tip followed by crack opening. The process of self-healing can be regarded as a reversal in two stages, i.e. crack wetting and a regain of strength over time (intrinsic healing). Intrinsic healing is a temperature dependent material property that is impacted by the chemical make-up of the asphalt binder. The proposed test method is to measure the intrinsic healing rate of an asphalt binder using the DSR. The procedure requires measuring the G* of an asphalt binder in the form of two separate disks that are brought into contact under a very small normal load of about 0.4 Newtons. The values of G* are measured after continually increasing rest periods. The results are compared to the G* of a single specimen of the same binder and with a geometry that is similar to the composite, two-piece specimen. The ratio of the shear modulus of the two-piece specimen to that of the one-piece specimen at a specific time interval is compared to quantify intrinsic healing characteristics of the asphalt binder. The test can be conducted at multiple temperatures. The test can be carried out using most automated DSRs.

Intrinsic healing tests have been performed on approximately six binders selected for their different compositions, and the intrinsic healing properties of these binders has been seen to vary according to the predictions of a material characterization model developed under the ARC program that explains the process of healing as the convolution of a wetting process and a longer term healing process. The cohesive bond energy (computed from surface energy measurements) of the binders has been found to be strongly related to intrinsic healing as predicted by the material characterization model. Molecular morphology has also been found to be strongly related to long term healing as predicted by the material characterization model.

It is envisioned that the intrinsic healing properties of the asphalt binder can be used as an additional dimension to select asphalt binders in a manner very similar to the current specifications for rutting and fatigue cracking. Once developed, this test procedure can be used for applications other than measurement of intrinsic healing. For example, one can use a composite of aged and virgin binder to determine the blending of virgin binder with recycled binder in RAP mixtures that produces superior healing properties. In this sense, healing should be viewed as an integral part of the overall fatigue fracture process of damage and healing.

Equipment Availability and Cost
Dynamic Shear Rheometer ($50,000 – DSR is already in use for other binder tests)

Potential Applications
Screening for intrinsic healing potential of asphalt binders

Targeted Users
DOT and other transportation agencies

Time and Skill Requirements
One day including binder specimen preparation and testing.

Skill level required is similar to that for binder DSR testing.

Recommended Next Steps

Technology Development Product #9

Lattice Micromechanical Model for Virtual Testing of Asphalt Concrete in Tension

ARC Research Program

ARC F3b

Format

Analysis Program

Estimated Completion Date

2/28/2012

ARC Partner

North Carolina State University

Product Description

A multiscale virtual-testing methodology will be developed with the ultimate goal of linking the binder and aggregate properties to the cracking performance of asphalt concrete. The main ingredients of the proposed methodology are (a) a virtual fabrication technique that generates the microstructure of asphalt concrete specimens without the need for physical fabrication, (b) a lattice modeling approach that simulates the micromechanical behavior of cracked asphalt concrete specimens, and (c) a multiscale methodology that incorporates the effects of aggregates of widely varying sizes. A failure criterion based on continuum damage theory will be implemented to simulate gradual degradation of lattice links. A stand-alone virtual microstructure fabrication approach will automatically attain the two-dimensional (2D) internal structure of HMA from the job mix formula. To improve computational efficiency, these two approaches will be integrated through the multiscale modeling method to perform a seamless microstructural analysis of actual HMA specimens with the ultimate aim of performance evaluation and mix design optimization.

The target audience includes practitioners and researchers who want to supplement the PG binder specification and Superpave volumetric mix design with virtual cracking performance testing. The main benefit of this model is the ability to determine the cracking resistance of a mixture without having to perform laboratory tests. As a result, multiple combinations of aggregate gradation and asphalt content can be virtually tested using the model, and the results may be used to aid the Superpave volumetric mix design by optimizing the aggregate gradation and asphalt content. It is expected that the virtual test results would be accurate enough to determine the mixture’s pass/fail acceptance in terms of cracking performance.

Time and Skill Requirements

1. Understanding of the effects of mixture parameters on cracking resistance of asphalt mixture
2. Computer skills capable of the operation of common MS Windows-based software
3. 2-5 hours of run time depending on the computer speed

Recommended Next Steps

1. Verification and calibration of the lattice model using a wide range of mixtures under varying conditions
2. Development of AASHTO specification based on the lattice model and ruggedness testing of the program

Technology Development Product #10

Cohesive Zone Modeling for Fracture Damage of Asphalt Mixtures

Format

Performance Predicting Model and Test Method

ARC Partner

University of Nebraska (sub-contractor to Texas A&M University)

Product Description

A model for predicting and characterizing fracture damage of asphalt mixtures will be prepared. The technique will be based on cohesive zone approach to model initiation and propagation of physical cracks. The cohesive zone approach can effectively and accurately address inelastic fracture damage and failure of heterogeneous asphaltic composites. In addition, the cohesive zone model can be incorporated with the influence of moisture diffusion to properly model moisture induced fracture in asphalt mixtures.

We will deliver the cohesive zone model in the form of a UEL (User ELement) code subroutine within a commercial finite element software, *ABAQUS* and laboratory test methods developed to identify cohesive zone model inputs such as fracture properties. In addition, a set of documents including theory manuals which describe constitutive equations of the cohesive zone model and testing protocols to estimate or measure the cohesive zone model parameters.

Potential Applications

The cohesive zone model herein predicts crack evolution based on physically measured fracture properties in realistic length scales. Therefore, it is a clearly attractive stand-alone alternative to other ARC modeling efforts that are based on continuum damage approaches which typically characterize damage using phenomenological internal state variables. In addition, the cohesive zone model can complement other ARC modeling efforts. The UEL computational code subroutine can be easily integrated with other computational modeling approaches such as the PANDA (Pavement Analysis Using Nonlinear Damage Approach) by providing a powerful fracture engine, so that nonlinear-viscoelastic-viscoplastic responses with microfracture to complete failure of asphaltic mixtures can be modeled.

Targeted Users

Since the technology developed herein is based on mixture-level characteristics by accurately accounting for the mixture microstructure and fundamental properties of individual mixture components and their interactions, this technology can benefit pavement- and materials engineers to select mixture components in a more engineered manner and to potentially improve current volumetric mix-design concepts. Consequently, target audience of this work would be materials engineers, pavement design practitioners as well as researchers who are interested in constitutive damage modeling and fracture mechanisms of pavement materials.

Time and Skill Requirements

Users need to be able to input model parameters and run the finite element software, ABAQUS. Time to run cases will be dependent on degrees of freedom. It may take a few minutes for small problems, while several hours would be necessary to conduct simulations of mixtures considering highly complicated microstructure.

Recommended Next Steps

Technology Development Product #11

Pavement Analysis Using Nonlinear Damage Approach (PANDA)

ARC Research Program

F3c

Format

Subroutines in the Abaqus finite element program

Estimated Completion Date

12/31/2012

ARC Partner

TTI

Product Description

The ARC will deliver a mechanistic model in the form of a User MATerial Computational Code (UMAT) subroutine within the finite element software, Abaqus. This model will incorporate several material constitutive relationships to define the behavior (viscoelastic, viscoplastic, mechanical damage, moisture damage, fatigue damage, fracture, aging, and healing) of the asphalt composite. These constitutive relationships will contribute to the overall ability of the mechanistic model to make reliable predictions of the appearance of important forms of damage to asphalt pavements. The final deliverables of the continuum damage modeling effort will be as follows:

(1) The first part is a computational material code written in Fortran programming language that is easily linked to the well-known finite element and commercially available software Abaqus. This subroutine – called **UMAT** (i.e. User MATerial computational code) in Abaqus – will include the finite element implementation of state-of-the-art constitutive equations of the ARC continuum damage material model. The developed computational code UMAT will be used to predict the constitutive behavior (viscoelastic response, permanent deformation, fatigue damage, moisture damage) of the asphalt mixture in an asphalt pavement structure. This computational code can be used to simulate the asphalt mixture behavior under various mechanical and environmental loading conditions.

(2) The second part is a set of geometrical finite element models for different pavement structures that will be prepared within Abaqus software and will be provided along with the computational code UMAT. This set of finite element structural models will include precise and robust finite element meshes, boundary conditions, loading conditions, and two-dimensional versus three-dimensional models. These structural models will be provided as CAE (Computer Aided Engineering) visual files within the Abaqus environment such that the user can choose to directly use these files to run performance simulations of a specific pavement structure without the need to create the model. However, the user will also have the flexibility to modify the provided structural models or even create completely new ones.

(3) The third part is a set of documents that include:

- guidelines to estimate or measure the material constants associated with the constitutive equations in UMAT.

- a theory manual which documents the constitutive equations of the continuum damage model included in the developed computational algorithms used to implement these equations in UMAT.
- description of different pavement structures (boundary conditions, method of applying repeated loading).

Equipment Availability and Cost

Subroutines will be developed as part of the Abaqus finite element package. The cost is that for the license of Abaqus.

Potential Applications

This model can be used to predict the performance of asphalt pavements.

Targeted Users

- Pavement and materials engineers/researchers;
- Consultant engineers;
- State DOT engineers

Time and Skill Requirements

Engineers will be able to input the model parameters, run the software, and make conclusion on performance. Workshops will be organized for training potential users.

Recommended Next Steps

It is recommended to extend this task to develop a stand-alone software for PANDA to it can be used without the Abaqus software.

Technology Development Product #12

Test Methods for Determining the Parameters of Material Models in PANDA (Pavement Analysis Using Nonlinear Damage Approach)

ARC Research Program

F3c and E1a

Format

AASHTO Test Procedure

Estimated Completion Date

12/31/2011

ARC Partner

TTI

Product Description

An experimental program will be developed for determining the parameters of the PANDA material model. It is envisioned that this experimental program will be in the form of creep recovery test at multiple stresses and temperatures. The tests will be conducted in uniaxial tension and triaxial compression at multiple confining stresses. The tests will allow determining the viscoelastic, viscoplastic and damage parameters of the model. It will rely on the analytical technique that was developed during the second year of the ARC project for separating viscoelastic deformation from viscoplastic deformation.

Equipment Availability and Cost

Universal testing machine with a Triaxial cell equipped to measure radial and axial strains, apply different confining stresses and operate under temperatures from 10C to 55C. (Estimate cost is about $100k).

Potential Applications

This set of testing is required for determining the parameters of the PANDA material model. The model is then used to predict the structural performance of asphalt pavements.

Targeted Users

1. Pavement and materials engineers/researchers;
2. State DOT technical personnel; and
3. Practitioners/lab technicians

Time and Skill Requirements

1. Pavement engineers and lab technicians can conduct the mechanical testing. The testing may take three to four weeks.
2. Engineers/researchers will be able to analyze the data to interpret the parameters of the PANDA material model. The analysis will take two working days.

Recommended Next Steps

Automate the method to analyze the data and write the procedure in AASHTO format.

Technology Development Product #13

Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures

ARC Research Program

E1a

Format

Test Method

Estimated Completion Date

9/30/2011

ARC Partner

Texas A&M University

Product Description

A test method has been developed to conduct and analyze the permanent deformation in asphalt mixtures. This test method is based on the viscoplastic analysis of the permanent deformation properties of asphalt mixtures. A general yield surface has been developed to fulfill the whole range of material friction angles and the non-associated flow rule will apply. A microstructural parameter and a continuum damage based parameter are introduced to modify the nominal stresses in the viscoplastic models so as to consider the inherent anisotropy and load-induced anisotropy, respectively. In the permanent deformation testing, a cylindrical specimen is tested in cyclic compressive loading with varying rest period sequences, while the changing viscoplastic strain and modulus degradation along different directions with load cycles is recorded. Through the anisotropic viscoplastic damage theory, a comprehensive permanent deformation accumulation relationship is developed for an asphalt mixture. A limited number of tests will be sufficient to investigate the effect of inherent anisotropy, load-induced anisotropy and rest period healing on the permanent deformation of asphalt mixtures. With implementation of the fracture mechanics theory on the test results in the tertiary phase, the crack initiation, propagation and size distribution along different directions can be calculated during the tertiary viscoplastic deformation of asphalt mixture. Therefore, the proposed test method will be able to analyze the permanent deformation and fatigue cracking properties of asphalt mixtures under compressive loading simultaneously. The material properties that are generated with this test sequence are fully compatible with the PANDA 3-dimensional performance prediction model. The properties include the material friction angles and effective cohesive shear strength in accordance with the well-known and widely used Mohr-Coulomb formulations, anisotropic yield and plastic potential functions, anisotropic Paris' Law parameters, and anisotropic healing properties.

Equipment Availability and Cost

1. MTS machine or equivalent with temperature chamber, LVDTs and load cell; and
2. Sample rotation equipment ($50) and scanner ($100) for determining inherent anisotropy.

Potential Applications

The data produced in this destructive compressive test can be used to accurately predict or simulate the rutting behavior of asphalt mixtures. If carried to the tertiary phase, it will be able to determine the extra load induced anisotropy. Data can also be used as input to PANDA for performance predictions.

Targeted Users

Materials engineers; Consulting engineers; Pavement design engineers; Contractor's engineers; Material suppliers technical personnel; Forensic engineers; and Lab technicians.

Time and Skill Requirements

1. Lab technicians who can run compressive tests on MTS equipment will be able to run this test which can be done on a single sample in one day.
2. Engineers need to be able to use Excel macros to analyze the data and determine the viscoplasticity characteristics of an asphalt mixture. The analysis time is between 1 hour and 2 hours.

Recommended Next Steps

1. Workshops for lab technicians to instruct and give them experience in operating both MTS equipment and capturing the required data; and
2. Worships for engineers to explain the theory underlying the data processing software and to give them hands-on experience in analyzing actual data.

Technology Development Product #14

Characterization of Fatigue and Healing Properties of Asphalt Mixtures Using Repeated Direct Tension Test

ARC Research Program

E1a

Format

Test Method and Data Analysis Program

Estimated Completion Date

9/30/2011

ARC Partner

Texas A&M University

Product Description

A test method has been developed to characterize the fatigue and healing properties of asphalt mixtures under repeated direct tensile loading. The test method and data analysis program have been documented in the Quarterly Reports of the Asphalt Research Consortium (ARC) Program that is sponsored by the Federal Highway Administration (FHWA). In the fatigue test protocol, a destructive haversine tensile load is applied to the asphalt mixture specimen repeatedly at a certain frequency for 1,000 loading cycles. The vertical deformation of the specimen is recorded using three linear variable differential transformers (LVDTs). The applied stress and measured strain are used to determine the dissipated pseudo strain energy (DPSE) and the recoverable pseudo strain energy (RPSE) in the specimen. The DPSE is then separated into two components: 1) DPSE for fracture, and 2) DPSE for permanent deformation. The DPSE for fracture is used to obtain the rate of fatigue crack growth, and the RPSE is employed to determine the starting point of the crack growth that is indicated by the mean air void radius (initial crack radius). An energy balance equation is established to determine the amount of energy dissipated to drive the fatigue crack growth and to predict the mean crack radius and the number of cracks with the increase of load applications. At the end of the fatigue test, a series of 1,000-cycles with reduced rest periods between two adjacent 1,000-cycles are applied to the same specimen to study the healing properties of the asphalt mixture. The preliminary results of the healing test protocol have demonstrated that the binder type has a significant effect on the healing properties of asphalt mixtures. The data analysis program of healing test is expected to be completed by the end of 2010.

Equipment Availability and Cost

1. MTS machine or equivalent with temperature chamber, LVDTs and load cell programmable loading; and
2. Same sample as used in nondestructive characterization, no sample-to-sample variance.

Potential Applications

Determine fatigue and healing properties of asphalt mixtures as well as the effects of aging and moisture on these properties.

Targeted Users

Material engineers; Consulting engineers; Forensic engineers; Materials lab technicians; Pavement design engineers; Material suppliers; and Contractor's engineers.

Time and Skill Requirements

The complete nondestructive characterization and tensile fracture and healing test can be run on a single sample in one day.

Technician skill is the same as required to run the nondestructive tensile properties test.

Engineers will need to be able to use Excel macros (already written) to generate the fatigue and healing properties from the measured data.

Recommended Next Steps

1. Workshops for lab technicians to give hands-on experience in running destructive tensile tests and recording the data necessary to generate fatigue and healing properties; and
2. Workshops for engineers to explain the theory of crack propagation, its measurement and data collection process, and hands-on experience with analyzing real data.

Technology Development Product #15

Nondestructive Characterization of Tensile Viscoelastic Properties of Undamaged Asphalt Mixtures

ARC Research Program

E1a

Format

Test Method and Data Analysis Program

Estimated Completion Date

Completed

ARC Partner

Texas A&M University

Product Description

A test method and a data analysis program have been developed to nondestructively characterize the viscoelastic properties of undamaged asphalt mixtures under tensile loading. The test method and data analysis program have been developed within the Asphalt Research Consortium (ARC) Program sponsored by the Federal Highway Administration (FHWA); they have been detailed in the Quarterly Reports of the ARC Program. In the test protocol, a constant tensile load or a monotonically increasing tensile load is applied to an asphalt mixture specimen for a short period of time that is less than one minute. The vertical deformation and horizontal deformation are recorded by linear variable differential transformers (LVDTs). The test is repeated at three temperatures: 10, 20 and 30°C. The applied load and measured deformations at each temperature are used to calculate the stress and strains that are transformed from the time domain into the frequency domain using the Laplace transform. The transformed stress and strain functions are then utilized to determine: 1) the master curve of the magnitude of the complex modulus; 2) the master curve of the phase angle of the complex modulus; 3) the master curve of the magnitude of the complex Poisson's ratio; and 4) the master curve of the phase angle of the complex Poisson's ratio. Since the test duration is less than one minute and it takes approximately two hours to change the specimen temperature, this test method provides an efficient approach to nondestructively characterize the viscoelastic tensile properties of asphalt mixtures in a single day. This test method does not introduce any damage to the specimen so the same specimen can be tested subsequently for its fatigue, healing and other properties.

Equipment Availability and Cost

1. MTS machine or equivalent with temperature chamber, LVDTs and load cell;
2. Sample saw for parallel ends;
3. Coring machine for a sample with uniform composition;
4. Gluing jig; and
5. Universal fixture for the base of the testing sample.

Potential Applications

Tensile characterization of the properties of an undamaged asphalt mixture must precede the determination of the fatigue and healing properties of the same mixture. It will also determine the effect that aging and moisture have on these undamaged properties.

Targeted Users

Material engineers and lab technicians.

Time and Skill Requirements

1. Materials engineers: fitting the lab data with the master curve functions for modulus, Poisson's ratios and their phase angles; and
2. Lab technicians: data for a complete tensile master curve for a mixture can be determine in one day.

Recommended Next Steps

Laboratory workshops for engineers followed by instruction and practical exercises on how to fit master curve functions to lab data and how to trouble-shoot faulty measurements.

Technology Development Product #16

Nondestructive Characterization of Field Cores of Asphalt Pavements

ARC Research Program

E1a

Format

Test Method and Data Analysis Program

Estimated Completion Date

9/30/2011

ARC Partner

Texas A&M University

Product Description

A test method has been developed to nondestructively characterize the properties of field cores taken from the asphalt layer of an asphalt pavement. The test method has been documented in the Quarterly Reports of the Asphalt Research Consortium (ARC) Program that is sponsored by the Federal Highway Administration (FHWA). In the test protocol, each field core is trimmed into construction lifts, and each construction lift is cut to a prismatic sample. A monotonically increasing tensile load is applied to the prismatic sample whose vertical deformation is recorded by linear variable differential transformers (LVDTs). The loading rate and loading time are carefully controlled in order to limit the vertical strain within a certain level so that the specimen is not further damaged by the laboratory testing. The same test is repeated at three temperatures, 10°C, 20°C and 30°C, in order to construct the master curve of the magnitude and phase angle of the complex modulus using the time-temperature superposition principle. The tested field cores have shown stiffness gradient with the pavement depth because the asphalt layer is not aged uniformly in the field. An analytical method has been developed to characterize the stiffness gradient with pavement depth of the field specimen. When this test method and analysis is perfected, it will provide an independent means of determining the effect of field aging on as-built asphalt mixtures.

Equipment Availability and Cost

1. MTS machine or equivalent with temperature chamber, LVDTs, load cell and end caps;
2. Parallel saw to prepare prismatic samples from field cores; and
3. Gluing jig.

Potential Applications

Determine the properties of mixtures that have been exposed in service and measure the effects of aging on mixture properties.

Targeted Users

Material engineers; Consultants; Forensic engineers; and Lab technicians.

Time and Skill Requirements

1. Lab technicians: complete characterization testing can be completed in one day for each core; and
2. Engineers: ability to use analytical program to extract the modulus gradient information from the test data.

Recommended Next Steps

1. Workshops for lab technicians to instruct them in all of the steps of sample coring, sawing, gluing, mounting and testing; and
2. Workshops for engineers to explain the effects of field expose on field samples and hands-on exercises on analyzing test data and to determine the effects of in service exposure.

Technology Development Product #17

Self-Consistent Micromechanics Models of Asphalt Mixtures

ARC Research Program

E1a

Format

Analytical Model and Data Analysis Program

Estimated Completion Date

6/30/2011

ARC Partner

Texas A&M University

Product Description

Inverse and forward self-consistent micromechanics models have been developed using micromechanics theory for composite materials to predict the properties of an asphalt mixture and its components. Both micromechanics models are developed within the Asphalt Research Consortium (ARC) Program that is sponsored by the Federal Highway Administration (FHWA). The inverse micromechanics model takes as input the volumetric composition of the mixture and the measured frequency-dependent bulk and shear properties of a mixture and a binder and extracts from them the bulk and shear properties of the aggregate. The forward micromechanics model takes as input the frequency-dependent bulk and shear properties of the aggregate and binder and produces the frequency-dependent properties of the mixture. These models are programmed in MATLAB using the System Identification Method and are applied to the analysis of the frequency-dependent magnitudes of the viscoelastic properties of an asphalt mixture at different aging periods. It has been proved that the inverse model and the forward model are in fact the inverse of each other and that the inferred aggregate properties are realistic. These models proved a technique to catalog the properties of aggregates and use them in a computerized determination of the combinations of binders, aggregates and air to produce desired properties of asphalt mixtures.

Equipment Availability and Cost

Measurement of the properties of aggregates, binders and mixtures separately and arranged in computerized catalog databases proceeds the use of the self-consistent micromechanics model.

Electronic access to the materials catalog data base and a computer to exercise the micromechanics model.

Cost of personal computer.

Potential Applications

1. Optimum design of asphalt concrete mixtures to have desired mechanical properties;
2. Forensic investigations of premature pavement failures; and
3. Material selection from among available candidate binders and aggregates to delay effects of aging and moisture damage.

Targeted Users
Mix design engineers; Consultants, forensic engineers; and Materials engineers, contractor's engineers for warranty jobs.

Time and Skill Requirements
1. Computer operation skills and understanding of the process of mixture design;
2. Computer operations to determine the properties of mixture components from the measured properties of mixtures sampled from distressed pavements; and
3. Computer operations to run the model with a variety of candidate materials to determine the appropriate combination(s).

Recommended Next Steps
1. Workshops for potential users to acquaint them with the use of this tool for all these purposes. Workshops should have small attendance and much personal attention from instructors; and
2. Generation of materials data bases that can be used by the workshop participants.

Technology Development Product #18

Nondestructive Characterization of Anisotropic Viscoelastic Properties of Undamaged Asphalt Mixtures under Compressive Loading

ARC Research Program

E1a

Format

Test Method

Estimated Completion Date

Completed

ARC Partner

Texas A&M University

Product Description

A test method has been developed within the Asphalt Research Consortium (ARC) Program to nondestructively characterize the anisotropic viscoelastic properties of undamaged asphalt mixtures under compressive loading. This test method includes three nondestructive test scenarios: 1) uniaxial compressive creep test, 2) uniaxial tensile creep test, and 3) indirect tensile creep test. The elastic-viscoelastic correspondence principle is used to determine the frequency-dependent magnitude and phase angle of six complex material properties, including: 1) compressive complex modulus in the vertical direction (compaction direction), 2) compressive complex Poisson's ratio in the vertical direction, 3) compressive complex modulus in the horizontal plane that is perpendicular to the compaction direction, 4) compressive complex Poisson's ratio in the horizontal plane, 5) tensile complex modulus, and 6) tensile complex Poisson's ratio. Each of these three test scenarios takes approximately one minute and is repeated at three temperatures (10°C, 20°C and 30°C) in order to construct master curves of the magnitude and phase angle of each complex property. This test method offers an efficient approach to nondestructively characterize the undamaged anisotropic viscoelastic properties of asphalt mixtures under compressive loading. The test results have demonstrated the significant difference between properties in the vertical direction and the properties in the horizontal plane. The measured anisotropic properties of the asphalt mixture will be taken as input into a finite element program to predict the pavement performance. Since this test does not introduce any damage to the specimens, the same specimens will be tested destructively for its viscoplasticity, fatigue, healing and other properties.

Equipment Availability and Cost

1. MTS and UTM machines or equivalent and temperature chamber, LVDTs and load cells;
2. Indirect tension loading fixture for 6-in long sample; and
3. Gluing jib for tensile creep test.

Potential Applications

The undamaged compressive properties must be known in order to determine the damaged properties of viscoplasticity and tertiary fracture. This has direct application to the prediction of rutting and tertiary fracture.

Targeted Users

Materials engineers; Pavement design engineers; Consulting engineers; Forensic engineers; Lab technicians; Material suppliers technical personnel; and Contractor's engineers.

Time and Skill Requirements

Lab technicians who can operate both MTS and UTM equipment have all of the required skill. The complete set of tests can be run on a simple sample in one day.

Engineers need to be able to use Excel macros (already written) to analyze the data and generate the directional mixture properties. Analysis time is between 30 minutes and 2 hours.

Recommended Next Steps

1. Workshops for lab technicians to instruct and give them experience in operating both MTS and UTM equipment and capturing the required data; and
2. Worships for engineers to explain the theory underlying the data processing software and to give them hands-on experience in analyzing actual data.

Technology Development Product #19

Mix Design for Cold-In-Place Recycling (CIR)

ARC Research Program

ARC-E1c

Format

Practice

Estimated Completion Date

12-31-2011

ARC Partner

University of Nevada, Reno

Product Description

The use of cold in place recycling (CIR) of asphalt has been gaining popularity due to its low cost and effectiveness in retarding reflective cracking. The CIR process consists of pulverizing the top 2 – 3 inches of the old HMA layer, stabilizing it with asphalt emulsion and laying it down in place. The CIR layer is then overlaid with a surface treatment when used on low volume roads or with an HMA overlay when used on heavy volume roads. The in-place re-use of the old HMA layer offers economic advantage over the option of reconstruction the entire pavement. In addition, the low binder content of the CIR layer results in a highly flexible layer that offers improved resistance to reflective cracking.

However, there is not a standard mix design method that is consistent for the design CIR mixtures. This practice will offer a mix design method for CIR that is consistent with the Superpave technology and that can be used to define the optimum combination of moisture content, emulsion content, and any additive that maybe required. The mix design process will use the standard equipment used in the Superpave volumetric mix design.

Equipment Availability and Cost

Commercial grade equipment is available at the cost of $30,000 - $40,000

Potential Applications

Mix Design Process

Targeted Users

State Highway Agencies, Research Laboratories, Commercial Laboratories, and Materials Suppliers and Producers

Time and Skill Requirements

Design can be conducted within 3-5 days and will require technician level skills to conduct.

Recommended Next Steps

Submit to AASHTO

Technology Development Product #20

Mix Design for Cold Mix Asphalt

ARC Research Program

E1c

Format

Practice

Estimated Completion Date

3-31-2012

ARC Partner

University of Nevada, Reno

Product Description

The use of cold mix asphalt offers few advantages in terms of cost, long construction season, and ease of construction. Cold mix asphalt consists of producing a mixture of asphalt emulsion and mineral aggregate that can be used as a surface course on a flexible pavement. The production of cold mix asphalt uses significantly less energy than the production of hot mix asphalt, and therefore, it is significantly less expensive. The construction of cold asphalt mix asphalt can be achieved year round regardless of the ambient temperatures. In addition, cold mix asphalt is produced and constructed at significantly lower emissions than hot mix asphalt, thereby making it very attractive with respect to workers safety and environmental pollution.

However, there is not a standard mix design method for the design of cold mix asphalt. This practice will offer a mix design method for cold mix asphalt that is consistent with the Superpave technology and that can be used to define the optimum combination of moisture content, emulsion content, and any additive that maybe required. The mix design process will use the standard equipment used in the Superpave volumetric mix design.

Equipment Availability and Cost

Commercial grade equipment is available at the cost of $30,000 - $40,000

Potential Applications

Mix Design Process

Targeted Users

State Highway Agencies, Research Laboratories, Commercial Laboratories, and Materials Suppliers and Producers

Time and Skill Requirements

Design can be conducted within 3-5 days and will require technician level skills to conduct.

Recommended Next Steps

Submit to AASHTO

Technology Development Product #21

Evaluation of RAP Aggregates

ARC Research Program

E2b

Format

Practice

Estimated Completion Date

4-30-2011

ARC Partner

University of Nevada, Reno

Product Description

As reclaimed asphalt pavement (RAP) usage becomes more common throughout the industry, the differences in handling RAP materials as compared to virgin aggregates are becoming more significant. These differences include RAP aggregate properties, such as specific gravity, absorption, and aggregate gradation, along with other aggregate properties of the virgin and RAP blends. In recent years, there have been many recommendations regarding the measurement and usage of these RAP properties. However, there has not been a consistent recommendation for assessing the RAP aggregate properties. Both the solvent extraction and the ignition oven methods can be used to recover RAP aggregates for specific gravity testing and for determining other properties of the aggregate blend. The solvent extraction method may leave a residue of asphalt on the aggregate while the ignition oven method may cause aggregate degradation. This practice will recommend the most effective methods for extracting RAP aggregates based on their impact on the various properties of the RAP aggregates and the volumetric calculations for the Superpave mix design. The practice utilizes the equipment being currently used in the Superpave volumetric mix design method.

Equipment Availability and Cost

Commercial grade equipment is available at the cost of $30,000 - $40,000

Potential Applications

Mix Design Process

Targeted Users

State Highway Agencies, Research Laboratories, Commercial Laboratories, and Materials Suppliers and Producers

Time and Skill Requirements

Tests can be conducted within 3-5 days and will require technician level skills to conduct.

Recommended Next Steps

Submit to AASHTO or ASTM

Technology Development Product #22

Identification of Critical Conditions for HMA mixtures

ARC Research Program

E2c

Format

Practice

Estimated Completion Date

12-31-2011

ARC Partner

University of Nevada, Reno

Product Description

Field performance data from the WesTrack project and other pavements indicate that every HMA mix has a critical temperature and a critical loading rate beyond which the mixture will become highly unstable that must be identified during the design process. Once these two critical conditions are identified, they must be checked against the expected field conditions where the HMA mix will be placed. Furthermore, it is believed that the critical conditions of an HMA mix can be significantly influenced through changes in binder content, binder properties, and aggregates gradation. This process will allow the mix design engineer to design excellent performing HMA mixtures for mainline traffic and traffic on off-ramps and at intersections with changes that can be accommodated in the production process without major interruptions, such as slightly modify the binder properties or slightly reduce the binder content as the construction approaches the intersection. The final product will be in the form of a recommended practice to identify the critical condition of an HMA mix at the mix design stage to avoid accelerated rutting failures of HMA pavements. An interim report (Characteristics of Dynamic Triaxial Testing of Asphalt Mixtures) has been completed which summarizes the state of stresses under the various loading conditions that were calculated using the pavement analysis software 3D-Move.

Equipment Availability and Cost

Commercial grade equipment is available at the cost of $70,000- $80,000.

Potential Applications

Mix Design Process and Mix Performance Evaluation.

Targeted Users

State Highway Agencies and Research Laboratories.

Time and Skill Requirements

Test can be conducted within 48 hours and will require technician level skills to operate.

Recommended Next Steps

Conduct Round Robin Testing

Technology Development Product #23

Modified Thermal Stress Restrained Specimen Test

ARC Research Program

E2d

Format

Test Method

Estimated Completion Date

9-30-2011

ARC Partner

University of Nevada, Reno

Product Description

The thermal stress restrained specimen test (TSRST) is currently being modified to account/incorporate for the following factors:

- A cylindrical test sample obtained from a Superpave Gyratory compacted specimen
- Accommodate variable cooling and warning rates to better simulate field conditions
- Improve repeatability of the measured fracture temperature and fracture stress
- Provide input that can be directly incorporated into the thermal stresses model

The UNR researchers are currently conducting laboratory experiments to assess the impact of sample size and variable cooling and warning rates on the response of the TSRST. The applicability of the modifications has been evaluated against the original TSRST with a beam sample and a constant cooling rate. In addition, the measurements from the modified TSRST have been compared with the low temperature properties of the binders used in the evaluated mixtures. The final version of the TSRST test will be practical to use with the current Superpave mix design method and will produce mix properties that are directly incorporated into the Thermal Stress Model currently being developed.

Equipment Availability and Cost

Commercial grade equipment is available at the cost of $60,000- $70,000.

Potential Applications

Mix performance evaluation and generate input to analysis/performance models

Targeted Users

State Highway Agencies, Research Laboratories, and Commercial Laboratories

Time and Skill Requirements

Test can be conducted within 48 hours and will require technician level skills to operate.

Recommended Next Steps

Conduct Round Robin Testing

Technology Development Product #24

HMA Thermal Stresses

ARC Research Program

E2d

Format

Model

Estimated Completion Date

3-31-2012

ARC Partner

University of Nevada, Reno

Product Description

Thermal cracking of HMA mixtures is caused by the non-polar oily or neutral fractions of the binder becoming a rigid solid at low temperature. Glass is a common example of such an amorphous super-cooled liquid and thus the analogy to glass is responsible for the term "glass transition temperature" of asphalts which is the temperature at which the liquid component of the asphalt freezes to a solid. Any attempt to deform the frozen structure results in fracture.

Field performance data indicate that HMA mixtures in the intermountain region of the U.S. experience severe thermal cracking distresses that are not well covered by the current technology. The intermountain region experiences significant hardening of the asphalt binder coupled with extreme thermal cycling, and highly absorptive aggregate leading to thermal cracks that are six inches wide.

The final product will be in the form of a thermal cracking model that can effectively simulate the long-term properties of HMA mixtures in the intermountain region and assess the impact of such properties on the resistance of HMA mixtures to thermal cracking.

Equipment Availability and Cost (Select one)

Commercial grade equipment is available at the cost of $60,000- $70,000.

Potential Applications

Mix Design Process and Mix Performance Evaluation

Targeted Users

State Highway Agencies, Research Laboratories, and Commercial Laboratories

Time and Skill Requirements

Modeling can be completed within 24 hours and will require engineering level skills.

Recommended Next Steps

Submit to AASHTO

Technology Development Product #25

Dynamic Model for Flexible Pavements: 3D-Move

ARC Research Program

VP3a

Format

Software

Estimated Completion Date

3-31-2011

ARC Partner

University of Nevada, Reno

Product Description

The loads generated by the moving vehicle are dynamic in nature, and they invoke a dynamic response from the pavement structure which is greatly impacted by the inertia of the pavement structure and the viscoelastic behavior of the hot mix asphalt (HMA) layer. The normal and shear dynamic stresses that are generated at the tire-pavement interface control the pavement response in terms of the stresses, strains, and deformations that are generated throughout the pavement structure. The tensile strains generated at the bottom of the HMA layer control the fatigue performance of the HMA pavement. The compressive stresses and strains generated throughout the various pavement layers greatly influence the rutting performance of the HMA pavement. The shear stresses and strains generated within the HMA layer greatly control the shoving performance of the HMA pavement at intersections, on off-ramps, and at facilities that service slow moving heavy loads such as seaports and airports. The final product will be in the form of a pavement analysis software that incorporates the viscoelastic properties of the HMA layer with the non-circular/non-uniform two dimensional pressure distributions at the tire-pavement interface along with vehicle speed. The model will also be capable of predicting pavement performance in terms of rutting and fatigue.

Equipment Availability and Cost

Computer hardware at the cost of $2,000.

Potential Applications

Mix Performance Evaluation.

Targeted Users

State Highway Agencies and Research Laboratories.

Time and Skill Requirements

Modeling can be completed within 24 hours and will require engineering level skills.

Recommended Next Steps

Submit to AASHTO.

Technology Development Product #26

Bitumen Bond Strength (BBS) Test.

Format

Test Method.

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC).

Product Description

The Bitumen Bond Strength (BBS) test is a simple, quick and repeatable approach for evaluating adhesion properties of asphalt-aggregate systems. The test method can measure the effect of moisture in the asphalt-aggregate interface. The BBS is a significantly modified version of the Pneumatic Adhesion Tensile Testing Instrument (PATTI). The main components of the BBS equipment are: portable pneumatic adhesion tester, pressure hose, piston, reaction plate and a metal pull-out stub. The pull-out stub has a rough surface that can prevent asphalt debonding from the stub surface by providing mechanical interlock and larger contact area between the asphalt binder and stub. To start the test, the piston is placed over the pull-out stub and the reaction plate is screwed on it. Then, a pressure hose is used to introduce compressed air to the piston. During the test, a pulling force is applied on the specimen by the metal stub. Failure occurs when the applied stress exceeds the cohesive strength of the binder or the bond strength of the binder-aggregate interface (i.e., adhesion). The BBS test can differentiate the effects of conditioning time, conditioning solution, and modification of binders. These factors significantly affect the pull-off tensile strength of asphalt-aggregate systems.

Equipment Availability and Cost

Pneumatic Adhesion Tensile Testing Instrument (PATTI) costs approximately $8,000. The specially designed pull-out stubs cost $50 each.

Potential Applications

Practical method to evaluate the bond strength between asphalt and aggregate in dry and moisture conditions. Evaluate the effect of anti-stripping or other modifications on the moisture susceptibility of asphalt-aggregate systems.

Targeted Users

State DOT's, Research Institutions, Asphalt Producers, and Test Laboratories for QC/QA.

Time and Skill Requirements

Time to conduct the dry BBS testing is approximately 4 hours (includes sample preparation). Moisture conditioning time needs to be added if testing wet specimens. A technician with minimal training can perform the test.

Recommended Next Steps

Verification of the BBS as a surrogate test for surface energy measurements and comparison with mixture testing using the standard Tensile Strength Ratio (TSR) method.

Technology Development Product #27

Elastic Recovery in the DSR test

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

A test procedure to measure the elastic recovery in the Dynamic Shear Rheometer (DSR). The current protocol measures the elastic recovery in a ductility bath which has the disadvantages of poor repeatability, manual data collection, and time consuming. The test can be performed on any DSR and it uses standard 8 mm parallel plate geometry. The procedure for measuring the elastic recovery in the DSR consists of two steps: a constant shear strain rate is applied for two minutes followed by a zero constant stress for an hour. The main difference from the current protocols can be seen in the last step where instead of cutting the sample a constant zero shear stress is applied. The elastic recovery in the ductility bath and elastic recovery in the DSR correlates very well. Moreover statistical analysis showed that very good correlation is obtained for reduced relaxation times. It is recommended to use 30 minutes relaxation time instead of 60 minutes.

Equipment Availability and Cost

Dynamic Shear Rheometer (DSR) costs between $50,000-80,000 depending upon the manufacture.

Potential Applications

Determine elastic recovery of asphalt binders. Replace highly variable results from elastic recovery tests with ductility bath.

Targeted Users

Asphalt Producers, State DOT's, and Contractors.

Time and Skill Requirements

Testing time is approximately 2 hours. Standard DSR training is required. A technician with minimal training can perform the test.

Recommended Next Steps

Draft standard specification for testing method.

Technology Development Product #28

Linear Amplitude Sweep (LAS) Test

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

The Linear Amplitude Sweep (LAS) test method quantifies fatigue damage accumulation of asphalt binders with a short-duration procedure that can be easily implemented into current practice. The results from the test are analyzed using the framework of Viscoelastic Continuum Damage (VECD) to derive a relation between number of cycles to failure and strain. Thus, from a single test one can account for both traffic loading (i.e., number of cycles to failure) and pavement structure (i.e., strain), which are known to affect fatigue resistance of pavements. It has been shown that LAS fatigue performance of asphalt binders can be correlated to mixture performance in the laboratory and to field fatigue performance.

The test procedure is run in the Dynamic Shear Rheometer (DSR) with standard 8 mm parallel plate geometry. The procedure consists of two tests. The first is a frequency sweep to obtain an undamaged material response. The second, which can be run directly following the frequency sweep, consists of cyclic loading at a constant frequency of 10 Hz, with systematically, linearly increasing strain amplitudes. Each strain step consists of 100 cycles of loading. Loading begins with 0.1% strain to obtain an undamaged material response. Loading proceeds with a 1% strain step followed by strain steps increasing in 1% increments up to 30% applied strain.

Equipment Availability and Cost

Dynamic Shear Rheometer (DSR) costs between $50,000-80,000 depending upon the manufacture.

Potential Applications

Determine binder contribution to mixture fatigue. Product can be used to rank asphalt binders based on fatigue damage resistance. It can be used to determine the effect of modification on the fatigue performance of asphalt binders. Contractors can be used procedure for selecting appropriate material based on fatigue cracking.

Targeted Users

Asphalt Producers, State DOT's, Contractors, Research Institutions, and Test Laboratories for QC/QA

Time and Skill Requirements

Total testing time with conditioning is approximately 30 minutes. Standard DSR training is required.

Recommended Next Steps

Finalize procedure and propose limits based on correlations to field Long Term Pavement Performance (LTPP) performance.

Technology Development Product #29

Binder Yield Energy (BYET) Test

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

The Binder Yield Energy Test (BYET) method measures the asphalt binders' resistance to yield-type failure under monotonic constant shear-rate loading. The BYET method is conducted using the Dynamic Shear Rheometer at the intermediate temperature performance grade (PG Grade) of the asphalt binder. The test method can be used with material aged using AASHTO T 240 (RTFOT) and/or AASHTO R 28 (PAV) to simulate the estimated aging for in-service asphalt pavements. It uses the 8-mm parallel plate geometry with a 2-mm gap setting and samples prepared consistent with Test Method AASHTO T 315 (ASTM D 7175-05) (DSR). The sample is monotonically sheared using a constant shear rate until peak shear strength is achieved and the sample has yielded. This test method is intended to evaluate the amount of energy required to cause yielding in the asphalt binder. The "yield energy" of the material can be used to identify the relative performance of different materials, and the stress-strain response curve can be useful in identifying the presence of polymer modifiers in the material. Some polymer modified binders are capable of accumulating considerable amount of damage in the post peak region of the stress-strain curve. Therefore, the parameter BYE20 which measures the area underneath stress-strain curve up to 2000% strain is used. The 2000% strain was selected because this strain level is beyond peak stress for all the tested binders and the effect of the double peak can be captured by this parameter. The binder stiffness is taken into account by normalizing the energy BYE20 to the stiffness (G*) to obtained normalized parameters: BYEpeak/G* and BYE20/G*.

Equipment Availability and Cost

Dynamic Shear Rheometer (DSR) costs between $50,000-80,000 depending upon the manufacture.

Potential Applications

Determine binder contribution to fatigue. Determine modification type in asphalt binder

Targeted Users

Asphalt Producers, State DOT's, and Contractors.

Time and Skill Requirements

Testing time is approximately 1 hour. Standard DSR training is required. A technician with minimal training can perform the test.

Recommended Next Steps

To be determined based on ETG feedback.

Technology Development Product #30

Rigden Voids Test

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

The Rigden voids test determines the voids in a dry and compacted filler sample. The test is conducted using a Rigden apparatus; hence the name "Rigden" voids. Knowing the voids in a compacted sample allows for determination of the percent volume of free asphalt a filler can carry. The void content is estimated by compacting dry fillers using specified mold size and compaction effort. Research has shown that Rigden voids significantly affects the stiffening effect of fillers on binders. Furthermore, research has demonstrated this stiffening effect is reflected in both mastic and mixture workability and rutting performance.

Equipment Availability and Cost

Rigden Apparatus cost approximately $3000.

Potential Applications

Improve HMA rutting and workability performance by controlling Rigden voids.

Targeted Users

Aggregate producers and state highway agencies.

Time and Skill Requirements

Testing time is approximately 1 hour. A technician with minimal training can perform the test.

Recommended Next Steps

Develop specification and define relation to HMA performance.

Technology Development Product #31

Asphalt Lubricity Test

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

The conventional laboratory method for evaluation of asphalt binder workability has been unable to demonstrate an ability to exhibit a measured reduction in viscosity due to the presence of warm mix additives consistent with enhanced mixture workability observed in the laboratory and field. Thus indicating that viscosity reduction is not the only mechanism by which warm mix additives allow for compaction at reduced temperatures. It is believed that some additives enhance mixture workability through improving the lubricating effects of asphalt binders through reduction in the internal friction of the material.

A standard test in the oil industry, ASTM D-5183: Standard Test Method for Determination of the Coefficient of Friction of Lubricants Using the Four Ball Wear Test Machine has been adapted to allow for the test to be conducted in the Dynamic Shear Rheometer (DSR). The apparatus consists of three lower balls which are clamped in a cup; a fourth ball held in a chuck is loaded against them, a sufficient amount of lubricant is added to produce a film between the chuck and clamped assembly. The chuck is rotated in one direction with resistance provided by the fixed balls in the cup below. During the test torque and normal force are monitored under a constant speed and the coefficient of friction of the asphalt binder is calculated. The test is conducted in the temperature range of conventional HMA/WMA compaction.

Equipment Availability and Cost

Standard Superpave testing equipment with the addition of four ball testing fixture. Cost of prototype fixture is approximately $5000.

Potential Applications

The test has potential use in mix design to optimize the use of WMA additives such that mixture workability is achieved in the desired temperature range.

Targeted Users

Research Laboratories and contractors.

Time and Skill Requirements

Testing time is approximately 2 hours. Standard Superpave testing equipment training is needed (DSR). Specific training on test procedure and analysis of data.

Recommended Next Steps

Establish repeatability and sensitivity to test parameters to allow for procedure development. Draft standard test method. Implement procedure to investigate use of lubricity to classify WMA additives.

Technology Development Product #32

Test Method to Quantify the Effect of RAP and RAS on Blended Binder Properties without Binder Extraction

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

A testing procedure that quantifies the effect of RAP and RAS on the fresh binder properties at all critical pavement temperatures has been prepared. The approach minimizes labor and eliminates the need for binder extraction. In the testing procedure mortar and binder samples are tested in the Bending Beam Rheometer (BBR) and Dynamic Shear Rheometer (DSR) to quantify the effect of RAP and RAS binder on the fresh binder continuous grade profile, allowing for an estimation of mixture binder properties at critical pavement temperatures. The testing procedure produces a RAP/RAS binder-fresh binder continuous grade improvement rate, that is, the rate of change of the fresh binder continuous grade per percent fresh binder replaced by RAP/RAS binder. This allows users to estimate the performance grade of the mixture binder given any amount of RAP and RAS binder replacement within the mixture. The RAP and RAS binder analysis procedure was verified by testing artificial RAP materials and was found to be capable of estimating the RAP binder-fresh binder continuous grade to within 2.4 degrees Celsius at low and intermediate temperatures and under three degrees Celsius at high temperature of the known binder grade. The procedure was also extended to RAP and RAS blends and was found to be capable of producing a fresh binder-RAP/RAS binder relationship that allows users the ability to adjust (optimize) RAP or RAS binder replacement and determine the mixture continuous grade (PG). The utility of this application is evident; current specifications regarding inclusion limits of RAP and RAS into new HMA can easily be evaluated to check the validity of the PG change recommendation.

Equipment Availability and Cost

Standard Superpave testing equipment with the addition of the ignition oven test

Potential Applications

High percentage RAP and RAS mixture performance grade optimization and establishing more reasonable mixture specifications as they pertain to allowable RAP and RAS materials.

Targeted Users

State DOT’s, Contractors, and Research Institutions.

Time and Skill Requirements

Standard Superpave testing equipment training (BBR, DSR, etc.).

Recommended Next Steps

Increase sample sizes (in RAP/RAS source) and finalize sample preparation procedure. Draft AASHTO standard specification for testing method.

Technology Development Product #33

Single-Edge Notch Bending (SENB)

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

The Single Edge Notch Bending (SENB) test measures the fracture properties of asphalt binders and mastic at low temperatures. The SENB test follows ASTM E399 and assumes that Linear Elastic Fracture Mechanics (LEFM) conditions are true. Asphalt binders samples prepared using the Bending Beam Rheometer (BBR) geometry with a notch on it are tested in three-point bending using displacement controlled mode. Load-displacement curves and fracture mechanics concepts are used to estimate both fracture energy (G_f) and fracture toughness (K_{IC}).

Preliminary results indicate that this test method is capable of differentiate good and poor low temperature performance of both asphalt binders and mastics. Furthermore, the effect of modification on the thermal cracking performance of asphalt binders can be evaluated with this method.

Equipment Availability and Cost

Modification of the Superpave Bending Beam Rheometer (BBR) to apply load using displacement control. The cost is approximately divided into BBR ($40,000) and Motor Step-Loading Frame ($12,000).

Potential Applications

Asphalt binders and mastics characterization at low temperatures. Asphalt binder grading based on fracture mechanics. Test method can be used to estimate the low temperature strength of BBR mixture beams. Product can be used for ranking of asphalt materials based on fracture toughness and to estimate the ductile to brittle transition of asphalt binders. Effect of modification on low temperature cracking of asphalt binders.

Targeted Users

Asphalt Producers, State DOT’s, Contractors, Research Institutions, and Test Laboratories for QC/QA.

Time and Skill Requirements

The time required for testing one specimen is 2 hours approximately. This includes sample preparation and sample conditioning at specified temperature for 1 hour. A larger set of experiments will significantly improve the time required for SENB testing. A technician with minimal training can perform the test.

Recommended Next Steps

Draft AASHTO test method. Validation with fracture mechanics-based mixture testing and field performance measured in MnROAD sections. Comparisons with test methods currently used by transportation agencies.

Technology Development Product #34

Binder Glass Transition Test

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

The glass transition temperature (T_g) and the coefficients of thermal expansion/contraction above and below T_g of asphalt binders are measured by means of a dilatometric test system. The apparatus monitors the dilatometric properties of binders while the samples are subjected to a prescribed temperature program. The specific volume vs. temperature data obtained from test can be used to fit a non-linear model that contains the glass transition temperature and the thermal coefficients of contraction/expansion above and below T_g as parameters. Very precise capillary tubes are used to measure volume changes in the sample during the test. The system is automated with precise pressure sensors that continuously measure the change of alcohol height, which is proportional to changes in specific volume of the binder. Furthermore, the dilatometric cells made of aluminum are sealed with military-specified o-rings to minimize the effect of rubber contraction on the test results.

Equipment Availability and Cost

Total estimated cost of equipment and assembly is approximately $2,500. The system is comprised of insulated chamber ($100), dilatometric cell ($1000), pressure sensor ($250), capillary tube ($100), and a cooling system with solenoid valve ($200). Liquid nitrogen is currently been used as cooling agent. A tank of nitrogen costs $70 (for 5 tests).

Potential Applications

Recent results show that the T_g has a very close relationship to the fracture properties and brittleness. The proximity of the pavement service temperature to the T_g is believed to be an important overlooked factor in predicting low temperature performance. Procedure can be used to accurately estimate coefficient of thermal expansion/contraction for design purposes.

Targeted Users

Asphalt research institutes

Time and Skill Requirements

Testing time is approximately 4 hrs for 1°C/min of cooling rate. The T_g test procedure is very straight forward and relatively simple, but the delicate equipment involved require the utmost care and patience in testing.

Recommended Next Steps

Draft standard for test method. The current usage of liquid Nitrogen as cooling agent is costly and inconvenient. Attempts will be made to replace the cooling system with an electric chiller system.

Technology Development Product #35

Asphalt Mixture Glass Transition Test

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

A new procedure for testing the thermal expansion and contraction coefficients as well as the glass transition temperature (T_g) for asphalt mixtures is currently been developed, in which beam samples are fabricated gluing rectangular prisms cut from gyratory compacted cylinders.

The T_g system for asphalt mixtures measures the change in specimen length by means of two LVDTs as function of temperature. The same non-linear model used for asphalt binders can be used for mixtures to estimate T_g and the coefficients of thermal expansion/contraction above and below T_g. The experimental data collected with this method will be used to modify current models and to provide typical/default values of T_g and contraction coefficients that can be used to predict thermal cracking.

Equipment Availability and Cost

Total estimated cost of equipment and assembly is approximately $3,500. The cost breakdown is the same as for the asphalt binder T_g but adding the cost of two LVDTs ($600) and two polymer invar rods ($50).

Potential Applications

The proximity of the pavement service temperature to the T_g is believed to be an important overlooked factor in predicting low temperature performance of pavements. Furthermore, the mixture coefficient of thermal expansion is an important factor for the prediction of thermal stress buildup. Results have shown that other than the binder T_g, the mixture T_g is affected by mixture volumetrics and aggregate structure. Thus, direct measurement of the mixture T_g, is very convenient.

Targeted Users

Asphalt research institutes

Time and Skill Requirements

The test takes approximately 4 hrs (based on cooling rate of 1°C/min). Compared to the binder T_g, the mixture T_g test is much simpler and significantly less delicate. The test mechanism is straight forward, resulting in good accuracy and minimal potential problems.

Recommended Next Steps

Finalize test procedure and propose limits based on correlations to field performance. Thermal cracking sensitivity analysis will be conducted to determine which of the glass transition parameters are statistically important for thermal cracking, which ones need to be measured, and what is the effect of using estimated rather than measured values.

Technology Development Product #36

Standard Practice for Determining Aggregate Structure in Asphalt Mixes by Means of Planar Imaging

Format

Test Method / Software

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

The Image Processing and Analysis System (iPas) has been developed to allow for the processing and analysis of planar images of asphalt mixes. This software can be used for the characterization of the internal aggregate structure. In addition to iPas, a standard practice has been developed to summarize the guidelines used in digital image analysis of asphalt mixtures. Research has shown that internal structure of asphalt mixtures may dictate the mechanical performance of the mix. A number of studies have been conducted to confirm this, yet each uses a different method of capturing, processing, and analyzing images of the asphalt mixes, many of which are cumbersome and therefore have not become widely accepted. User confidence, or lack thereof, also prevents several methods from widespread adoption. iPas allows for a systematic and repeatable means of determining internal structure of asphalt mixes from planar images. The new system not only caters to users of nearly any level of experience, but also provides feedback matching processed image information with known laboratory volumetrics to ensure the user that the image is appropriately processed before moving on the analysis phase.

Equipment Availability and Cost

Standard flatbed scanner ($50)

Potential Applications

Ease and improved resolution of internal structure characterization of asphalt mixes that may aid in determining the contribution of a given structure to mechanical performance. It can be used to determine number of contact points and degree of segregation in the asphalt mixture. The orientation of the aggregates can also be estimated to determine level and method of compaction.

Targeted Users

State DOT's, Research Laboratories, and Contractors.

Time and Skill Requirements

Basic computer skills and asphalt mixture design knowledge. Analysis time varies upon resolution of the image. It usually takes about 30 min to process one image.

Recommended Next Steps

Analysis of broad range of images to define relation to HMA performance

Technology Development Product #37

Gyratory Pressure Distribution Analyzer

Format

Test Method

ARC Partner

University of Wisconsin – Madison, Modified Asphalt Research Center (UWMARC)

Product Description

The test method measures cyclic forces on the surface of an asphalt mixture at a minimum of three points located at 120°. Forces are monitored with time during each gyration through use of a separate device inserted into the mold with the material specimen. Asphalt mixtures are to be prepared per Superpave procedures as specified in AASHTO MP-2. The device is inserted into the SGC mold on top of the mixture prior to compaction. The reactive force and its effective location with respect to the material sample centerline (eccentricity) imparted by the material specimen are measured during compaction. These combined measurements (force x distance) may also be represented as a tilting moment and are used to calculate the resistive effort of the mix. The relationship between resistive effort and mixture densification is used to evaluate mixture workability and stability.

Equipment Availability and Cost

Super Pave Gyratory Compactor and Gyratory Pressure Distribution Analyzer (GPDA) required. The GPDA is currently being marketed by Troxler and sells for approximately $8000.

Potential Applications

This technology has most use as a mix design tool. Aggregate gradation, asphalt binder grades, and types of modification can be optimized by establishing a mixture that exhibits workability during construction and adequate aggregate interlock for in-service stability. The GPDA also has potential use as a QC tool by specifying a level of resistive effort for a given gyration.

Targeted Users

Research Laboratories, Contractors, and State Agencies.

Time and Skill Requirements

Testing time is approximately 1 hour. Standard Superpave mix design training. Specific training related to use of the GPDA and analysis of the data collected is also required.

Recommended Next Steps

Establish precision and bias statement for incorporation into draft ASTM Standard that is currently under review. Compare GPDA indices with new SGC equipment that implements external measurement of shear to estimate tilting moment.

Technology Development Product #38

Improved Oxygen and Thermal Transport Model of Binder Oxidation in Pavements

Format

Methodology, Publication

ARC Partner

TAMU

Product Description

An improved oxygen and thermal transport model of binder oxidation in pavements will be developed. Improvements will include both fast-rate and constant-rate binder oxidation kinetics; an air void size distribution model based upon CT imaging determinations of air voids; consideration of limiting cases of oxygen levels in the air voids (provided either by convective flow or by diffusion through the pores only); and an improved pavement temperature model (each of these elements is described in a separate product description.) The improved model will use input data (pavement location for use in determining environmental data that impacts temperature over time, pavement air voids structure, binder kinetics parameters) to calculate binder oxidation and hardening in pavements as a function of time an depth. These results can be used with mixture models to estimate changes in mixture properties such as fatigue resistance that occur due to binder oxidation.

Equipment Availability and Cost

N/A. This product is a methodology and not test equipment.

Potential Applications

The model will provide essential information for an improved pavement design method. Current methods provide only empirical estimates of binder oxidation in pavements that are quite imprecise and in addition overlook some important effects of binder oxidation on mixture properties and performance.

Targeted Users

Pavement researchers, pavement design and maintenance engineers

Time and Skill Requirements

Researchers with background in thermal and mass transport, binders, mixtures, and computational methods will incorporate the methodology into design, maintenance, and forensic activities.

Recommended Next Steps

Validation of the pavement oxidation model using field locations across the country is ongoing with more planned. Longer term, plans should be made to incorporate the model into a new generation pavement design guide.

Technology Development Product #39

Field Validation of an Improved Oxygen and Thermal Transport Model of Binder Oxidation in Pavements

Format

Methodology, Field Data, Publication

ARC Partner

TAMU

Product Description

Validation of the pavement oxidation model will be conducted with field cores taken over time from a number of pavements. Planned test sites are the WRI test sections in several locations in the central part of the U.S. and Canada. Validation will include measuring the binder oxidation kinetics parameters (both fast-rate and constant-rate parameters, provided original binder is available), core total air voids and pore size distribution, and binder oxidation levels of binder recovered from cores at several times in each pavement's service life. An initial validation with a number of cores taken from Texas pavements has been completed.

Equipment Availability and Cost

Potential Applications

A verified model will provide essential information for an improved pavement design method. Current methods provide only empirical estimates of binder oxidation in pavements that are quite imprecise and in addition overlook some important effects of binder oxidation on mixture properties and performance.

Targeted Users

Time and Skill Requirements

Recommended Next Steps

Obtain cores for the WRI and other test (or other pavement) sections.

Technology Development Product #40

Validation of an improved Pavement Temperature Transport Model for use in an Oxygen and Thermal Transport Model of Binder Oxidation in Pavements

Format

Methodology, Publication

ARC Partner

TAMU

Product Description

An improved pavement temperature model will be validated by comparing predictions (as a function of time and depth) to measurements (available in the LTPP data base) at locations across the U.S.

Equipment Availability and Cost

Potential Applications

Targeted Users

Time and Skill Requirements

Recommended Next Steps

Validation with additional sites.

Technology Development Product #41

Pavement Air Voids Size Distribution Model for use in an Oxygen and Thermal Transport Model of Binder Oxidation in Pavements

Format

Methodology, Publication

ARC Partner

TAMU

Product Description

Using a distribution of air void pore sizes, instead of a single average size, in the oxygen and thermal transport model for binder oxidation in pavements, will provide more accurate estimates of binder oxidative aging in pavements. The methodology will determine a distribution of air void pore sizes from CT imaging techniques which will be used to calculate upper and lower limits on binder oxidation rate estimates for two limiting cases: convective air flow through interconnected pores in the pavement versus diffusive flow only. In reality, probably both mechanisms contribute to supplying oxygen to pavement pores.

Equipment Availability and Cost

Potential Applications

This product will allow improved modeling of binder oxidation in pavements, essential for accurate prediction of pavement performance over time and in the presence of deterioration due to oxidative embrittlement of binders.

Targeted Users

Time and Skill Requirements

Recommended Next Steps

Validation with additional pavement sites.

Technology Development Product #42

Improved Understanding of Fast-Rate, Constant-Rate Binder Oxidation Kinetics Mechanism through the Effects of Inhibitors

Format

Publication

ARC Partner

TAMU

Product Description

This product will provide both fast-rate and constant-rate binder oxidation kinetics parameters for use in pavement oxidation models. Previously, it has been assumed that the slower, constant-rate reaction mechanism has been the primary oxidation process over the life of the pavement. Field data and modeling has shown that the shorter lasting, but faster rate initial reaction process can have a significant impact on binder oxidation in pavements, especially in colder climates, and must be understood in order to make improved performance predictions. Measuring both fast-rate and constant-rate kinetics parameters will provide the information needed for pavement modeling, but measuring each individual asphalt material is prohibitively time consuming. The goal of this work is to deliver a more fundamental understanding of the reaction mechanisms, or at least relationships between the fast-rate and constant-rate reaction processes, that will lead to a sufficiently complete kinetics picture for each binder but with a greatly reduced measurement effort.

Equipment Availability and Cost

Potential Applications

Targeted Users

Time and Skill Requirements

This is a long-term effort. Understanding reaction mechanisms or at least relationships between fast-rate and constant-rate mechanisms is an effort with unknown probability of success, yet the reward from a successful effort will be significant. A minimum of one year is required to determine if such a venture is likely to be successful. Then another year likely will be needed to finish the product.

Recommended Next Steps

Measure the effect of oxidation inhibitors on both fast-rate and constant-rate reaction kinetics.

Technology Development Product #43

Improved Understanding of Fatigue Resistance Decline with Binder Oxidation

Format

Publication

ARC Partner

TAMU

Product Description

This effort will deliver quantitative measurement of mixture fatigue resistance as it is affected by binder oxidation for a number of ARC binders and mixtures. Previous work has shown that the fatigue resistance of a mixture declines with binder oxidation, but how the rate of this decline is related to mixture design parameters is unknown. This is fundamental experimental work that will complement theoretical modeling of mixture properties.

Equipment Availability and Cost

Potential Applications

Targeted Users

Time and Skill Requirements

Recommended Next Steps

To measure fatigue resistance in WRI test section cores taken at several times in the pavements' lives and in laboratory prepared mixtures having different mixture parameters.

Technology Development Product #44

Micromechanical Properties of Various Structural Components in Asphalt using Atomic Force Microscopy (AFM)

ARC Research Program

F2d

Format

Test and Analysis Method

Estimated Completion Date

3/2011

ARC Partner

TAMU/TTI

Product Description

The purpose of this test and analysis method is to characterize the micromechanical properties of various structural components in asphalt using Atomic Force Microscopy (AFM) and to quantify mechanical, viscoelastic properties of the phase components of asphalt binders before and after various degrees of oxidative aging. Nano-indentation experiments have been performed under work element F2d on a micro-grid of asphalt. TAMU has been successful in determining micromechanical properties such as stiffness, adhesion and elastic/plastic behavior. TAMU has noted a substantial difference in these mechanical properties between unaged and aged binders. The binders tested to date are AAB, AAD and ABD from the Materials Reference Library (MRL) of the Strategic Highway Research Program (SHRP). These binders were chosen based on the variation in crude source, chemical composition and elemental analysis that represent.

This product will be a test method in AASHTO recommended practice format to used nano-indentation to quantify viscoelastic properties of the phases of the asphalt binder as well as the composite asphalt binder before and after aging. These properties will ultimately be used to predict the fracture, hardening, fatigue, permanent deformation and fracture healing potential of asphalt binders and their performance in asphalt mixtures. The recommended standard practice will address the testing methodology and the methods by which to extract the viscoelastic properties as well as the utility of using these viscoelatic properties to screen for performance potential in terms of facture, fatigue, permanent deformation and compatibility with aggregate of all size fractions within the asphalt mixture.

Equipment Availability and Cost

An AFM capable of performing this function can be purchased for approximately $35,000 and is available from Agilent Technologies among other manufacturers.

Potential Applications

This methodology should be used as a screening tool for asphalt binder fracture, fatigue, and permanent deformation potential and development of adhesive (with aggregate) and cohesive bond energy in a mixture and thus compatibility with a selected aggregate as well as moisture susceptibility.

Targeted Users
Central laboratories of the FHWA and state DOTs as well as consultancies will be likely to immediately benefit.

Time and Skill Requirements
Use of the AFM requires a dedicated technician, knowledgeable in the science and use of the AFM. The testing protocol will be sufficiently specific, however, to make this a reasonable and beneficial effort.

Recommended Next Steps
Complete the testing protocol and develop methods of analysis to define viscoelastic properties.