Western Research
INSTITUTE

Asphalt Research Consortium

Quarterly Technical Progress Report
July 1-September 30, 2013

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By
Western Research Institute
Texas A&M University
University of Wisconsin-Madison
University of Nevada-Reno
Advanced Asphalt Technologies
National Center for Asphalt Technology

www.westernresearch.org
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INTRODUCTION

This document is the Quarterly Report for the period of July 1 to September 30, 2013, for the Federal Highway Administration (FHWA) Contract DTFH61-07-H-00009, the Asphalt Research Consortium (ARC). The Consortium is coordinated by Western Research Institute with partners Texas A&M University, the University of Wisconsin-Madison, the University of Nevada Reno, Advanced Asphalt Technologies, and the National Center for Asphalt Technology.

The report is presented as a progress report on the 77 anticipated project deliverables. The project deliverables are grouped into three areas, Reports, Test Methods/Practices, and Models and/or Software. The deliverables consist of 28 Reports, 42 Test Methods/Practices, and 7 Models and/or software. Of the 77 deliverables, 15 draft reports and 32 test methods/practices have been submitted for review. Most of the planned work is completed or nearing completion, therefore, many of the original Work Elements and Subtasks have coalesced into a larger product(s), as planned. The Table of Deliverables is presented following this introduction and identifies the title of the deliverable, expected draft delivery date, and expected final delivery date. The table is updated each quarter. In addition, this Quarterly Report reports on Other Research Activities which may develop deliverables as the work progresses. The project deliverables result from research that was grouped into seven areas, Moisture Damage, Fatigue, Engineered Paving Materials, Vehicle-Pavement Interaction, Validation, Technology Development, and Technology Transfer.

The Quarter of July 1 to September 30, 2013, is the second quarter of the Year 7 contract year. Reviewers may want to reference the previous Annual Work Plans and many other documents that are posted on the ARC website, www.ARC.unr.edu. The more detailed information about the research such as approaches to test method development, data collection, and analyses have been and will continue to be reported in research publications as part of the deliverables.

SUPPORT OF FHWA AND DOT STRATEGIC GOALS

The Asphalt Research Consortium research is responsive to the needs of asphalt engineers and technologists, state DOT's, and supports the FHWA Strategic Goals and the Asphalt Pavement Road Map. More specifically, the research reported here supports the Strategic Goals of safety, mobility, and environmental stewardship. By addressing the causes of pavement failure and thus determining methods to improve asphalt pavement durability and longevity, this research will provide the motoring public with increased safety and mobility. The research directed at improved use of recycled asphalt pavement (RAP), warm mix asphalt, and cold mix asphalt supports the Strategic Goal of environmental stewardship.

TABLE OF ASPHALT RESEARCH CONSORTIUM DELIVERABLES

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Overall Report	Summary Narrative Report on ARC members and accomplishments	1/31/2014	5/31/2014	All	All	
Summary Report	Comprehensive Summary Report (Level 1) (Report summarizing all work elements in significant detail to provide a single source documentation of ARC accomplishments)	10/31/2013	12/15/2013	TAMU	All	Reference level 2 and 3 deliverables for details, 508
Report A	Summary report on Moisture Damage (Level 2)	Completed 1/31/2013	9/30/2013	TAMU	Masad	Sent to FHWA for review, Reference level 3 deliverables for details, NTIS
Report B	Characterization of Fatigue Damage and Relevant Properties (Level 2)	Completed 8/15/2013	10/31/2013	TAMU	Bhasin	NTIS
Report C	PANDA: Pavement Analysis using a Nonlinear Damage Approach (Level 2)	Completed 8/31/2013	11/30/2013	TAMU	Darabi	Summary of PANDA methodology including descriptions of methods for indentifying model parameters, 508

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Report D	Characterization of Asphalt Binders using Atomic Force Microscopy (Level 2) Microstructural Chemo-Mechanical Behavior of Asphalt Aging and Fatigue	Completed 7/26/2013	10/31/2013	TAMU	Little	Summary report on methodology for characterizing the phases of asphalt binder with description of composite implications NTIS
Report E	Lattice Model and Continuum Damage to Fracture (Level 2)	Completed 9/03/2013	9/30/2013	NCSU	R. Kim	Submitted to FHWA for review, Comprehensive report on lattice model.
Report F	Microstructure Cohesive Zone Modeling for Moisture Damage and Fatigue Cracking (Level 2)	Completed 3/21/2013	8/31/2013	UNL	Y.R. Kim	Sent to FHWA for review, Comprehensive report on cohesive zone model
Report G	Design System for HMA Containing a High Percentage of RAP Material	12/31/2013	3/31/2014	UNR	Sebaaly Hajj	
Report H	Critically Designed HMA Mixtures	12/31/2013	3/31/2014	UNR	Hajj Sebaaly	Comprehensive report describing the developed mechanistic-based approach for critically designed mixtures
Report I-A	Study of Pavement Temperature Rates in HMA Layers	9/26/2013		UNR		Received MS Word and Hardcopy
Report I	Thermal Cracking Resistant Mixes	2/15/2014	12/31/2013	UNR	Hajj Sebaaly	

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Report J	Pavement Response Model to Dynamic Loads 3D Move	2/28/2014	5/31/2014	UNR	Hajj Sebaaly	Delayed. Research team focused on addressing and solving the various bugs reported by the users for newly released Ver. 2 of the software
Report K	Development of Materials Database	10/31/2013	3/31/2014	UNR	Hajj Ekedahl	Outline only
Report L	Development and Validation of the Bitumen Bond Strength Test (BBS)	Completed 10/31/11	Completed 10/31/13	UWM	Hanz	Extended to incorporate new information from NCHRP 9-50
Report M	Development of Test Procedures for Characterization of Asphalt Binder Fatigue and Healing	Completed 10/31/11	Completed 10/31/13	UWM	Tabatabaee	Received MS Word version and tech brief. Section 508 and image descriptions needed.
Report N	Guideline for Selection of Modification Techniques	12/31/2013 from 9/30/2013	3/31/2014	UWM	Tabatabaee	3 month extension of draft report deadline approved by FHWA
Report O	Characterization of Binder Damage Resistance to Rutting	Completed 9/30/2013	12/31/2013	UWM	Tabatabaee	Received draft MS Version
Report P	Quantifying the Impacts of Warm Mix Asphalt on Constructability and Performance	12/31/2013 from 9/30/2013	3/31/2014 from 12/31/2013	UWM	Hanz	3 month extension of draft report deadline requested

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Report Q	Improvement of Emulsion Characterization and Mixture Design for Cold Bitumen Applications	12/31/2013 from 12/31/2013	3/31/2014 from 3/31/2014	UWM	Hanz	3 month extension of draft report deadline requested
Report R	Studies on Tire-Pavement Noise and Skid Response	Completed 12/31/11	7/30/2013	UWM	Roohi	Received MS Word version and tech brief
Report S	Molecular dynamics results for multiple asphalt chemistries	12/30/2013	3/31/2014	URI	Greenfield	3 month extension of draft report deadline requested. NTIS format report with Technical Brief
Report T	Progress Toward a Multi-scale Model of Asphalt Pavement- Including Test Methods for Model Input Parameters	12/30/2013	3/31/2014	WRI/VT/URI	Pauli	3 month extension of draft report deadline requested. FHWA format
Report U	Design Guidance for Fatigue and Rut Resistance Mixtures	12/31/2013	3/31/2014	AAT	Bonaquist Christensen	3 month extension of draft report deadline requested. NTIS format report with Technical Brief
Report V	Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures (Level 2)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Draft submitted to FHWA Reference appropriate level 3 deliverables NTIS
Report W	Characterization of Fatigue and Healing Properties of Asphalt Mixtures (Level 2)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Draft submitted to FHWA Reference appropriate level 3 deliverables NTIS

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Report X	Characterization of Field Cores of Asphalt Pavements (Level 2)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Draft submitted to FHWA Reference appropriate level 3 deliverables NTIS
Report Y	Water Vapor Diffusion in Pavement and Its Effects on the Performance of Asphalt Mixtures (Level 2)	Completed 07/26/2013	11/30/2013	TAMU	Lytton/Luo	Draft submitted to FHWA Reference appropriate level 3 deliverables NTIS
Report Z	Effect of Extraction Methods on the Properties of Aggregates in Reclaimed Asphalt Pavement (NTIS format)	Completed 3/1/2013	10/30/2013	UNR	Hajj Sebaaly	Draft submitted to FHWA Final pending receipt of peer review comments
Report AA	Laboratory Assessment of Asphalt Mixture Long Term Aging	3/31/2014	6/30/2014	UWM	Tabatabaee	3 month extension of draft submittal requested.

TABLE OF ASPHALT RESEARCH CONSORTIUM PRODUCT DELIVERABLES

Deliverable/ Product	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method	Simplified Continuum Damage Fatigue Analysis for the Asphalt Mixture Performance Tester	12/31/2013	3/31/2014	AAT	Bonaquist Christensen	Development documented in Report U
AASHTO Method	Wilhelmy Plate Test (Level 3)	Completed 03/07/2013	6/30/2013	TAMU	Bhasin	Draft submitted to FHWA Referenced in Reports A & B
AASHTO Method	Universal Sorption Device (Level 3)	Completed 03/07/2013	6/30/2013	TAMU	Bhasin	Draft submitted to FHWA Referenced in Reports A & B
AASHTO Method	Dynamic Mechanical Analysis (Level 3)	Completed 03/07/2013	6/30/2013	TAMU	Kassem	Draft submitted to FHWA Referenced in Reports A & B
ASTM Method	Automated Flocculation Titrimetric Analysis	Completed		WRI	Pauli	ASTM D-6703
AASHTO Method	Determination of Polymer in Asphalt	Completed		WRI	Harnsberger	
AASHTO Method	A Method for the Preparation of Specimens of Fine Aggregate Matrix of Asphalt Mixtures (Level 3)	Completed 1/31/2013	6/30/2013	TAMU	Kassem	Draft submitted to FHWA Referenced in Reports A & B
AASHTO Method	Measuring intrinsic healing characteristics of asphalt binders	Completed 03/07/2013	9/30/2012	TAMU/ UT	Bhasin	Draft submitted to FHWA Referenced in Report B
AASHTO Method	Test Methods for Determining the Parameters of Material Models in PANDA (Pavement Analysis Using Nonlinear Damage Approach) (Level 3)	Completed 09/26/2013	2/28/2014	TAMU	Kassem Darabi	Referenced in Report C

Deliverable/ Product	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Test Method & Model	Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report V
Test Method & Model	Characterization of Fatigue and Healing Properties of Asphalt Mixtures (Level 3)	Completed 07/26/2013	9/30/2013	TAMU	Lytton/Luo	Appendix in Report W
Test Method Analysis Program	Nondestructive Characterization of Tensile Viscoelastic Properties of Undamaged Asphalt Mixtures (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report W
Test Method & Model	Characterization of Field Cores of Asphalt Pavements (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report X
Test Method Analysis Program	Nondestructive Characterization of Anisotropic Viscoelastic Properties of Undamaged Asphalt Mixtures under Compressive Loading (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report V
AASHTO Practice	Mix Design for Cold-In-Place Recycling (CIR)	12/31/2013		UNR	Sebaaly Hajj	Detailed in Report Q
AASHTO Practice	Mix Design for Cold Mix Asphalt	3/31/2014 from 9/30/2013	6/30/2014 from 3/31/2014	UWM	Hanz	Extension requested to coincide with submittal of draft for Report Q
AASHTO Practice	Evaluation of RAP Aggregates	12/31/2012		UNR	Sebaaly	Detailed in Report G
AASHTO Practice	Identification of Critical Conditions for HMA mixtures	Completed 5/31/2013		UNR	Hajj Sebaaly	Detailed in Report H
AASHTO Method	Determining Thermal Crack Properties of Asphalt Mixtures Through Measurement of Thermally Induced Stress and Strain	Completed 5/31/2012		UNR	Hajj Tabatabaee	Detailed in Report I
AASHTO Method	Determining Asphalt Binder Bond Strength by Means of the Bitumen Bond Strength Test (BBS)	Completed	Completed 6/30/13	UWM	Hanz	Complete, no additional work planned.
AASHTO Method	Measurement of Asphalt Binder Elastic Recovery in the Dynamic Shear Rheometer (DSR)	Completed 1/31/2013	Complete 6/30/2013	UWM	Tabatabaee	Complete, no additional work planned.

Deliverable/ Product	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method	Estimating Fatigue Resistance of Asphalt Binders Using the Linear Amplitude Sweep (LAS)	Completed	Completed 9/30/2013	UWM	Tabatabaee	Complete, no additional work planned.
AASHTO Method	Binder Yield Energy Test (BYET)	Completed 1/31/2013	Complete 6/30/2013	UWM	Tabatabaee	Complete, no additional work planned.
AASHTO Method	Measurement of Rigden Voids for fillers	Completed 1/31/2013	Completed 6/30/2013	UWM	Hanz	Complete, no additional work planned.
AASHTO Method	Measurement of Asphalt Binder Lubricity Using the Dynamic Shear Rheometer (DSR)	12/31/2013 from 9/30/2013	3/31/2014 from 12/31/2013	UWM	Hanz	3 month extension requested to coincide with submittal of draft final Report P
AASHTO Method	Procedure for Evaluation of Coating for Cold Mix Asphalt	Completed 4/30/2013	Completed 9/30/2013	UWM	Hanz	Complete, no additional work planned
AASHTO Method	Cold Mix Laboratory Specimen Preparation Using Modified SGC Molds	Completed 8/30/2013	Completed 6/30/2013	UWM	Hanz	Pending comments from FHWA/ETG
AASHTO Method Software	RAP Binder PG True Grade Determination	Completed 9/30/2012	Completed 6/30/2013	UWM	Hanz	Complete, no additional work planned
AASHTO Method	Measurement of Asphalt Binder Fracture Properties Using the Single Edge Notch Bending Test	Completed 9/30/2012	Completed 9/30/2013	UWM	Tabatabaee	Complete, no additional work planned
AASHTO Method	Test Method for Measurement of the Glass Transition Temperature of Asphalt Binders	Completed 1/31/2013	Completed 6/30/2013	UWM	Tabatabaee	Action pending FHWA/ETG comments
AASHTO Method	Test Method for Measurement of the Glass Transition Temperature of Asphalt Mixtures	Completed 4/30/2013	Completed 6/30/2013	UWM	Tabatabaee	Refer to UNR TSRST procedure for additional information

Deliverable/ Product	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method Software	Analysis of Asphalt Mixture Aggregate Structure through Use of Planar Imaging and Image Processing & Analysis System (IPAS)	Completed 4/30/2013	Completed 9/30/2013	UWM	Roohi	Action pending ETG comments
AASHTO Method	Determining the Resistive Effort of Asphalt Mixtures during Compaction in a Gyrator Compactor using an Internal Device	Completed ASTM	12/31/2013 from 9/30/2013	UWM	Hanz	Extended to address comments from ASTM
AASHTO Method	Micromechanical Properties of Various Structural Components in Asphalt using Atomic Force Microscopy (AFM) (Level 3)	Completed 03/07/2013	8/31/2013	TAMU	Little	Draft submitted to FHWA, Referenced in Report D
AASHTO Method	Test Method for Fatigue of Binder and Mastics: A cyclic direct tension test that can provide direct evaluation of fatigue for binder and mastic. It can also provide model validation and model parameter inputs.	12/30/2013	3/30/2014	VT	Wang	Draft data extension requested
AASHTO Method	Evaluate Healing using Continuum Damage Approach (Level 3)	Completed 08/22/2013	8/31/2013	TAMU/ UT	Bhasin	Appendix in Report B
Test Method & Analysis Program	Self-Consistent Micromechanics Models of Asphalt Mixtures (Level 3)	Completed 07/26/2013	10/31/2013	TAMU	Lytton/Luo	Appendix in Report W
AASHTO Method & Analysis Program	Prediction of Apparent Viscosity of Asphalt Binders Using a Generalized Oldroyd-B Model	Completed 10/16/2013	9/30/2013	TAMU	Little	Draft submitted to FHWA for review
AASHTO Method	Method to determine surface roughness of aggregate and fines based on AFM	9/30/2013	4/30/2014	WRI	Grimes	Will be subject of Tech. Pub.
AASHTO Method	A method to determine ductile-brittle properties via AFM measurements	10/30/2013	2/28/2014	WRI	Grimes	Will be subject of Tech. Pub.
AASHTO Method	AFM-based micro/nano-scale cyclic direct tension test	Completed 3/31/2013	10/31/2013	WRI	Grimes	Draft submitted to FHWA Will be subject of Tech. Pub.

Deliverable/ Product	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method	Measurement and Texture Spectral Analysis of Pavement Surface Profiles Using a Linear Stationary Laser Profiler (SLP)	Completed 9/30/2012	Completed 6/30/2013	UWM	Roohi	Complete, FHWA decided not to pursue draft standard.
Model	HMA Thermal Stresses in Pavement	3/31/2014		UNR	Hajj	Detailed in Report I
Software	Dynamic Model for Flexible Pavements 3D-Move	3/31/2014		UNR	Hajj Siddharthan	Detailed in Report J
Model & Test Method	Improved Oxygen and Thermal Transport Model of Binder Oxidation in Pavements (Level 3)	5/31/2013	10/31/2013	TAMU	Glover	Part of Report B & Summary Report References to Dissertations and Journal Papers
Model & Test Method	Pavement Air Voids Size Distribution Model for use in an Oxygen and Thermal Transport Model of Binder Oxidation in Pavements (Level 3)	5/31/2013	10/31/2013	TAMU	Glover	Part of Report B & Summary Report References to Dissertations and Journal Papers
Model	Approaches to interpret MD simulation results and experimental data to quantify the composition and temperature dependence of free energy.	12/30/2013		URI	Greenfield	Detailed in Report S
Model and Software	Phase-Field Model of Asphalt Binder Fracture and COMSOL Code for Model	12/30/2013	3/31/2014	VT	Wang	Extension Requested Detailed in Report T
Software	PANDA Software (Pavement Analysis using a Nonlinear Damage Approach)	12/31/2013	6/20/2014	TAMU	Sun-Myung Kim	

REPORTS

REPORT A0: ARC TAMU COMPREHENSIVE SUMMARY REPORT

Status: Draft delivery date October 31, 2013.

REPORT A: SUMMARY REPORT ON MOISTURE DAMAGE

Status: The report is completed and submitted to FHWA for review.

REPORT B: CHARACTERIZATION OF FATIGUE DAMAGE AND RELEVANT PROPERTIES

Status: The report is completed and submitted to FHWA for review.

REPORT C: PAVEMENT ANALYSIS USING A NONLINEAR DAMAGE APPROACH (PANDA)

Status: The report is completed and submitted to FHWA for review.

The main progress of this quarter can be outlined as follows:

- **PANDA report**

The PANDA report was completed and submitted to FHWA during this quarter. The testing protocol for calibration of PANDA constitutive relationships was also submitted to FHWA during this quarter. The focus of the current and next quarter will be on finalizing the PANDA chapter in the comprehensive summary report.

- **Development of PUI and PPI**

During this quarter, ARC team continued to enhance the PANDA Parameter Identifier (PPI) package by implementing the procedure for identification of parameters associated with the hardening-relaxation constitutive relationship. Refinement and enhancement of PPI will be the focus of the current and the next quarter.

- **Further validation of PANDA**

During this quarter, PANDA was further validated against ARC test results and the test results conducted at Waterways Experiment Station. ARC test results were used to further validate the aging and fatigue damage constitutive relationships. Waterway Experiment Station data were used to further validate the viscoplastic and hardening-relaxation constitutive relationships.

The focus of the next quarter will be on further calibration and validation of PANDA against ARC test results as well as the other available and on-going experimental data (Waterways Experiment Station data, ARC lab experiments on selected asphalt mixtures, and Ohio test sections) and previously collected data from the Accelerated Loading Facility at Turner-Fairbanks, the Nottingham facility at Nottingham University.

The effect of realistic tire contact stresses will also be incorporated in PANDA for more accurate analysis of pavement structures. Dr. Imad Al-Qadi from University of Illinois-Urban is helping in this task through predicting the contact pressures from different types of tires at different temperatures. Those predictions will be used as inputs into the realistic rutting and fatigue damage simulations using PANDA. This work is still undergoing and will be the focus of the next quarter.

- **Development of extrapolation techniques for performance predictions and auditing constitutive relationships of PANDA**

The ARC researchers have been collaborating closely with Dr. David Allen, a retired professor and former dean of engineering at the University of Nebraska at Lincoln who is well-known in the fields of constitutive modeling and mechanics, to audit the constitutive relations implemented in PANDA. Because of his extensive experience with Schapery's non-linear viscoelastic and viscoplastic models and computational modeling of asphalt and composites, we have asked Dr. Allen to critically examine the constitutive relations implemented in PANDA and provide us with the areas that may need more refinements and enhancements.

The focus of this quarter was on development of an extrapolation technique to predict rutting performance of pavements. The focus of the current and next quarter will also be on development of extrapolation techniques to predict rutting and fatigue damage performance of pavements subjected to large number of loading cycles. This task is conducted jointly by the ARC researchers and Dr. David Allen. The basis of the extrapolation technique has been developed during this quarter. Enhancement, refinement, and implementation of these extrapolation techniques will be the focus of future efforts.

We will focus our future efforts on the following subjects:

- Enhancement and refinement of PUI and PPI packages.
- Further validation of PANDA against ARC data, Waterways Experiment Station data, and Ohio test sections.
- Incorporation of realistic tire contact stresses in PANDA.
- Enhancement, refinement, and implementation of extrapolation techniques for performance simulations.

REPORT D: CHARACTERIZATION OF ASPHALT BINDERS USING ATOMIC FORCE MICROSCOPY

Status: The report is completed and submitted to FHWA for review. The work described below is beyond the scope of the plan of study but recent success in this area has provided the motivation to continue this work. The ARC report D, previously submitted will be augmented, or supplemented, by this work.

Main progress achieved during this quarter and focus of future work

Analysis of the impact of loading on the microstructural changes within the binder has been initiated. A micro loading device has been developed which is able to precisely apply a desired amount of strain. In order to test bulk binder specimens as opposed to thin films a new specimen making protocol has been developed. Asphalt binders are now being tested before and after load is applied using AFM imaging. This work may lead to a better understanding of damage mechanisms within the asphalt binder. Close examination of various phases present within the asphalt binder before and after leading will lead help decipher the processes occurring during the application of tensile loading.

Preliminary results suggest that as tensile load is applied incrementally phase separation occurs. Typical phase separation seems to occur around the bee/bee enclosure phases. Some early signs of fracture have also been noted (shown in figure 1 below). Observations suggest that the hypothesis of Kringos et al is supported here. This hypothesis suggests that a weak interstitial zone exists between the bee enclosure phase and the surrounding continuous phase. Further, as load is applied phase separation/damage occurs in this region at the nano/micro scale leading to the degradation of material properties at the macro scale.

Image analysis of specimens before and after the application of load conclusively suggests occurrence of changes within the microstructure of the examined AAD binder samples (see figure 1 below). Geometrical parameters such as feature count, total area of features, average size of features, %area of features etc. have been analyzed using ImageJ image analysis software.

The work above is being repeated for different types of SHRP and ARC binders. Statistical analysis of distribution of measurements are also being completed. A correlation between the data obtained through the above mentioned stress testing and Force-distance curves obtained through the Atomic Force Microscopy is being established. Further indentation experiments are also being completed in order to obtain micromechanical properties for validation of observations made during the stress testing experiment described above.

Separate conference presentations at the 2nd International Transportation PhD Student Symposium, and at the Peterson Conference have been given. A journal publication with the work described is currently being prepared.

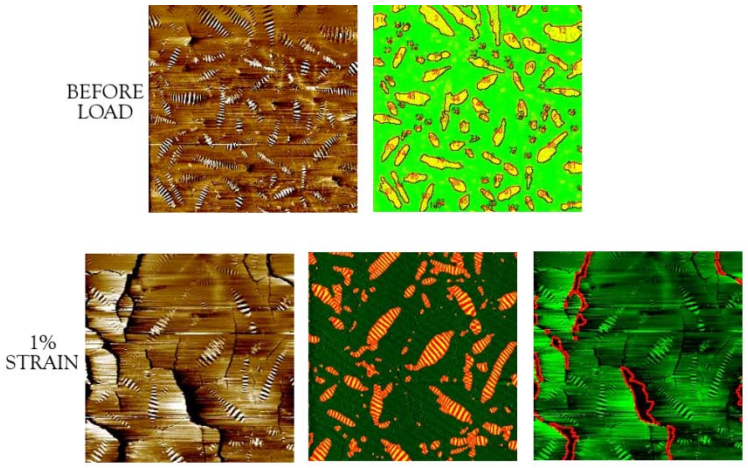

Figure 1. Image analysis highlighting the presence of multiple phases before and after application of 1% tensile strain.

REPORT E: MULTISCALE VIRTUAL FABRICATION AND LATTICE MODELING.

Status: The report is completed and submitted to FHWA for review.

REPORT F: MICROSTRUCTURE COHESIVE ZONE MODELING FOR MOISTURE DAMAGE AND FATIGUE CRACKING

Status: The report is completed and submitted to FHWA for review.

REPORT G: DESIGN SYSTEM FOR HMA CONTAINING A HIGH PERCENTAGE OF RAP MATERIAL

Included Work Elements/Subtasks
Work Element E2b: Design System for HMA Containing a High Percentage of RAP Materials

Status and Work Planned
On Schedule.

The following list describes the work items completed this quarter:

- Finalized the fractionation percentage of the RAP to be used in the mixture design.
- Determined the retained percentage of RAP material on each sieve to obtain precise estimation of the extracted RAP aggregate gradations.
- Determined the specific gravity of virgin aggregate and extracted RAP aggregate.
- Finalized sieving of the required amount of RAP and original aggregates.
- Finalized mixture design with 30% RAP.
- Started phase I of the DP work plan which includes studying the rutting resistance of lab-produced RAP mixtures with several dust-to-binder proportions (1.0, 1.5, and 2.0%). Based on the results from phase I, potential factors will be included in phase II which will investigate the effect of dust-to-binder on fatigue life and endurance limit of RAP HMA mixtures.
- Completed the fatigue endurance limit literature review including the major driving factors as well as obtaining and analyzing fatigue results generated from tension-compression uniaxial fatigue testing.
- Completed a literature review regarding fractionation procedures.

The following list the work planned for next quarter:

- Finalize phase I of the DP work plan including testing 18 specimens using RLT.
- Conduct a calibration and verification study on the newly acquired beam fatigue equipment.
- Start Phase II of the study including testing beam fatigue specimens at several factors against the DP levels.
- Identify field produced mixtures with several RAP contents.

REPORT H: CRITICALLY DESIGNED HMA MIXTURES

Included Work Elements/Subtasks
Work Element E2c: Critically Designed HMA Mixtures

Status and Work Planned
Behind Schedule. The report is currently undergoing a final internal review. The delivery date was revised in the Table of ARC deliverables.

The following list describes the work items completed this quarter:

- Finalized Report H.
- Presented the validation of the mechanistic-based approach during the FHWA Asphalt Mixture ETG meeting in Fall River, MA.
- Prepared and submitted a technical paper for presentation at the TRB 93rd annual meeting. The paper got accepted for presentation.

The following list the work planned for next quarter:

- Submit a draft version of Report H to FHWA for review and input.

REPORT I: THERMAL CRACKING RESISTANT MIXTURES

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

Status and Work Planned
Behind Schedule. Report I-A was completed: "STUDY OF PAVEMENT TEMPERATURE RATES IN HMA LAYERS," to avoid a hugely large comprehensive Report I. The report summarizes the investigation completed on the pavement temperature rates to assess whether any differences exist between inside and outside intermountain regions. Temperature profiles for fifteen LTPP sections as well as three sections from the accelerated test track facility "WesTrack" were evaluated. The delivery date for Report I is revised accordingly.

The following list describes the work items completed this quarter:

- Developed a stand alone pavement temperature profile prediction software.
- Analysis of the results of UTSST test on the Minnesota field validation samples were conducted and plan for further testing is under development.
- The UTSST testing of the Nevada field validation samples is completed. The analysis of the results is underway.
- Evaluation of the Core materials is also underway. All of the binder aging and associated rheological measures have been completed, with the accompanying Fourier Transform Infrared (FTIR) testing well under way.
- Continued the validation of asphalt binder aging model in free atmospheric condition and in the mixture.
- The UTSST measurements of the laboratory aged specimens have been completed. The evolution of thermo-viscoelastic properties with aging was evaluated and has been submitted in a paper that has been accepted for presentation in the coming Transportation Research Board 93rd annual meeting.
- The outline of the E2d report on thermal cracking resistant mixtures is set and writing is underway by UNR and UWM.
- Development of the thermal cracking analysis package (TCAP) software is underway.

The following list the work planned for next quarter:

- Complete the Core binder testing.
- Continue working on the subroutines for thermal cracking analysis package.
- Continue writing of Report I.

REPORT J: PAVEMENT RESPONSE MODEL TO DYNAMIC LOADS 3D-MOVE

Included Work Elements/Subtasks
Work Element VP3a: Pavement Response Model to Dynamic Loads

Status and Work Planned
Behind Schedule. The date is revised to reflect the delay in Report J.

The work on the report resumed this quarter and it is 30% complete. Because of the issues faced with Ver. 2 and based on users feedback a new platform for next 3D-Move version (Ver. 3) is currently under development. It is envisioned that the new platform of the next version of 3D-Move (Ver. 3) will include the following features:

- Capability of running two or more projects simultaneously by using parallel processing technology (70% progress);
- Incorporation of additional empirical procedures that are available to calculate asphalt dynamic modulus (10 % progress);
- Interchangeability between SI and US unit systems, in the middle of a 3D-Move run (40% progress);
- Use of Artificial Neural Network in the interpolation of non-uniform tire contact pressure distribution from the database (70 % progress);
- Inclusion of additional options for output in PDF and Crystal Report formats (Not started yet).

The following is a list work elements planned for next quarter:

- Continue work on Final Report and the 3D-Move documentation;
- Work on the new platform for next version of 3D-Move (Ver. 3).

REPORT K: DEVELOPMENT OF MATERIALS DATABASE

Included Work Elements/Subtasks
Work Element TT1d: Development of Materials Database

Status and Work Planned
Behind Schedule.

The following list summarizes the work items completed or in progress this quarter. Note that many of these complete items were action items from the ARC training presentation at the FHWA during September 2013:

1. FHWA Turner Fairbanks Highway Research Center (TFHRC) meeting: Members from the ARC and FHWA met at Turner Fairbanks on 9/11 and 9/12 for the purposes of demonstrating the ARC database to the FHWA and obtaining feedback about the system and its usability. Many of the work items completed this quarter were action items identified at this meeting.

2. File upload system status report: No additional problems have been reported related to the File System Upload system following the numerous fixes made last quarter. The following table summarizes the file upload activity during this quarter and for the life of the project. This table was created using the new ListReportCounts.aspx form (discussed in the next section). Table 1 shows the total number of reports uploaded to the ARC system to date.

Table 1. Total reports uploaded.

fldOrgDesc	fldLastName	fldUserName	FileCount
Ohio University	Scheer	ms307106	508
Texas A&M University	Ashouri	ashouri	380
Texas A&M University	Darabi	darabi	3
Texas A&M University	Karki	karki	10
Texas A&M University	Luo	slair	84
Texas A&M University	tong	tongyunwei	131
Texas A&M University	Zhang	zhang	112
University of Illinois	Hernandez	hrnndzr2	419
University of Nevada, Reno	Chamoun	zchamoun	514
University of Nevada, Reno	Ekedahl	ekedahl	64
University of Nevada, Reno	Hajj	elieh	1159
University of Nevada, Reno	Morian	morian	8
University of Wisconsin-Madison	Rajaei	mrajaei	1006
University of Wisconsin-Madison	Tabatabaee	tabatabaee	32
Western Research Institute	Harnsberger	mharnsberger	1522

3. Report count list (FHWA TFHRC meeting action item): In order to determine the volume of data uploaded to the ARC system, a new form was created named **ListReportCounts.aspx** and is accessible from the menu path **Admin Functions / Lists / List Report Counts.** These summary statistics were requested by Eric Weaver and others so as to determine the support files

uploaded and the relative completion of the ARC project. The report counts listed in the preceding section were created using this new form.

- Reports selected can be restricted to those that were uploaded between a date range or selected using all dates. At this time, only one range of dates can be selected.
- To meet suggested usability requirements, the SQL used to generate the table can be optionally displayed. SQL availability is being made through the user interface to help users create and execute custom queries, if necessary.

The remaining filters are designed to improve data quality, allowing data reviewers to see the volume of data having appropriate metadata and the state of data as it moves through the review process.

- Reports selected can be restricted to those which are approved or not approved. In addition, all approval levels can be selected.
- Reports can be selected based on whether a material has been assigned and/or whether a work item has been assigned.
- Once the reports are selected, they are aggregated. Reports can be aggregated by organization, user, or the month and year that the report was uploaded. Any of the above options can be used for aggregation.

Note that the development team is considering listing the actual reports in addition to the aggregated summary. This way reports without material assignments or work task assignments can be easily identified and the appropriate metadata attached to the report.
Another form might need to be developed to more thoroughly summarize measure data collected. At this time total measures can be displayed using the ListRecordCounts form. Figure 1 shows the input section of the new List Report Counts form. The form uses a sequence of steps and sub-steps to select the data.

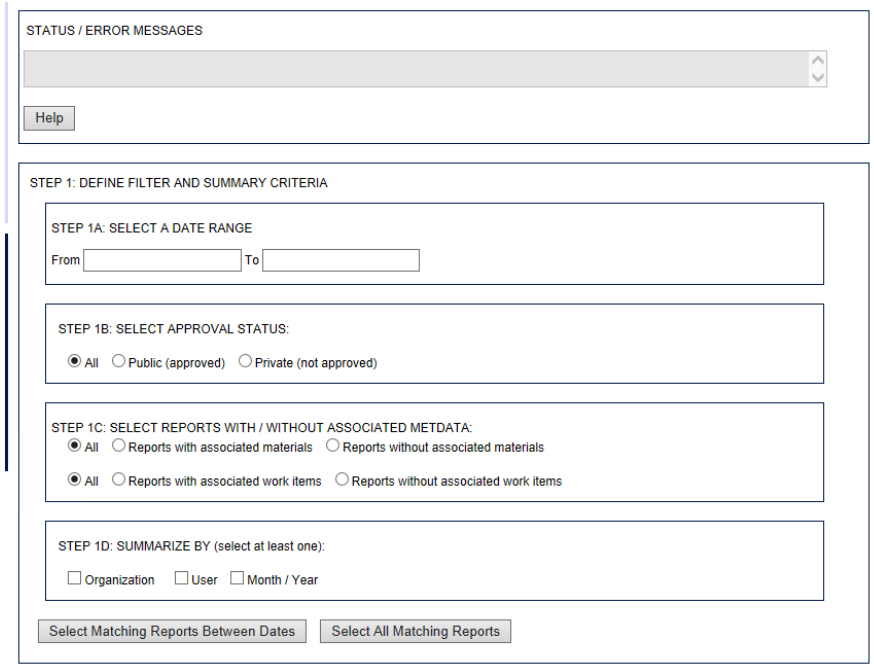

Figure 1. List Report Counts form – input section.

4. Data Dictionary list (FHWA TFHRC meeting action item): To meet FHWA requirements, Eric Weaver requested that a data dictionary be generated comparable to the data dictionary created for the LTPP database. The ARC data dictionary is built-in to the database itself utilizing Microsoft SQL Server descriptive fields and metadata. So that the data dictionary will always be current, an SQL stored procedure was created to retrieve this metadata and render it in a tabular form. The Data Dictionary document and these table results will form the basis of the Data Dictionary segment of the ARC final report. Per Eric Weaver, the SQL needed to extract the data dictionary into a suitable form should be included in final reports.

- The developed SQL stored procedure for generating the data dictionary report uses Transact-SQL (Microsoft SQL Server) INFORMATION_SCHEMA objects to retrieve columnar metadata. (Note that Microsoft's INFORMATION_SCHEMA complies with the ISO INFORMATION_SCHEMA standard).
- Microsoft SQL Server specific metadata is retrieved from the "sys" database to retrieve metadata specific to Microsoft SQL Server.
- Currently the SQL implemented as a stored procedure named DataDictionary.
- A more detailed discussion of the data dictionary will appear in the ARC final report.

The form named **DataDictionary.aspx** is accessible from the menu path **Admin Functions / Lists / Data Dictionary List.** The form contains buttons that will display the data dictionary as a grid or export the grid to an Excel *.csv file. For this first implementation, the following dictionary data points are listed. Note also that a help file was created for this form.

- **DatabaseName**: The database name known by the Microsoft SQL Server instance. It is possible that the ARC system might be used to operate with multiple SQL Server database.
- **Schema:** The schema name known by the SQL Server instance.
- **TableName**: The table name within the database. All ARC defined tables begin with the name "tbl". SQL Server related tables begin with the prefix "sys.
- **ColumnName**: The column name within the table. All ARC defined columns begin with the name "fld".
- **Position**: The 1-based position of the column within the database table.
- **OBJECT_ID**: This is an internal object used by SQL Server to identify a database table. It is used here to reference the SQL Server extended properties and thereby retrieve the column description for each field.
- **Column_ID:** Unique column identifier.
- **Value**: The extended column description. It is this column description that accurately describes the columns purpose within the ARC system.
- **DefaultValue**: When a record is inserted into the database, a default value can be inserted if a specific value is not inserted. Presently, the ARC does not ordinarily use default files.
- **Nullable**: A Boolean indicator to identify whether the field is nullable or not. Nullable fields are optional and can store a null value implying that the value does not exist. Some fields are not nullable such as those used as a primary key.
- **DataType**: The Microsoft SQL Server data type of the field.
- **MaximumLength**: For strings, the maximum length of the string. A MaximumLength of -1 for string data types implies the maximum length for the underlying data type or an

undefined maximum length. This value is inferred for numeric data types based on the number of bytes requires to store the value.

- **Precision**: For SQL Server numeric data types, precision is the maximum number of digits in a number.
- **Scale**: For SQL Server numeric data types, scale is the maximum number of digits to the right of the decimal point.
- **Identity**: Identify fields are used for primary keys and provide automatic counters for those keys. The ARC database uses identify fields extensively for primary keys.

As the ARC database does not use fixed columns for material properties and property dimensions, the Data Dictionary (internal tables) do not fully convey the end-user semantics. Thus, the following reports have been developed to express material and property relationships.

- The form **PropReport.aspx** accessible from the menu path **Properties / Lists / List of Properties** displays this report**.** This form was enhanced to optionally display the SQL again allowing for possible user modification of queries.
- The form **MaterialReport.aspx** accessible from the menu path **Materials / Lists / List of Materials.** This form was enhanced to optionally display the SQL again allowing for possible user modification of queries.
- *Note that these reports might require additional enhancements so as to display the actual values of multi-factor (dimensional) properties and the possible valid values for qualitative properties.*

5. Batch status sort order (TFHRC meeting action item): To improve data entry usability, the ARC users suggested creating a sort order for the descriptive field corresponding to a batch status so that the item order appearing in drop-down boxes follows the order of the data entry and approval process. A sort order field was added to the batch status table (tblBatchStatus) and the user interface was modified accordingly. The following forms were modified in order to display the batch status drop-downs based on a user-defined sequence:

- BatchStatus.aspx - added fldOrder to handle sorting.
- The forms named BatchViewer.aspx, FileUpload.aspx, and the user control named ucBatchSelector were modified to use the new ordered batch selector.
- Other forms will be modified as necessary.

6. New file download form and measure viewer: The original file download form has been replaced with an entirely new version, built from reusable controls. This new form follows the user interface pattern of a well-defined step sequence, whereas the old form did not. *Note: there are a couple of known bugs in this first implementation of the selectors.* The new form offers a stepwise user interface. It also includes additional filters and filter combinations (e.g. **approval status**; **user(s)**; **organization(s)**; **property group**; **material**; **file type**; **Work elements**; **keyword**; **date range**;

Note that there is a known bug in the file type display causing blank descriptions to appear. The development team is also considering the development of a freetext search for data in the report description field. Also note that the old file download form still exists but further maintenance on this form will not be performed.

Work continues on the new measure viewer. The same controls used on the file download form will be used to select connected measures.

7. Data compliance report draft: Last quarter, work began on a report addressing how the ARC database complies with the Federal Data Quality Act. The DQA report for the LTPP database was sourced as a foundation for this document. Consortium members were polled and responses gathered from the questionnaire appearing in last quarter's report. A draft of the data compliance act report has been completed. This draft has been placed on the ARC database Web site for review and comments. At this point, there are missing data items for some institutions.
*The draft report can be accessed from the **Tutorials menu** on the ARC web site.*

8. Batch File Upload System: Most of the development occurred last quarter for a system to upload significant numbers of files, and very large files. This feature was initially requested by Texas A&M. The following list summarizes the characteristics of this subsystem:

- A physical media device (DVD, external USB drive, or other device) is designed to be connected directly to the Web server or immediate network. The physical media device contains a file system whose files will be copied to the ARC file system based on a configuration file.
- A .csv file is used as a configuration file used by the application to process the physical media contents.
- An application, that when run, will verify the configuration file against the media provided and the ARC file system. If all entries are valid, the physical media files will be copied into the ARC file system and all database links updated accordingly.

Minor improvements were made to the system last quarter. In September, the first files were received from Texas A&M along with the corresponding configuration file.

- The original template was designed such that the requestor would select a relative output folder in addition to the input folder. The application is being modified to mirror the input and output folder structures when no output folder is specified.
- Currently, no batch has been specified in the template file. The program is being modified to allow the user to select a batch from the manual input system.
- Work elements are listed in the input file as a semicolon separated list. The nomenclature might need to be modified for accuracy.
- Mentioned in the previous quarter, the template provided by Texas A&M did not account for material associations or task assignment associations. Work element associations have been provided but there are no material assignments. This is likely due to the nature of the data and will not pose a problem.
- Mentioned in the previous quarter, material file extensions must be changed in the template file from the file extension name to the actual Association ID because many file types share the same file extension.

We expect to have read at least the first file set this quarter and the others will follow. Processing subsequent batch requests will be trivial so long as the template has the same structure.

9. Role System: Last quarter, work started on the role management subsystem to refactor roles as plans are made to potentially use the ARC database beyond the ARC project and ARC

consortium. As part of this effort, several more granular roles were added and system conversion is underway to fully utilize these new roles. System code is being updated, as necessary to support these roles and existing users are being migrated to the new roles. These changes should be transparent to the end users.

10. Miscellaneous Improvements: During the FHWA meeting, members commented that the menu system was hard to read because of minimal contrast. The menu colors were changed accordingly. Form revision continues to improve formatting consistency between applications.

The following list summarizes the work planned for next quarter.

- Implementation has started on a timeout warning. This request was made at the ARC FHWA TFHRC meeting in September.
- Create a protocol/documentation for adding users and maintaining user roles. This task will be completed this quarter as part of the creation of the ARC final report.
- In some cases, the request was made to make record descriptions searchable. The development team will add a description search on a table by table basis, based on the number of table records.
- From the ARC FHWA TFHRC meeting, it was suggested to add a redundancy check for material types.
- Create a permanent test bed for ARC FHWA. This task is almost complete and will be finished by 10/30/2013.
- Create tutorials for commonly performed tasks. This will be part of the ARC final report. Tutorials will be created this quarter.
- Create draft final ARC project report. The draft was not created this quarter in favor of completing the FHWA fix requests.
- Complete batch upload of data from Texas A&M.
- Finalize DQA report draft.
- Continue user interface enhancements.

REPORT L: DEVELOPMENT AND VALIDATION OF THE BITUMEN BOND STRENGTH TEST (BBS)

Included Work Elements/Subtasks
Work Element M1a: Affinity of Asphalt to Aggregate

Status and Work Planned
Complete

Work Completed: Completed revisions to draft final report and Tech Brief. Summarized response to reviewer comments. Three new sections related to applications of the BBS to mastics, evaluation of WMA, and emulsions were added. In addition the most recent version of AASHTO TP-91 was included as an appendix. Report, Tech Brief, Picture Descriptions, and Section 508 Descriptions to FHWA 10/30/2013.

Work Planned: Address editorial review comments from FHWA as needed.

Revised Delivery Dates
Draft Report: 10/30/11 (Submitted)
Final Report: 10/30/2013 (Revised – Extended from 6/30/2012, 9/30/2012, 3/30/2013, 6/30/2013, 9/30/2013)

REPORT M: DEVELOPMENT OF TEST PROCEDURES FOR CHARACTERIZATION OF ASPHALT BINDER FATIGUE AND HEALING

Included Work Elements/Subtasks
Work Element F1d: Healing
Subtask F1d-6: Evaluate Relationship Between Healing and Endurance Limit of Asphalt Binders
Work Element F2a: Binder Tests and Effect of Composition
Work Element F2e: Verification of the Relationship Between DSR Binder Fatigue Tests and Mixture Fatigue Performance

Status and Work Planned
Complete

Work Completed: Addressed peer review comments and submitted final report. Four new sections were added 1) Binder fracture and crack propagation during test, 2) Overview of modifications made to LAS procedure, 3) LAS ruggedness testing results, 4) Healing Analysis Procedure based on Diffusion

Work Planned: Submit revised Section 508 Descriptions, Image Descriptions, and Tech Brief.

Revised Delivery Dates
Draft Report: 10/31/11 (Submitted)
Final Report: 10/31/13 (Submitted)

REPORT N: GUIDELINES FOR SELECTION OF MODIFICATION TECHNIQUES

Included Work Elements/Subtasks
Work Element E2a: Comparison of Modification Techniques
Work Element E3a: Effect of Extenders (such as Sulfur) and Alternative Binders (such as Bio-Binders) on Mixture Performance

Status and Work Planned
Behind Schedule (Submission of Draft Final Report)

Work Completed: Completed evaluation of extenders on binder performance properties and mixture design factors. Chemical evaluation was also conducted and completed for the oils extenders and the modified binders. A technical paper was prepared and submitted to TRB based on the summary of results.

Work Planned: Complete analysis of data and submit draft final report and associated documents by 12/31/2013.

Delivery Dates
Draft Report: 12/31/2013, (revised from 9/30/2013)
Final Report: 3/31/2014

REPORT O: CHARACTERIZATION OF BINDER DAMAGE RESISTANCE TO RUTTING

Included Work Elements/Subtasks
Work Element E1b: Binder Damage Resistance Characterization (DRC)
Subtask E1b-1: Rutting of Asphalt Binders
Subtask E1b-2: Feasibility of Determining Rheological and Fracture Properties of Asphalt Binders and Mastics Using Simple Indentation Tests
Work Element V3f: Validation of the AASHTO MP-19 Specifications and Improvements of the TP-70 Procedure

Status and Work Planned
On Schedule

Work Completed: Submitted draft final report.

Work Planned: Complete Section 508 formatting, Image Descriptions, and Tech Brief. Submit to FHWA.

Delivery Dates
Draft Report: 9/30/2013 (Completed), extended from 6/30/2013
Final Report: 12/31/2013

REPORT P: QUANTIFYING THE IMPACTS OF WARM MIX ASPHALT ON CONSTRUCTABILITY AND PERFORMANCE

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
Subtask E1c-1: Warm Mixes

Status and Work Planned
Behind Schedule

Work Completed: Presented concept of selecting compaction temperatures based on mastic viscosity was presented to the Mix ETG September 2013 and received feedback. Completed work on developing the relationship between quality of coating as measured by the boiling test and moisture damage in mixtures. As a result, new procedures for selection of both mixing and compaction temperatures have been developed. It is anticipated that these concepts apply to both HMA and WMA.

Work Planned: Revise previously completed chapters on mixing and compaction temperatures based on new findings and ETG comments. Continue work on the draft final report and associated documents. Coordinate with UNR and submit draft final report at the end of the quarter.

Reason for Delay: Additional time is requested to incorporate recent findings into the report and to prepare the associated documents (i.e. Tech Brief, 508 formatting, Figure Descriptions).

Delivery Dates
Draft Report: 12/31/2013 – extended from 9/30/2013, 3/31/2013
Final Report: 3/31/2014 – extended from 10/31/2013, 12/31/2013

REPORT Q: IMPROVEMENT OF EMULSION CHARACTERIZATION AND MIXTURE DESIGN FOR COLD BITUMEN APPLICATIONS

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
Subtask E1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications
Work Element E3b: Development of PG Specification for Emulsions used in Surface Treatments, Cold Mixes, and Cold-In-Place Recycled Mixes

Status and Work Planned
Behind Schedule

Work Completed: Completed study on the effects of cement on volumetric and moisture damage resistance. Summarized preliminary mixture design procedure in a paper and submitted to TRB. Paper was accepted for presentation and publication. Preliminary design procedure includes use of the CMA coating test and curing procedures developed as part of this work element.

Work continues collecting fresh emulsion and residue performance properties. An application based framework for selecting emulsions was presented at the WRI P3 Symposium and summarized in a TRB Synthesis publication. In regards to field validation, work continues by WRI on sampling emulsion residues from the field after 4 years in-service and characterizing their chemical properties and rheological properties using the 4mm Parallel Plate geometry in the DSR.

Work Planned: Finalize mixture design procedure and design experiment for performance evaluation of CMA. Candidate tests include: Flow Number, Dynamic Modulus, and Moisture Resistance (TSR). Testing of recovered and PAV aged residue properties of emulsions used in various applications, including both preservation and cold mix will continue. Validation activities will continue in cooperation with NCAT and WRI. Final report preparation will continue.

Reasons for Delay
More time is requested to include preliminary results from field validation sections, finalize CMA mix design procedure, and to conduct performance evaluation for submission of the final report.

Delivery Dates
Draft Report: 3/31/2014, from 9/30/2013, 12/31/2013
Final Report: 6/30/2014, from 3/31/2014

REPORT R: STUDIES ON TIRE-PAVEMENT NOISE AND SKID RESPONSE

Included Work Elements/Subtasks
Work Element VP2a: Mixture Design to Enhance Safety and Reduce Noise of HMA

Status and Work Planned
Complete.

Work Completed: Reviewer comments were addressed and final report was submitted to FHWA.

Work Planned: Address FHWA editorial comments as needed.

Delivery Dates
Draft Report: 12/31/2011 (Submitted)
Final Report: 7/30/2013 (Submitted)

REPORT S: MOLECULAR DYNAMICS RESULTS FOR MULTIPLE ASPHALT CHEMISTRIES

This report can be delivered in non-508 format. A section 508 format report could be written if LaTeX notation format for equations provides sufficient clarity to visually impaired readers and if having only a small number of graphs can be deemed acceptable. The solution for describing complex organic chemistry molecules to visually impaired readers is unclear at this time.

Included Work Elements/Subtasks

Subtask F3a-1: *ab initio* Theories, Molecular Mechanics/Dynamics and Density Functional Theory Simulations of Asphalt Molecular Structure Interactions
- Sub-subtask F3a-1.1. Specify desired asphalt compositions and chemistries for testing multiscale asphalt modeling effort (large cluster simulations) (URI, WRI)
- Sub-subtask F3a-1.2. Develop algorithms and methods for directly linking molecular simulation outputs and phase field inputs (URI, NIST)
- Sub-subtask F3a-1.3. Obtain temperature-dependent dynamics results for model asphalts that represent asphalts of different crude oil sources (URI)
- Sub-subtask F3a-1.4. Simulate changes in asphalt dynamics after inducing representations of chemical and/or physical changes to a model asphalt (URI)

Subtask F3a-4. Overall integration for multiscale modeling (VT, URI, and WRI)
Subtask F3a-5. Experimental verification and validation (VT, URI, and WRI)

Status and Work Planned

Sub-subtask F3a-1.1. Specify desired asphalt compositions and chemistries for testing multiscale asphalt modeling effort (large cluster simulations) (URI, WRI)

On Schedule.

Compositions were identified in previous quarters. A peer-reviewed publication that disseminates new proposed compositions for AAA-1, AAK-1, and AAM-1 appeared on-line in the journal *Fuel* during the quarter after being accepted the day the quarter started. The article will appear in print in January 2014.

Sub-subtask F3a-1.3. Obtain temperature-dependent dynamics results for model asphalts that represent asphalts of different crude oil sources (URI)

Slight delay during the past quarter.

Results from molecular simulations of model asphalts continued to be analyzed to obtain physical insights. A manuscript was submitted to the *Journal of Chemical Physics* that quantified the raw dynamics results. Results from past quarters for filtered, smoothed molecular simulation predictions of $|G^*|$ and phase angle δ, had been calculated previously using stress results from that manuscript. Interpretations were finalized during the quarter, and submitting another manuscript that describes these complex modulus results was delayed due to Prof Greenfield's

teaching responsibilities. It will be submitted in the first month of the upcoming quarter. These efforts have focused on the new AAA-1, with results for other model asphalts set aside as the methods and understanding are refined.

Sub-subtask F3a-1.4. Simulate changes in asphalt dynamics after inducing representations of chemical and/or physical changes to a model asphalt (URI)

Delay during the past quarter.

Work to simulate additional asphalt systems continues to proceed more slowly than expected. Simulations have been initiated for multiple additional model asphalts using new compositions, though simulations at additional temperatures are required prior to full data analysis. The delay is a result of two factors. The main factor is the ongoing new teaching load assigned to the PI, which has slowed research progress significantly. Getting existing computer hardware operational and new computer hardware in place has also been impacted by the very large teaching load.

Sub-subtask F3a-1.2. Develop algorithms and methods for directly linking molecular simulation outputs and phase field inputs (URI)
Subtask F3a-4. Overall integration for multiscale modeling (VT, URI, and WRI)
Subtask F3a-5. Experimental verification and validation (VT, URI, and WRI)

Technical work – Delay during past quarter.

These Subtasks and Sub-subtasks constitute the ARC Model Deliverable for obtaining free energy from a molecular perspective. Developing models to interpret molecular simulations to parameterize free energy models is proceeding, as described above. The inputs for these calculations are the molecule positions, velocities, and stress fluctuations that are calculated in the detailed molecular simulations.

The Model Deliverable itself will be a detailed description of the steps that can be taken to set up a model asphalt system, to run a molecular simulation, and to interpret the quantitative results. Report S will focus especially on interpreting the peer-reviewed publications in the chemistry literature into language and concepts that are most familiar to the asphalt pavement research community. The report will include detailed descriptions of the simulation data that will be included within the ARC database.

Results from the sequence of molecular simulations, interpretations, correlations, interpolations, and extrapolations will be incorporated into Report S. This includes relationships between the simulation conditions and the energy. Report T, entitled “Progress Toward a Multi-scale Model of Asphalt Pavement- Including Test Methods for Model Input Parameters”, will be written primarily by Troy Pauli of WRI.

REPORT T: PROGRESS TOWARD A MULTI-SCALE MODEL OF ASPHALT PAVEMENT

Included work elements/subtasks
Sub-subtask F3a-1.5. Molecular mechanics simulations of asphalt-aggregate interfaces (VT)
Sub-subtask F3a-1.6. Modeling of fatigue behavior at atomic scale (VT)
Sub-subtask F3a-1.7. Modeling of moisture damage (VT)
Sub-subtask F3a-1.8. *ab initio* Calculations of Asphalt Molecular Structures and Correlation to Experimental Physico-Chemical Properties of SHRP Asphalts (WRI-TUDelft)

Formerly listed in Y3 Work Plan as:
Subtask F3a-2. Phase-Field Modeling of Asphalt Molecular Moieties
Sub-subtask F3a-2.1. Derive phase field model expressions for colloidal nano-emulsion phase separation thermo-kinetic processes (NIST)
Sub-subtask F3a-2.2. Derive phase field model expressions for wax crystallization thermo-kinetic processes (NIST)

Presently re-Titled as:
Subtask F3a-2. Multiscale modeling based on phase field method and MD simulation (VT)
Sub-subtask F3a-2.1 Multiscale modeling of single mode cracking (VT)
Sub-subtask F3a-2.2 The generalized J – integral in multiscale modeling (VT)
Sub-subtask F3a-2.3 Multiscale modeling of Phase separation (VT)
Sub-subtask F3a-2.4 Potential multiscale applications (VT)
Subtask F3a-3. Phase-Field and Continuum Mechanical (Finite Element) Modeling of Asphalt Binder, the Unified Chemo-Mechanical Model of Asphalt Binder
Subtask F3a-4. Overall integration for multiscale modeling (VT, URI, TUDelft and WRI)
Subtask F3a-5. Experimental verification and validation (VT, URI, TUDelft and WRI)

Status and Work Planned for WE F3a:
The writing of Report T is in progress with an anticipated draft completion date of Dec. 30, 2013. Elements of Report S will be reflected in the present report regarding Subtask F3a-1.

Status and Work Planned for Sub-subtasks F3a-1.5, 6 and 7:
On Schedule

Status and Work Planned for Sub-subtasks F3a-1.8:
Complete

Status and Work Planned for Subtask F3a-2:
On Schedule

At this moment, this research progress is on time according to the plan. Subtasks F3a 2.1-2.3 are completed. Work Element F3a-2.4 is ongoing with additional research planned for the next quarter.

Research on the single mode cracking by multiscale modeling combining phase field method and molecular dynamics simulation has been conducted. The bridging area for both approaches is in the crack tip. It is expected that the continuum Phase-field system will control the cracking process and MD simulation will dominate at the crack tip. The stress and strain from the phase field simulation will be used as the boundary condition in the MD simulation by LAMMPS (P → M) and then the MD simulation returns the elastic energy into the two-way coupled system (M → P).

If we want to expand the single mode cracking research to a general case, we need to figure out *J* – integral in the Multi-scale modeling. Since we have determined *J* – integral in Phase field system, the *J* - integral in MD simulation must also be obtained.

In the zero temperature equilibrium, the generalized Eshelby stress tensor is given as [Jones et al 2011]

$$\boldsymbol{b} = F\mathbf{I} - (\boldsymbol{\nabla}\mathbf{u})^{\mathrm{T}}\boldsymbol{P} \tag{F3a-2.3.1}$$

where F is the total free energy density, **I** is the identity tensor, **u** is the displacement field and $\boldsymbol{P}$ is the first Piola-Kirchhoff stress. *J*-integral is then calculated as the boundary integral of $\boldsymbol{b}$**.** Note that, in the zero temperature equilibrium, any material is brittle and thus all the "usable" free energy will be transformed to the surface energy of two newly created surfaces.

In order to obtain the free energy density, the corresponding Hamiltonian needs to be figured out. Considering the classical harmonic oscillator [Sethna 2006], the harmonic oscillator of mass *m* and frequency ω has the total Hamiltonian

$$\mathcal{H}(p,q) = \frac{p^2}{2m} + m\omega^2 q^2/2 \tag{F3a-2.3.2}$$

and the corresponding partition function is (using $\hbar = \frac{h}{2\pi}$)

$$Z = \int_{-\infty}^{+\infty} dq \int_{-\infty}^{+\infty} dp \, \frac{1}{h} e^{-\beta\left(\frac{p^2}{2m} + m\omega^2 \frac{q^2}{2}\right)} = \frac{1}{\beta\hbar\omega} \tag{F3a-2.3.3}$$

Considering

$$F = -k_B T ln Z \tag{F3a-2.3.4}$$

we get

$$F = k_B T log(\hbar\omega/k_B T) \tag{F3a-2.3.5}$$

which is the expression for the free energy density in equation (F3a-2.3.1). The first Piola-Kirchhoff stress will be determined in the next quarter.

Status and Work Planned for Subtask F3a-3:
Complete

Status and Work Planned for Subtask F3a-4 and F3a-5:
On Schedule

References

Jones, R. E., J. A. Zimmerman, J. Oswald and T. Belytschko, 2011, An atomistic J-integral at finite temperature based on Hardy estimates of continuum fields. *Journal of Physics: Condensed Matter*, Vol. 23, 015002.

Sethna, J. P., 2006, *Statistical Mechanics: Entropy, Order Parameters and Complexity*. Oxford University Press, USA.

REPORT U: DESIGN GUIDANCE FOR FATIGUE AND RUT RESISTANCE MIXTURES

Included Work Elements/Subtasks
Work Element E2e: Design Guidance for Fatigue and Rut Resistance Mixtures

Status and Work Planned
Behind Schedule

Work on the NTIS report continued this quarter. The revised delivery date for the NTIS report is December 31, 2013.

Work on the NTIS report will be completed.

REPORT V: CONTINUUM DAMAGE PERMANENT DEFORMATION ANALYSIS FOR ASPHALT MIXTURES

Status: The report is completed and submitted to FHWA for review.

REPORT W: CHARACTERIZATION OF FATIGUE AND HEALING PROPERTIES OF ASPHALT MIXTURES

Status: The report is completed and submitted to FHWA for review.

REPORT X: CHARACTERIZATION OF FIELD CORES OF ASPHALT PAVEMENTS

Status: The report is completed and submitted to FHWA for review.

REPORT Y: MODEL WATER VAPOR DIFFUSION IN PAVEMENT AND ITS EFFECTS ON THE PERFORMANCE OF ASPHALT MIXTURES

Status: The report is completed and submitted to FHWA for review.

REPORT Z: EFFECT OF EXTRACTION METHODS ON THE PROPERTIES OF AGGREGATES IN RECLAIMED ASPHALT PAVEMENT

Included Work Elements/Subtasks
Work Element TT1d: Development of Materials Database

Status and Work Planned
Completed.

Submitted the responses to the reviewers technical comments.

REPORT AA: LABORATORY ASSESSMENT OF ASPHALT MIXTURE LONG-TERM AGING

Included Work Elements/Subtasks
Work Element E3c: Laboratory Assessment of Asphalt Mixture Long-term Aging

Status and Work Planned
Behind Schedule

Work Completed:
Rheological tests using the DSR and BBR completed on a new base binder and additional filler types were added to test matrix based on previous findings. Chemical compositional tests were performed using FTIR and GPS procedures on the binders extracted from the aged mastics to determine effect of aggregate filler characteristic on long term aging properties. A collaboration meeting was held with WRI and a plan was made for additional comparative chemical tests to be conducted at WRI to confirm and extend current results and findings using other methods.

Work Planned:
Complete extended test matrix using the mechanical and chemical compositions tests to develop a model and test analysis methodology for assessing long term aging effects of aggregates on aging based on the filler characteristics. Work on draft report will begin in order to submit in accordance to the updated delivery date.

Delivery Dates
Draft Report: 3/31/2014, revised from 9/30/2013, 12/31/2013
Final Report: 6/30/2104

TEST METHODS

DRAFT AASHTO METHOD/PRACTICE: SIMPLIFIED CONTINUUM DAMAGE FATIGUE ANALYSIS FOR THE ASPHALT MIXTURE PERFORMANCE TESTER

Included Work Elements/Subtasks
Work Element E2e: Design Guidance for Fatigue and Rut Resistance Mixtures

Status and Work Planned
Behind schedule

The majority of the draft practice was completed this quarter; however, the draft practice has proven more difficult to finish that expected.

The draft practice will be completed next quarter. The revised delivery date for the draft practice is December 31, 2013.

TEST METHOD AND MODEL: CONTINUUM DAMAGE PERMANENT DEFORMATION ANALYSIS FOR ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element F2c: Mixture Testing Protocol (TAMU)
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Competed.

The Test Method and Model "Continuum Damage Permanent Deformation Analysis of Asphalt Mixtures" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report V "Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures" as an appendix.

TEST METHOD AND MODEL: CHARACTERIZATION OF FATIGUE AND HEALING PROPERTIES OF ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Completed.

The Test Method and Model "Characterization of Fatigue and Healing Properties of Asphalt Mixtures" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report W "Characterization of Fatigue and Healing Properties of Asphalt Mixtures" as an appendix.

TEST METHOD AND ANALYSIS PROGRAM: NONDESTRUCTIVE CHARACTERIZATION OF TENSILE VISCOELASTIC PROPERTIES OF UNDAMAGED ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element E1a: Analytical and Micro-Mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Completed.

The Test Method and Model "Nondestructive Characterization of Tensile Viscoelastic Properties of Undamaged Asphalt Mixtures" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report W "Characterization of Fatigue and Healing Properties of Asphalt Mixtures" as an appendix.

TEST METHOD AND MODEL: CHARACTERIZATION OF FIELD CORES OF ASPHALT PAVEMENTS

Included Work Elements/Subtasks
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Completed.

The Test Method and Model "Characterization of Field Cores of Asphalt Pavements" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report X "Characterization of Field Cores of Asphalt Pavements" as an appendix.

TEST METHOD AND ANALYSIS PROGRAM: NONDESTRUCTIVE CHARACTERIZATION OF ANISOTROPIC VISCOELASTIC PROPERTIES OF UNDAMAGED ASPHALT MIXTURES UNDER COMPRESSIVE LOADING

Included Work Elements/Subtasks
Work Element F2c: Mixture Testing Protocol (TAMU)
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Completed.

The Test Method and Analysis Program "Nondestructive Characterization of Anisotropic Viscoelastic Properties of Undamaged Asphalt Mixtures under Compressive Loading" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Model has been attached to and referenced in the Level 2 Report V "Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures" as an appendix.

DRAFT AASHTO PRACTICE: MIX DESIGN FOR COLD-IN-PLACE RECYCLING (CIR)

Included Work Elements/Subtasks
Work Element E1c-2: Improvement of Emulsion Characterization and Mixture Design for Cold Bitumen Applications

Status and Work Planned
Behind Schedule.

The following list describes the work items completed this quarter:

- Completed the forensic evaluation of Matterhorn Blvd CIR material.
- Started the characterization of RAP materials.
- Started the mix design using the proposed seven-step mix design method.

The following list describes the work planned for next quarter:

- Continue the RAP characterization.
- Perform the mix design using the proposed seven-step mix design method.
- Determine the moisture susceptibility of the designed CIR mixes.
- Sample preparation for the performance tests.

DRAFT AASHTO METHOD/PRACTICE: MIX DESIGN FOR COLD MIX ASPHALT

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
SubtaskE1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications
Subtask E1c2-Yr6-I: Protocol for Selecting Aggregates and Emulsions for CMA
Subtask E1c2-Yr6-II: Evaluation of CMA Laboratory Compaction Methods and Curing Conditions

Status and Work Planned
Behind Schedule

Work Completed: Preliminary mix design was completed and summarized in a paper submitted to TRB. Paper was accepted for presentation and publication. Completed evaluation of the effects of emulsion content, aggregate type, and the use of cement on moisture damage resistance and volumetrics.

Work Planned: Design study to finalize mix design procedure. Assess of sensitivity of mix design properties to CMA performance.

Reasons for Delay:
Submission of standard was extended to coincide with revised delivery date of draft final report.

Delivery Dates
Draft AASHTO Practice: 3/31/2014, from 9/30/2013
Final AASHTO Practice: 6/30/2014, from 3/31/2014

DRAFT AASHTO PRACTICE: EVALUATION OF RAP AGGREGATES

Included Work Elements/Subtasks
Work Element E2b: Design System for HMA Containing a High Percentage of RAP Materials
Subtask E2b-1: Develop a System to Evaluate the Properties of RAP Materials

Status and Work Planned
On Schedule.

The findings from the report entitled: "Effect of Extraction Methods on the Properties of Aggregates in Reclaimed Asphalt Pavement," were considered in the final recommendations of NCHRP 09-46 study completed by NCAT.

Responded to the reviewers technical comments on Report Z, "Effect of Extraction Methods on the Properties of Aggregates in Reclaimed Asphalt Pavement."

DRAFT AASHTO PRACTICE: IDENTIFICATION OF CRITICAL CONDITIONS FOR HMA MIXTURES

Included Work Elements/Subtasks
Work Element E2c: Critically Designed HMA Mixtures

Status and Work Planned
On schedule.

The draft version of the AASHTO Standard Practice entitled "Determining the Asphalt Mixture Critical Conditions for Rutting Evaluation by Means of Dynamic Repeated Load Triaxial Test (RLT)" has been submitted to FHWA and ETG for review and input.

DRAFT AASHTO METHOD: DETERMINING THERMAL CRACK PROPERTIES OF ASPHALT MIXTURES THROUGH MEASUREMENT OF THERMALLY INDUCED STRESS AND STRAIN

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States
Subtask E2d-3: Identify an Evaluation and Testing System

Status and Work Planned
On Schedule

The following list describes the work items completed this quarter:

- Evaluated the sensitivity of the UTSST test results to the amount of RAP, WMA technology, and cooling rate.
- Analysis of the UTSST results on the field validation samples and working on a plan for further testing.
- Testing the standard aluminum specimens to calibrate the UTSST.
- Working with a manufacturer/supplier company to modify its TSRST setup to meet the UTSST requirements.

The following list the work planned for next quarter:

- Revise and refine the UTSST AASHTO draft as need it.

DRAFT AASHTO METHOD/PRACTICE: DETERMINING ASPHALT BINDER BOND STRENGTH BY MEANS OF THE BITUMEN BOND STRENGTH TEST

Included Work Elements/Subtasks
Work Element M1a: Affinity of Asphalt to Aggregate

Status and Work Planned
Completed

Work Completed: Final version of AASHTO procedure was submitted to AASHTO and included in Final Report L.

Work Planned: None.

Delivery Dates
Revised Standard: 6/30/2013 (Complete)

DRAFT AASHTO TEST METHOD: MEASUREMENT OF ASPHALT BINDER ELASTIC RECOVERY IN THE DYNAMIC SHEAR RHEOMETER (DSR)

Included Work Elements/Subtasks
Work Element F2a: Binder Tests and Effect of Composition

Status and Work Planned
Completed

Work Completed: Product combined with BYET procedure. Please see BYET report for details.

Work Scheduled: Please see BYET report for details.

Delivery Dates
Completed, see BYET report for delivery dates.

AASHTO TEST METHOD: ESTIMATING FATIGUE RESISTANCE OF ASPHALT BINDERS USING THE LINEAR AMPLITUDE SWEEP

Included Work Elements/Subtasks
Work Element F2e: Verification of the Relationship between DSR Binder Fatigue Tests and Mixture Performance

Status and Work Planned
Complete

Work Completed: Ruggedness testing and modifications to the AASHTO procedure were complete. Update was presented to the FHWA Binder ETG in September, 2013. Revisions were detailed and justified in the final version of Report M.

Work Planned: Work item is considered complete. Any comments by AASHTO or ETG for implementation will be addressed.

Delivery Dates
Submit Revised Draft AASHTO Method to ETG: Completed.
Presentation at FHWA Binder ETG Meeting: 5/02/2013 (Complete).
Presentation at FHWA Binder ETG Meeting: 9/17/2013 (Complete).
Final AASHTO Method: 9/30/2013 (Complete), based on new findings and ETG comments (Extended from 6/30/2013).

AASHTO TEST METHOD: BINDER YIELD ENERGY TEST (BYET)

Included Work Elements/Subtasks
Work Element F2e: Verification of the Relationship between DSR Binder Fatigue Tests and Mixture Performance

Status and Work Planned
Completed.

Work Completed: Draft of combined ER-DSR and BYET procedures were submitted to the AASHTO SOM by FHWA for consideration in the August 2013 meeting.

Work Scheduled: Address AASHTO comments as necessary.

Delivery Dates
Draft AASHTO Method: 1/31/2013 (extended from 12/31/2012) – *Complete.*
Presentation at FHWA Binder ETG Meeting: 5/02/2013 – *Complete.*
Final AASHTO Method: 6/30/2013 – *Complete.*

DRAFT AASHTO TEST METHOD: MEASUREMENT OF RIGDEN VOIDS FOR MINERAL FILLERS

Included Work Elements/Subtasks
Work Element F2e: Verification of the Relationship between DSR Binder Fatigue Tests and Mixture Performance

Status and Work Planned
Completed

Work Completed: Draft standard was submitted to AASHTO SOM for consideration in August, 2013 meeting. Standard was also presented to FHWA Mixtures ETG in September 2013 meeting.

Work Planned: Address comments from AASHTO as needed.

Revised Delivery Dates
Draft AASHTO Method: Complete (1/31/2013).
Final AASHTO Method: Complete (9/30/2013).

DRAFT AASHTO TEST METHOD: MEASUREMENT OF ASPHALT BINDER LUBRICITY USING THE DYNAMIC SHEAR RHEOMETER (DSR)

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
Subtask E1c-1: Warm Mixes
Subtask E1c-1-Y6-I: Guideline for Determination of Mixing and Compaction Temperatures for Conventional HMA Mixes
Subtask E1c-1-Y6-II: Guideline for Determination of Acceptable WMA Production Temperatures

Status and Work Planned
Behind Schedule

Work Completed: Work on draft AASHTO standard continued. Additional testing to verify procedure was conducted.

Work Planned: Complete AASHTO standard and submit to FHWA. Standard will provide instruction for measuring lubricating properties of asphalt binders in both the hydrodynamic and boundary lubrication regimes.

Reasons for Delay: Deadline extended to coincide with submittal of draft final report.

Delivery Dates
Draft AASHTO Method: 12/31/2013 - from 6/30/2013, 3/31/2013, 9/30/2013
Final AASHTO Method: 3/31/2014 - from 9/30/2013, 12/31/2013

DRAFT AASHTO METHOD/PRACTICE: PROCEDURE FOR EVALUATION OF COATING FOR COLD MIX ASPHALT

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
SubtaskE1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications
Subtask E1c2-Yr6-I:Protocol for Selecting Aggregates and Emulsions for CMA

Status and Work Planned
On Schedule

Work Completed: Applied standard procedure to evaluate coating for CMA mix design and summarized results in a paper submitted to TRB. Paper was accepted for publication and presentation. No request from the ETG was made to review for the standard.

Work Planned: None, standard is considered complete. Address comments from FHWA/ETG as necessary.

Delivery Dates
Draft AASHTO Method: Completed 4/30/2013 – extended from 3/31/2013 and 12/31/2012
Presentation at FHWA Mixtures ETG Meeting (if necessary): N/A
Final AASHTO Standard: 9/30/2013 (Complete)

DRAFT AASHTO METHOD/PRACTICE: COLD MIX LABORATORY SPECIMEN PREPARATION USING MODIFIED SGC MOLDS

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
Subtask E1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications
Subtask E1c2-Yr6-II: Evaluation of CMA Laboratory Compaction Methods and Curing Conditions

Status and Work Planned
On Schedule

Work Completed: Submitted draft AASHTO procedure to FHWA for consideration. Procedure was also used to prepare samples detailed in a recently accepted TRB paper.

Work Planned: Address FHWA/ETG comments as necessary.

Delivery Dates
Draft AASHTO Method: 8/30/2013 (Complete) – extended from 6/30/2012, 12/31/2012
Final AASHTO Standard: 12/31/2013

DRAFT AASHTO TEST METHOD: RAP BINDER PG TRUE GRADE DETERMINATION

Included Work Elements/Subtasks
Work Element E2b: Design System for HMA Containing a High Percentage of RAP Materials

Status and Work Planned
Completed.

Work Completed: Based on a request from the FHWA Mixture ETG, the draft standard was presented to the Binder ETG at the September 2013 meetings. No further action items were established.

Work Planned: Address future comments from ETG/FHWA/AASHOT as necessary.

Delivery Dates
Draft AASHTO Test Method: Completed (9/30/2012).
Presentation at Mix ETG Meeting: Completed (4/30/2013).
Presentation at Binder ETG Meeting: Completed (9/20/2013).
Final AASHTO Test Method: Completed (6/30/2013).

AASHTO TEST METHOD: MEASUREMENT OF ASPHALT BINDER FRACTURE PROPERTIES USING THE SINGLE EDGED NOTCHED BENDING TEST

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

Status and Work Planned
Behind Schedule

Work Completed: Update regarding analysis procedure and test conditions were presented to the FHWA Binder ETG in the Sept. 2013 meeting.

Work Planned: No additional work is planned this task is considered complete. Will address additional comments from ETG/FHWA as needed.

Delivery Dates
Draft AASHTO Method: Completed (9/30/2012).
Presentation at Binder ETG Meeting: 5/2/2013 (Completed).
Presentation at Binder ETG Meeting (if necessary): 9/20/2013.
Final AASHTO Test Method: Completed (9/30/2013) (Extended from 6/30/2013).

DRAFT AASHTO TEST METHOD: TEST METHOD FOR MEASUREMENT OF THE GLASS TRANSITION TEMPERATURE OF ASPHALT BINDERS

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

Status and Work Planned
Completed

Work Completed: None, no request for presentation was made by FHWA Binder ETG. Draft standard and context document were completed last quarter.

Work Planned: Address comments from Binder ETG/AASHTO as necessary.

Delivery Dates
Draft AASHTO Test Method: Complete (1/31/2013) – extended from 12/31/2012.
Presentation to Binder ETG (if necessary): 9/20/2013.
Final AASHTO Test Method: 6/30/2013, revisions pending ETG review and comment.

DRAFT AASHTO TEST METHOD: TEST METHOD FOR MEASUREMENT OF THE GLASS TRANSITION TEMPERATURE OF ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

Status and Work Planned
Behind Schedule

Work Completed: Combined ATCA/UTSST test method was completed and submitted to Mix ETG by UNR.

Work Planned: None planned under this product. UNR team has taken the lead in obtaining approval of combined test procedure from Mixture ETG.

Revised Delivery Dates
Draft AASHTO Test Method: 4/30/2013 (Completed).
Presentation to Mix ETG: 5/2/2013 (Completed).
Final AASHTO Test Method: 6/30/2013 (Completed).

DRAFT AASHTO TEST METHOD/PRACTICE: ANALYSIS OF ASPHALT MIXTURE AGGREGATE STRUCTURE THROUGH USE OF PLANAR IMAGING
ARC MODELS AND/OR SOFTWARE: IMAGE PROCESSING AND ANALYSIS SYSTEM (IPAS^2)

Included Work Elements/Subtasks
Work Element E1b: Binder Damage Resistance Characterization (DRC)
SubtaskE1b-1: Rutting of Asphalt Binders

Status and Work Planned
On Schedule

Work Completed: Numerous publications relating aggregate structure to performance were drafted and submitted last quarter. No request was made by ETG for presentation in September meeting.

Work Planned: This item is considered complete, address comments from FHWA/ETG as necessary.

Delivery Dates
Draft AASHTO Method: 3/31/2013.
Presentation to Mix ETG (if necessary): 9/20/2013.
Final AASHTO Standard: 9/30/2013 (Complete).

DRAFT AASHTO METHOD/PRACTICE: DETERMINING THE RESISTIVE EFFORT OF ASPHALT MIXTURES DURING COMPACTION IN A GYRATORY COMPACTOR USING AN INTERNAL DEVICE

Included Work Elements/Subtasks
Work Element E1c: Warm and Cold Mixes
SubtaskE1c-1: Warm Mix Asphalt
Subtask E1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications

Status and Work Planned
Behind Schedule.

Work Completed: Work continued on addressing the comments from ASTM and development of the work plan for the ILS study. Equipment measurement and analysis software was evaluated and discussed with manufacturer.

Work Planned: Address ASTM comments and submit for review. Complete design of ILS study.

Reasons for Delay
Delays were encountered in receiving comments from ASTM, now that comments were received, work will resume to address them.

Delivery Dates
Draft ASTM Standard: Complete.
Finalize ASTM Standard to address comments and include P&B Statement: 12/31/2013 (extended from 6/30/2013, 9/30/2013).

TEST METHOD AND ANALYSIS PROGRAM: SELF-CONSISTENT MICROMECHANICS MODELS OF ASPHALT MIXTURES

Included Work Elements/Subtasks
Work Element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Status and Work Planned
Status: Completed.

The Test Method and Analysis Program "Self-Consistent Micromechanics Models of Asphalt Mixtures" has been completed by the Research Team and has been edited by the Research Editor of the Texas A&M Transportation Institute.

The edited Test Method and Analysis Program has been attached to and referenced in the Level 2 Report W "Characterization of Fatigue and Healing Properties of Asphalt Mixtures" as an appendix.

DRAFT AASHTO METHOD: A METHOD TO DETERMINE SURFACE ROUGHNESS OF AGGREGATE AND FINES BASED ON AFM

Included Work Elements/Subtasks
M1b-2: Work of Adhesion at Nano-Scale using AFM

Status and Work Planned
Progress on this work element involved the development of a method to analyze AFM surface contour data to remove low-frequency (saw-cut) roughness so that the micro-scale (higher-frequency) roughness is separated out. The technique, which allows for the determination of micro-scale roughness without extensive mechanical polishing of the sample surface, represents significant progress toward development of this method.

Due to personnel and equipment sharing between tasks, no work was conducted on this subtask this quarter. This work is currently on schedule to meet the revised completion date.

DRAFT AASHTO METHOD: A METHOD TO DETERMINE DUCTILE-BRITTLE PROPERTIES VIA AFM

Included Work Elements/Subtasks
M1b-2: Work of Adhesion at Nano-Scale using AFM
M2a-2: Work of Cohesion at Nano-Scale using AFM

Status and Work Planned
Force displacement curves have been collected and analyzed as a function of temperature and stress rate for two SHRP core asphalts. Both asphalts exhibit a clear step in an otherwise smooth change in fracture energy as the test temperature is increased. The tests indicate that, as expected, ductile brittle transition is sensitive to the stress rate as well as the temperature. Results of this testing indicate that stress rate must be considered in the determination of ductile-brittle transition temperature.

Development of this test method will continue in the next quarter. The AFM-based direct tension test will be used to assess ductile-brittle properties of polymer modified asphalt binders. Work next quarter will be directed toward these modified binders and some selected model compounds. This subtask is currently on schedule to meet the revised completion date.

DRAFT AASHTO METHOD: AFM-BASED MICRO/NANO-SCALE CYCLIC DIRECT TENSION TEST

Included Work Elements/Subtasks
M1b-2: Work of Adhesion at Nano-Scale using AFM
M2a-2: Work of Cohesion at Nano-Scale using AFM

Status and Work Planned
Draft AASHTO Method has been completed

CHIP ADHERENCE STABILITY TEST APPARATUS

This new work element will generate a scaled-up adhesion test based upon the micro/nano-scale work described in previous reports. The new test method measures the adhesion of an aggregate chip as a function of both rate and temperature. The test provides a measure of fracture toughness as well as ultimate adhesive strength. The fracture toughness term incorporates the effects of embrittlement and should, therefore, provide a much better performance predictor than simple measures of ultimate adhesive strength. The new test is designed specifically to help assess and predict the performance, both short and long term, of various surface applied pavement preservation materials. Other possible applications are also being considered.

Status and Work Planned
A prototype chip adherence stability (CAS) test apparatus is about half completed at the time of this writing. The apparatus uses the frame and reaction table from a Bolens direct tension test apparatus, and an environmental chamber from an obsolete Hewlett Packard gas chromatograph. Both of these ‘scrounged’ components will be fitted with modern controllers and PC interface. Most of the design and specifications has been completed and fabrication work has begun at the machine shop. We expect to complete the assembly of this test apparatus on schedule in the next quarter.

DRAFT AASHTO METHOD/PRACTICE: MEASUREMENT AND TEXTURE SPECTRAL ANALYSIS OF PAVEMENT SURFACE PROFILES USING A LINEAR STATIONARY LASER PROFILER (SLP)

Included Work Elements/Subtasks
Work Element VP-2a: Mixture Design to Enhance Safety and Reduce Noise in HMA

Status and Work Planned
Completed

Work Completed: Standard was not pursued by FHWA. Test procedure has been used for other research projects.

Work Planned: None planned; AASHTO Standard will be included in an Appendix in Report R.

Delivery Dates
Draft AASHTO Method: Complete (9/30/2012).
Final AASHTO Standard: Complete (6/30/2013), extended from 3/31/2013.

MODELS AND SOFTWARE

MODEL: HMA THERMAL STRESSES IN PAVEMENT

Included Work Elements/Subtasks
Work Element E2d: Thermal Cracking Resistant Mixes for Intermountain States

Status and Work Planned
On Schedule.

The following list describes the work items completed or in progress this quarter:

- Validation of aging model for the laboratory aging and field aging conditions are in progress.
- Worked on the subroutine to calculate the thermal build-up stress in pavement considering the effects of aging and nonlinear thermal coefficient of contraction.
- Work on the possible approach to include the effect of physical hardening to thermal cracking predictions.

The following list the work planned for next quarter:

- Continue the development of the full package for calculation of thermal stress in asphalt pavement considering the effects of aging and nonlinear thermal coefficient of contraction.

SOFTWARE: DYNAMIC MODEL FOR FLEXIBLE PAVEMENTS 3D-MOVE

Included Work Elements/Subtasks
Work Element VP3a: Pavement Response Model to Dynamic Loads

Status and Work Planned
On schedule. The delivery date for the software was changed since modifications and improvements on the software are still undergoing.

Most of the work done in this quarter focused on the following: (1) Preparing of final report; (2) Preparing a standalone documentation of 3D-Move (Theory, Verification and Application) and (3) Developing a new platform for next 3D-Move version (Ver. 3).

New Platform for Next Version (Ver. 3)
It is envisioned that the new platform of the next version of 3D-Move (Ver. 3) will include the following features:

- Capability of running two or more projects simultaneously by using parallel processing technology (70% progress);
- Incorporation of additional empirical procedures that are available to calculate asphalt dynamic modulus (10 % progress);
- Interchangeability between SI and US unit systems, in the middle of a 3D-Move run (40% progress);
- Use of Artificial Neural Network in the interpolation of non-uniform tire contact pressure distribution from the database (70 % progress);
- Inclusion of additional options for output in PDF and Crystal Report formats (Not started yet).

The following is a list work elements planned for next quarter:

- Continue work on Final Report and the 3D-Move documentation;
- Assist users with issues ranging from usage questions, concepts clarifications, and bugs;
- Work on the new platform for next version of 3D-Move (Ver. 3);
- Keep maintaining the 3D-move forum.

OTHER RESEARCH ACTIVITIES

Subtask E2b-2: Compatibility of RAP and Virgin Binders

Status and Work Done This Quarter

To evaluate how asphaltene particles of RAP binders disperse in an asphalt, asphaltene separation based on two different solvents, iso-octane and n-heptane, were used to calculate the asphaltene compatibility index. The asphaltene compatibility index (ACI) is a measure of the dispersibility of asphaltene in an asphalt binder and is defined as

$$\text{ACI} = \frac{Asphaltene_{Iso-Octane}}{Asphaltene_{n-heptane} + Asphaltene_{Iso-octane}} x10$$

The results indicate that asphaltene derived from RAP binders have a poorer dispersibility compared to asphaltenes derived from RTFO-aged SHRP asphalt binders. This finding may help explain why RAP binders have a higher modulus and are stiffness than virgin binders.

A technical paper on the influence of RAP content on chemical and rheological properties of neat asphalts has been submitted to 2014 AAPT for consideration for publication and presentation.

Work Planned Next Quarter

Maltene fractions separated with iso-octane from RTFO-aged AAA-1 and AAC-1 will be mixed at different concentrations with maltene fractions separated from RAP binders. These blended maltene fractions will be subject to viscosity measurements. The viscosities of maltene crossblends will be used to verify if the Pal-Rhodes model can be employed to characterize the flow properties of recycled asphalt pavement (RAP) binder blends.

Work Element E3a: Effects of Extenders and Alternative Binders on Performance

Work Done This Quarter

Completed evaluation of extenders on binder performance properties based DSR tests including standard Superpave high and intermediate temperature performance tests, MSCR, and the Linear Amplitude Sweep test. Furthermore mixture tests including coating evaluation using the boiling test, thermal cracking resistance using the ATCA were carried out on mixtures containing oil extenders. Samples were also prepared for testing using the cyclic IDT fatigue tests. Chemical evaluation using FTIR and GPC was also conducted and completed for the oils extenders and the modified binders. A technical paper was prepared and submitted to TRB based on the summary of results.

Work Planned Next Quarter

Mixture testing on the IDT fatigue samples will be completed. Furthermore, analysis of the large amount of data gathered over the last quarter will continue and be completed this quarter. Work on the draft final report will continue and be completed by the end of the quarter for submission in accordance to the updated delivery date.

Proposed Research Product and Timeline

Results will be added as a number of chapters to Report N: Guidelines for Selection of Modification Techniques.

Due Date for Draft Report Submittal: 12/31/2013 (extended from 9/30/2013).
Due Date for Final Report Submittal: 6/30/2014.

Significant Problems, Issues and Potential Impact on Progress

None.

Publications

Zhang, L.; Golalipour, A.; Tabatabaee, H.A.; Bahia, H.U.; “Prediction of Effect of Bio-Based and Refined Waste Oil Modifiers on Rheological Properties of Asphalt Binders,” Accepted for Presentation at the Transportation Research Board Annual Meeting, 2014.

Work Element E3b: Development of a PG Specification for Emulsions used in Surface Treatments, Cold Mixes, and Cold-In-Place Recycled Mixes

Work Done This Quarter

Emulsion testing framework was summarized in a TRB Symposium paper and continues to be used on emulsions for various applications. Field data and initial performance measurements were collected from four chip seal sites in WI.

A new opportunity for validation was discovered through collaboration with NCAT. Field sampled materials were received and residues recovered. Field monitoring of performance by NCAT is now underway and DSR testing is scheduled. WRI also continues validation efforts to sample emulsions, extract particulate matter, and measure performance properties (using 4 mm parallel plate) on four chip seal sections constructed nearly four years ago as part of the federal lands project.

Work Planned Next Quarter

Apply fresh emulsion and emulsion residue testing frameworks to additional emulsions intended for use in all three major applications. Propose specification limits based on variation in properties observed during testing and mixture performance data.

Residue properties of materials from NCAT sections will be tested and compared to early performance data measurements. WRI will continue work on validation work related to FLH sections. UW-M ARC will pursue potential validation sites in Wisconsin.

Proposed Research Product and Timeline

Results will be summarized as part of Report Q: Improvement of Emulsion Characterization and Mixture Design for Cold Bitumen Applications

Due Date for Draft Report Submittal: 3/31/2014, extended from 9/30/2013, 12/31/2103
Due Date for Final Report Submittal: 6/30/2014

Significant Problems, Issues and Potential Impact on Progress

More time is requested to include preliminary results from field validation sections and incorporate new findings related to curing of CMA and emulsions into the final report. Also extended time will allow for incorporation of preliminary NCHRP 9-50 findings into the project.

Publications

Ling, C. Hanz, A.J., Bahia, H.U., “Developing Evaluation Method for Moisture Susceptibility of Cold Mix Asphalt.” Accepted for presentation and publication at the 2014 TRB Meeting.

Work Element E3c: Laboratory Assessment of Mixture Long Term Aging

Work Done This Quarter

Rheological tests using the DSR and BBR completed on a new base binder and additional filler types were added to test matrix based on previous findings. Chemical compositional tests were performed using FTIR and GPS procedures on the binders extracted from the aged mastics to determine effect of aggregate filler characteristic on long term aging properties. A collaboration meeting was held with WRI and a plan was made for additional comparative chemical tests to be conducted at WRI to confirm and extend current results and findings using other methods.

Work Planned Next Quarter

Complete extended test matrix using the mechanical and chemical compositions tests to develop a model and test analysis methodology for assessing long term aging effects of aggregates on aging based on the filler characteristics. Work on draft report will begin in order to submit in accordance to the updated delivery date.

Proposed Research Product and Timeline

Results will be summarized in a final report titled: “Laboratory Assessment of Long Term Aging of Asphalt Mixtures” it is proposed this deliverable be labeled as “Report AA.”

Due Date for Draft Report Submittal: 3/31/2014, from 12/31/2013 and 9/30/2013.
Due Date for Final Report Submittal: 6/30/2014.

Work element V1a: Use and Monitoring of Warm Mix Asphalt Sections

Work Done This Quarter

NCAT has completed field testing and monitoring for six field projects, including two test sections on I-84 in CT, two test sections on US 287 in TX, two test sections on US 69 in MS, three test section on CR 159 in AL, four test section on I-70 in CO, and four test sections in Indianapolis IN. Laboratory testing is completed for the I-84 and CR 159 projects and in ongoing for other projects.

Work Planned Next Quarter

The NCAT team will continue testing the materials sampled from the field projects and working on reports for field testing and monitoring that have been completed.

Monitoring the Manitoba WMA and RAP sites was conducted in August 2013.

Work element V1b: Construction and Monitoring of Additional Comparative Pavement Validation Sites

Work Done This Quarter

The project team at WRI and NCAT continued testing the materials sampled from the Arizona RAP project and other field projects. In addition, NCAT finished field testing and documenting the construction of three test sections on Route 7 in MO.

Work Planned

The NCAT team will continue testing the materials sampled from the two field projects and preparing reports for field works that have been completed.

Monitoring the Manitoba WMA and RAP sites was conducted in August 2013.
Tentatively monitoring of the Minnesota site will be conducted in the spring of 2014.
The newly constructed ARC RAP test site in Arizona north of Phoenix will be tentatively monitored in the next quarter.