Western Research
INSTITUTE

Asphalt Research Consortium

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

INTRODUCTION

This document is the Quarterly Report for the period of April 1 to June 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, 11 draft reports and 27 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 April 1 to June 30, 2013 is the first 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
(Note: Highlighted areas show changes)

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	5/31/2104	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)	8/31/2013	12/15/2013	TAMU	All	Reference level 2 and 3 deliverables for details
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
Report B	Characterization of Fatigue Damage and Relevant Properties (Level 2)	8/15/2013	10/31/2013	TAMU	Bhasin	In final editing
Report C	PANDA: Pavement Analysis using a Nonlinear Damage Approach (Level 2)	8/31/2013	11/30/2013	TAMU	Darabi	Summary of PANDA methodology including descriptions of methods for identifying model parameters

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)	Completed 5/31/2013	10/31/2013	TAMU	Little	Summary report on methodology for characterizing the phases of asphalt binder with description of composite implications
Report E	Lattice Model and Continuum Damage to Fracture (Level 2)	5/31/2013	9/30/2013	NCSU	R. Kim	Comprehensive report on lattice model. In final editing by NCSU
Report F	Microstructure Cohesive Zone Modeling for Moisture Damage and Fatigue Cracking (Level 2)	Completed 1/31/2013	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	9/30/2013	3/31/2014	UNR	Hajj Sebaaly	Comprehensive report describing the developed mechanistic-based approach for critically designed mixtures

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Report I	Thermal Cracking Resistant Mixes	8/31/2013	12/31/2013	UNR	Hajj Sebaaly	
Report J	Pavement Response Model to Dynamic Loads 3D Move	9/30/2013	12/31/2013	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	
Report L	Development and Validation of the Bitumen Bond Strength Test (BBS)	Completed 10/31/11	9/30/2013	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	10/30/2013	UWM	Tabatabaee	Final pending receipt of peer review comments
Report N	Guideline for Selection of Modification Techniques	9/30/2013	3/31/2014	UWM	Tabatabaee	On schedule
Report O	Characterization of Binder Damage Resistance to Rutting	9/30/2013	12/31/2013	UWM	Tabatabaee	Report under internal review
Report P	Quantifying the Impacts of Warm Mix Asphalt on Constructability and Performance	9/30/2013	12/31/2013	UWM	Hanz	Draft extended 6 months
Report Q	Improvement of Emulsion Characterization and Mixture Design for Cold Bitumen Applications	12/31/2013	3/31/2014	UWM	Hanz	Three month extension requested

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Report R	Studies on Tire-Pavement Noise and Skid Response	Completed 12/31/11	7/30/2013	UWM	Roohi	Extended to address comments
Report S	Molecular dynamics results for multiple asphalt chemistries	8/15/2013	12/31/2013	URI	Greenfield	
Report T	Progress Toward a Multi-scale Model of Asphalt Pavement- Including Test Methods for Model Input Parameters	9/30/2013	3/31/2014	WRI	Pauli	Delayed because of Delft finite element work
Report U	Design Guidance for Fatigue and Rut Resistance Mixtures	9/30/2013	3/31/2014	AAT	Bonaquist Christensen	NTIS format report with Technical Brief
Report V	Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures (Level 2)	Completed 5/31/2013	10/31/2013	TAMU	Lytton/Luo	Sent to FHWA Reference appropriate level 3 deliverables
Report W	Characterization of Fatigue and Healing Properties of Asphalt Mixtures (Level 2)	Completed 5/31/2013	10/31/2013	TAMU	Lytton/Luo	Sent to FHWA Reference appropriate level 3 deliverables
Report X	Characterization of Field Cores of Asphalt Pavements (Level 2)	Completed 5/31/2013	10/31/2013	TAMU	Lytton/Luo	Sent to FHWA Reference appropriate level 3 deliverables
Report Y	Water Vapor Diffusion in Pavement and Its Effects on the Performance of Asphalt Mixtures (Level 2)	Completed 5/31/2013	11/30/2013	TAMU	Lytton/Luo	Sent to FHWA Reference appropriate level 3 deliverables

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Report Z	Effect of Extraction Methods on the Properties of Aggregates in Reclaimed Asphalt Pavement (NTIS format)	Completed 3/1/2013		UNR	Hajj Sebaaly	Final pending receipt of peer review comments
AASHTO Method	Simplified Continuum Damage Fatigue Analysis for the Asphalt Mixture Performance Tester	9/30/2013	3/31/2014	AAT	Bonaquist Christensen	Development documented in Report U
AASHTO Method	Wilhelmy Plate Test (Level 3)	Completed 1/31/2013	6/30/2013	TAMU	Bhasin	Sent to FHWA for review, Referenced in Reports A & B
AASHTO Method	Universal Sorption Device (Level 3)	Completed 1/31/2013	6/30/2013	TAMU	Bhasin	Sent to FHWA for review, Referenced in Reports A & B
AASHTO Method	Dynamic Mechanical Analysis (Level 3)	Completed 1/31/2013	6/30/2013	TAMU	Kassem	Sent to FHWA for review, 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	Sent to FHWA for review, Referenced in Reports A & B
AASHTO Method	Measuring intrinsic healing characteristics of asphalt binders	Completed 1/31/2013	6/30/2013	TAMU/ UT	Bhasin	Sent to FHWA for review, Referenced in Report B

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method	Test Methods for Determining the Parameters of Material Models in PANDA (Pavement Analysis Using Nonlinear Damage Approach) (Level 3)	8/31/2013	2/28/2014	TAMU	Kassem Darabi	Referenced in Report C
Test Method & Model	Continuum Damage Permanent Deformation Analysis for Asphalt Mixtures (Level 3)	Completed 5/31/2013	10/31/2013	TAMU	Lytton/Luo	Referenced in Report V
Test Method & Model	Characterization of Fatigue and Healing Properties of Asphalt Mixtures (Level 3)	Completed 5/31/2013	9/30/2013	TAMU	Lytton/Luo	Referenced in Report W
Test Method Analysis Program	Nondestructive Characterization of Tensile Viscoelastic Properties of Undamaged Asphalt Mixtures (Level 3)	Completed 5/31/2013	10/31/2013	TAMU	Lytton/Luo	Referenced in Reports V & Y
Test Method & Model	Characterization of Field Cores of Asphalt Pavements (Level 3)	Completed 5/31/2013	10/31/2013	TAMU	Lytton/Luo	Referenced in Reports W & X
Test Method Analysis Program	Nondestructive Characterization of Anisotropic Viscoelastic Properties of Undamaged Asphalt Mixtures under Compressive Loading (Level 3)	Completed 5/31/2013	10/31/2013	TAMU	Lytton/Luo	Referenced 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	9/30/2013	3/31/2014	UWM	Hanz	On schedule
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

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method	Determining Asphalt Binder Bond Strength by Means of the Bitumen Bond Strength Test (BBS)	Completed	Completed 6/30/13	UWM	Hanz	Includes minimum of 3 months external peer review
AASHTO Method	Measurement of Asphalt Binder Elastic Recovery in the Dynamic Shear Rheometer (DSR)	Completed 1/31/2013	Completed 6/30/2013	UWM	Tabatabaee	Combined with BYET test
AASHTO Method	Estimating Fatigue Resistance of Asphalt Binders Using the Linear Amplitude Sweep (LAS)	Completed	9/30/2013	UWM	Tabatabaee	Final Delivery extended 3 month to accommodate ETG request
AASHTO Method	Binder Yield Energy Test (BYET)	Completed 1/31/2013	Completed 6/30/2013	UWM	Tabatabaee	Submitted to AASHTO SOM by FHWA
AASHTO Method	Measurement of Rigden Voids for fillers	Completed 1/31/2013	Completed 6/30/2013	UWM	Hanz	Pending ETG comments
AASHTO Method	Measurement of Asphalt Binder Lubricity Using the Dynamic Shear Rheometer (DSR)	9/30/2013	12/31/2013	UWM	Hanz	Submittal delayed due to activities with other products
AASHTO Method	Procedure for Evaluation of Coating for Cold Mix Asphalt	Completed 4/30/2013	9/30/2013	UWM	Hanz	Pending ETG review
AASHTO Method	Cold Mix Laboratory Specimen Preparation Using Modified SGC Molds	8/30/2013	12/31/2013	UWM	Hanz	Standard under internal review
AASHTO Method Software	RAP Binder PG True Grade Determination	Completed 9/30/2012	Complete 6/30/2013	UWM	Hanz	Work with ETG as necessary
AASHTO Method	Measurement of Asphalt Binder Fracture Properties Using the Single Edge Notch Bending Test	Completed 9/30/2012	9/30/2013	UWM	Tabatabaee	Extended to provide additional information to ETG

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
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	4/30/2013	Completed 6/30/2013	UWM	Tabatabaee	Refer to UNR TSRST procedure for additional information
AASHTO Method Software	Analysis of Asphalt Mixture Aggregate Structure through Use of Planar Imaging and Image Processing & Analysis System (IPAS)	4/30/2013	9/30/2013	UWM	Roohi	Action pending ETG comments
AASHTO Method	Determining the Resistive Effort of Asphalt Mixtures during Compaction in a Gyratory Compactor using an Internal Device	Completed ASTM	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 3/31/2013	8/31/2013	TAMU	Little	Sent to FHWA for review, 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.	4/30/2013	10/31/2013	VT	Wang	
AASHTO Method	Evaluate Healing using Continuum Damage Approach (Level 3)	8/15/2013	8/31/2013	TAMU/ UT	Bhasin	Appendix in Report B
Test Method & Analysis Program	Self-Consistent Micromechanics Models of Asphalt Mixtures (Level 3)	Completed 5/31/2013	10/31/2013	TAMU	Lytton/Luo	Referenced in Report W

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
AASHTO Method & Analysis Program	Rutting Prediction of Asphalt Binder Considering Stress-Dependence of Creep Behavior (Level 3)	8/31/2013	9/30/2013	TAMU	Little	References to Dissertation & journal papers
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	3/31/2013	10/31/2013	WRI	Grimes	Will be subject of Tech. Pub.
AASHTO Method	Measurement and Texture Spectral Analysis of Pavement Surface Profiles Using a Linear Stationary Laser Profiler (SLP)	Completed 9/30/2012	3/31/2013	UWM	Roohi	Pending FHWA review
Model	HMA Thermal Stresses in Pavement	3/31/2014		UNR	Hajj	Detailed in Report I
Software	Dynamic Model for Flexible Pavements 3D-Move	9/30/2013		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

Deliverable	Description	Draft Delivery Date	Final Delivery Date	ARC Partner	Staff Assignment	Notes
Model	Approaches to interpret MD simulation results and experimental data to quantify the composition and temperature dependence of free energy.	8/15/2013		URI	Greenfield	Detailed in Report S
Model and Software	Phase-Field Model of Asphalt Binder Fracture and COMSOL Code for Model	9/30/2013	3/31/2014	VT	Wang	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 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 will be submitted to FHWA on August 15^{th}.

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

Status: The PANDA report is submitted to TTI for editing and will be submitted to FHWA by August 31st.

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

- **PANDA report**

The focus of the current and next quarter will be on finalizing the reports associated with PANDA development. The testing protocol for calibration of PANDA models has been summarized in AASHTO format. We have submitted the PANDA calibration protocol to TTI for editorial review. This report will be submitted to FHWA by August 31st 2013.
Also, the PANDA report has been drafted. This report is submitted to TTI and will be submitted to FHWA by August 31st 2013.

- **Development of PUI and PPI**

During this quarter, researchers at Texas A&M University continued to develop the PANDA Parameter Identifier (PPI) package and PANDA User Interface (PUI). PPI includes a series of Matlab codes that automatically extract PANDA parameters from the experimental data. PPI enables the users to extract these parameters directly from the raw data without the need to analyze the experimental data. The PANDA User Interface (PUI) has also been created to facilitate the use of the PANDA model in Abaqus software. In order to allow users to utilize versatile features of Abaqus without having in-depth knowledge in Abaqus pre-processing functions, the PUI was developed at Texas A&M University by a team of researchers who are familiar with Abaqus and have expertise in the development of user friendly interfaces. PUI is customized for pavement applications such that users can conduct performance simulations of pavements without having the in-depth knowledge of using Abaqus.

- **Workshop on PANDA**

A workshop on Pavement Analysis using Nonlinear Damage Approach (PANDA) was held in June of 2013 at Texas A&M University to illustrate the effectiveness of using PANDA models with PPI and PUI. This workshop provided training in the use of PANDA that is under development by ARC researchers at Texas A&M University. The workshop was offered over a span of two days. The first day covered the theory of models used in PANDA, calibration of the PANDA constitutive models from experimental data using PPI, and laboratory experiments and analytical techniques that are used to determine model parameters. The second day was devoted mostly to demonstrating the PANDA User Interface (PUI) that allows the user to access the capabilities of the model implemented in Abaqus finite element software without requiring in-depth experience in Abaqus pre-processing functions.

We are currently preparing a short report based on the comments provided by workshop attendees. This report will be used as the basis to further refine PANDA, PUI, and PPI. The PANDA workshop was well received by the invited guest with an overall rating of approximately 4.5 out of five by the participants.

- **Further validation of PANDA**

The focus is also 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 experiences 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. He is currently preparing a report based on his inspection of PANDA.

The focus of the current and next quarter will also be on developing mechanistic-based extrapolation techniques to predict 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.
- Finalizing the ARC reports and deliverables.

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

The Atomic Force Microscope (AFM) analysis of SARA fractions has been completed. The adhesion properties of asphalt binders with different compositions of SARA fractions have already been reported in the thesis of Robert Allen. SARA fractions containing high amounts of saturates seemed to significantly increase the density and size of the bee structures. However, adhesion measurements showed that the bee structures themselves are more polar in nature than the surrounding continuous phases.

The next step in this work is the analysis of the impact of loading on the microstructural changes within the binder. 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. A publication has been planned for an October submittal which will detail the processes along with the findings of this work.

The work above will be repeated for multiple different binders. Images obtained through AFM imaging will be analyzed and comparisons will be made. Statistical study of the different phases and phases along with the formation of the phase separation will be performed.

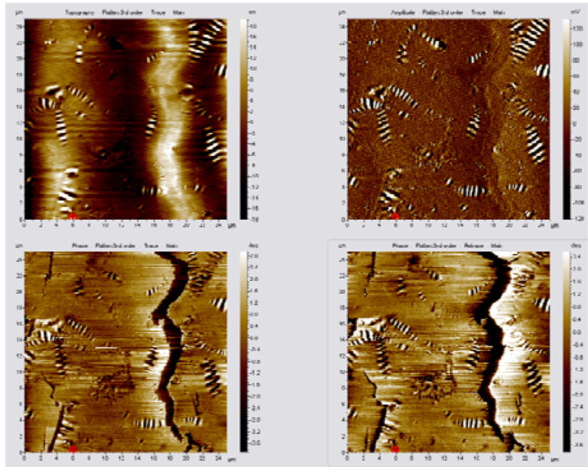

Figure 1: Phase separation and possibly damage in the form of cracking due to the application of tensile load

REPORT E: MULTISCALE VIRTUAL FABRICATION AND LATTICE MODELING.

Status: The report is edited by TTI and sent back to NCSU for addressing some editorial comments. This report will be submitted to FHWA by August 31st.

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:

- Determined the required retained percentage of RAP material on each sieve to obtain a precise estimation of the extracted RAP aggregate gradations.
- 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.
- Continue 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.
- Continued a literature review regarding fractionation procedures.
- Completed a literature review regarding the major factors affecting fatigue endurance limit.

The following list the work planned for next quarter:

- Complete 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 if received on time.
- Start Phase II of the study including testing beam fatigue specimens at several factors against the DP levels.
- Sample 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
On Schedule.

The following list describes the work items completed this quarter:

- Continued the work on Report H. Some delay resulted from the preparation of all figures into the appropriate format. The delivery date of the draft report has been revised accordingly.
- Prepared and submitted to FHWA a draft AASHTO procedure for evaluating the critical conditions of HMA mixtures.

The following list the work planned for next quarter:

- Finalize and 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
On Schedule.

The following list describes the work items completed this quarter:

- The thermal stress and strain measurements have been completed on the Minnesota field validation samples. The tests were conducted following the draft AASHTO standard procedure for the uniaxial thermal stress and strain test (UTSST).
- The aging and testing of the Nevada field validation samples is underway and is expected to be complete in this quarter.
- Evaluation of the Core materials is also underway. All of the binder aging has been completed, with almost 75% of the accompanying testing being complete.
- The added mixture aging at 85°C and testing related to the systematic shifting of the activation energy of binders aged in mixtures and in laboratory pans have been completed. All of the samples have been aged and have been tested for dynamic modulus and UTSST. The extraction, recovery, rheology, and FTIR testing on those samples have also been completed.
- Modeling of asphalt binder aging in free atmospheric condition and in the mixture has been completed. Laboratory validation of the model is under process.
- The direct tension test specimens for polymer-modified asphalt mixtures have been completed. Analyzing direct tension test results to find the appropriate test condition is under process.
- The UTSST testing of the laboratory aged specimens have been completed. The analysis of the results is undergoing to evaluate and quantify the effect of binder oxidative aging on thermo-viscoelastic properties of asphalt mixtures.
- Statistical based predictive models has been developed to estimate changes in viscoelastic properties of asphalt mixtures as a function of binder oxidative aging and asphalt mixture material properties at the initial condition, before long-term aging.
- Continued the work on the approach to relate the mechanical properties of asphalt mixtures to the physio-chemical and rheological changes in asphalt binders due to oxidative aging.

The following list the work planned for next quarter:

- Complete the mixture testing of the field validation sections.
- Complete the Core binder testing.
- Conduct mixture testing on two of the core materials.
- Continue working on the subroutines for thermal cracking analysis tool.
- Continue the UTSST and direct tension tests on field validation mixtures

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.

Several bugs were reported after the release of the 3D-Move Ver. 2 which largely delayed the work on the report. The focus of the UNR research team this quarter was to address and solve the various reported bugs in a timely and effective manner. A new Ver. 2.1 was released on June 2013. Given no further significant bugs are reported, the work on the report will resume in the next quarter.

The Web site was updated, as necessary to replace the 3D-Move software 2.0 with Ver. 2.1. The software itself and release notes were updated on the ARC web site. Existing users were notified of the update.

REPORT K: DEVELOPMENT OF MATERIALS DATABASE

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

<u>Status and Work Planned</u>
Behind Schedule.

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

- File Upload System Status Report and New jQuery FileUpload control;
  - This quarter, 30 batches were created by various users and 562 reports uploaded. No problems or errors were reports using the file upload system. In addition, random log files were checked throughout the quarter. Roughly 10 percent of the file uploads were validated. Again, no errors were found.
  - The performance of the file system selector control was deemed to be slow. The original implementation refreshed the entire file structure with each page post back causing a performance bottleneck as the file system needed to be reloaded each time the page was reloaded. The original system design accommodated file uploads but was not designed to operate with such a large file system structure. Because of the sheer number of uploaded files and the size of the directory structure, the control needed to be rewritten.
  - The File Upload user control was completely re-implemented to use jQuery and AJAX technologies. Using these two technologies, only root-level directories are initially loaded. As the user expands folders, only the child folders applicable to the selected node are loaded into the TreeView. In addition, only the jQuery tree is refreshed. The remaining parts of the page are not refreshed thereby improving performance considerably. The request to get folders is made via the jQuery AJAX request and a small server-side ASP.net connector application.
- Work progress on the batch file upload system;
  - Last quarter, analysis and design were completed and development began for a system to upload significant numbers of files, and very large files. The design of the system involves the following components:
    - 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.
- Add features to the test run import system that will allow users to replace or append existing measures;

    - The code has been developed to replace one batch import with another. This module is undergoing testing and will be deployed shortly. The code to merge uploads has not yet been completed.
- Continue work on the public user interface using independent study student resources;
- Complete role documentation system;
    - The role management subsystem is being refactored as plans are made to potentially use the ARC database beyond the ARC project and ARC consortium. As part of this effort, the roles are being made more granular and new roles are being added.
- Revisit the FileLinker form as subsystem, as necessary (no activity reported this quarter);
- Begin Data Compliance Act Report (Unplanned);
    - Work has started on the ARC report to document compliance with the Data Quality Act (DQA) passed by the United States Congress in 2001. UNR and the ARC development team have completed the following steps to create the DQA Report:
    - A UNR student has been retained as a technical writer to develop the DQA report working with the ARC development team and contacts from each institution belonging to the ARC consortium. Note that primary ARC contacts will be responsible for collecting data from their respective subcontractors.
    - A draft outline was first created to describe data collection methods and protocols that apply to DQA compliance. The outline was created based on materials from the LTPP DQA compliance standards appearing on the LTPP Web site along with other sources.
    - A questionnaire has been created and will be circulated to ARC members by July 10, 2013. UNR hopes to have responses from the ARC representatives no later than July 30 so as to complete the DQA report this quarter.
- General bug fixes and user interface improvements.
    - As the ARC database gets increasing use, the development team has, as time permits, continued to standardize several formatting and user interface characteristics as follows:
        - **jQuery Calendar control**. The ASP.net Calendar control is rather cumbersome. This old ASP control has been replaced by a jQuery calendar from the jQuery UI library. This new jQuery calendar does not require postbacks as the user interacts with the calendar, so the number of postbacks is significantly reduced. The BatchViewer, FileUpload, ValidationSite, and BulkEditor forms were affected by this new control. Date selection will be added to other forms, as necessary and as those forms are revised.
        - **Excel Grid Export Feature**. It seems many ARC grids (visible GridView) instances would be more useful if their contents could be exported to Excel. The code used by selected forms has been standardized and can now be called from any grid to export the entire Grid contents. At this point, the export features has been added to the following forms and controls, and will be extended to other forms as time permits: BatchViewer.aspx and ManageSources.aspx.

    - Added paging to the File Metadata page (**FileMetaData.aspx**). Added Excel export feature and standardized formatting with other controls. Added the internal identifier to the visible grid so as to support the batch file upload procedure.
    - Fixed Help page link in the Suppliers form (**ManageSources.aspx, usSourceEditor.ascx**). Added pagination feature to page. Added Excel export feature.
    - Convert controls and pages form the DetailsView control to the FormView control for consistency with the overall ARC application.
    - Reformatted the materials form (**Materials.aspx**). The material details now appear in a standardized FormView replacing the DetailsView control. Also, reformatted the material composition form used to attach a supplier to a material.
    - **MaterialReport.aspx** was modified. There was no filter to display all materials. Added the help file for the report.
    - Added paging to Property Group form (**Property Group.aspx**). Added Excel export feature to the grid. Standardized formatting of the page
    - Significantly revised the Properties Editor user interface (**PropEntry.aspx**) to use the same formatting (fonts, sizes typefaces) as other parts of the application. Reformatted column headers.

The following list summarizes the work planned for next quarter.

- Complete DQA report draft for review by ARC members.
- Depending on the arrival of materials from Texas A&M, complete, the batch file upload system.
- Complete File Download form changes and begin demonstrations and acceptance testing.
- Continue final development of the role management subsystem.
- Create draft final ARC project report. The delivery date of the draft report has been revised.
- 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
Behind Schedule (Final Report Submission)

Work Completed: BBS test results for emulsions and emulsion residues collected for the NCHRP 9-50 report demonstrated sensitivity to emulsion type and modification in regards to curing of fresh emulsion, dry bond strength of emulsion residues, and moisture sensitivity of emulsion residues. The previously submitted draft final report did not include information detailing use of the BBS for characterization of emulsions. Based on the significant use of the BBS in this area and inclusion of the emulsion evaluation in the AASHTO TP-91 standard, it was deemed necessary to add a section to the report.

Work Planned: Revise draft final report to incorporate new information related application of the BBS test to emulsions. Complete internal review of final report, complete Section 508 formatting, and submit to FHWA.

Reasons for Delay: Additional time is required to incorporate new information related to application of the BBS test to fresh emulsions and to maintain consistency with guidance in AASHTO TP-91.

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

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
Behind Schedule (Final Report Submission)

Work Completed: In the last quarter the report was revised to add sections corresponding to the LAS ruggedness testing and new findings with regards to cracking of binder DSR samples during oscillatory loading. A new procedure for assessment of binder healing using the DSR was developed also incorporated in the final report. UW has previously submitted draft final report in full 508 format and is awaiting peer review feedback.

Work Planned: Address comments from peer review feedback upon receipt.

Reasons for Delay: Delays have been realized in receiving peer review comments. Upon receipt of the comments, it is anticipated that approximately 2 to 3 months will be needed to revise and submit the final report.

Revised Delivery Dates
Draft Report: 10/30/11 (Submitted)
Final Report: Tentative: 10/30/2013, assumes review comments received by 8/31/13

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
On Schedule

Work Completed: Extensive thermal cracking (SENB) and fatigue (LAS) testing was performed for the expanded extender set, as well tests on moisture sensitivity through BBS and the mixture boiling test. This work is further described in the “New Work Element” update document under “E3a”.

Work Planned: Complete experimental plan for E3a. Results of Work Element E3a will be integrated into existing draft of E2a report during next quarter pending completion of the E3a work plan. The results of this work will be integrated into Report N.

Delivery Dates
Draft Report: 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: Recent work aimed at quantifying effect of binder elasticity and viscous response on mixture rutting mechanisms to determine optimum modified binder behavior that will minimize rutting potential of mixture was integrated into the draft final report. This work will contribute significantly to the analysis and discussion of Report O. The draft final report is complete and currently under internal review.

Work Planned: Complete internal review of draft final report and associated Section 508 formatting. Submit to FHWA.

Delivery Dates
Draft Report: 9/30/2013, 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
On Schedule

Work Completed: Report chapters related to initial findings regarding selection of mixing and compaction temperatures were completed. This work is related to the work element added in the ARC Yr. 6 work plan. For selection of mixing temperature a new approach that considers both extent and quality of coating and the associated test procedures are detailed. In regards to selection of compaction temperatures, the concept that sole use of binder properties is insufficient for compaction temperature selection is detailed based on previously noted concepts. Mastic viscosity is the proposed parameter for mixing temperature selection as both filler mineralogy and concentration have significant impacts on mastic viscosity and thus workability. These concepts were verified through analysis of aggregate structure. A procedure to estimate compaction temperatures based on asphalt binder properties and information in the mix design is currently under development. These activities are also related to efforts in the Mixing and Compaction Temperature Selection Task Force within the FHWA Binder ETG.

Work Planned: Continue work on the draft final report and integrate chapters related to the impacts of WMA on performance in coordination with UNR. Submit draft final report at the end of the quarter.

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

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: Cold mix design including procedures for evaluating coating, mixture compaction, and curing were finalized based on work related to compaction of CMA. The study demonstrated sensitivity of both indirect tensile strength and volumetrics to emulsion content. A separate study was started evaluating the impacts of replacement of a portion of the mineral filler with cement to improve curing and mechanical properties was started.

Work continues collecting fresh emulsion and residue performance properties. An application based framework for selecting emulsions was presented at the WRI P3 Symposium. 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: The study related to the effects of cement on volumetrics and moisture damage resistance will be completed. The proposed curing procedure (72 hours @ 60°C) will be validated by comparing results of indirect strength testing with samples cured for an extended period under laboratory conditions. Performance evaluation of CMA will start, candidate mixture performance 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.

Reasons for Delay
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.

Delivery Dates
Draft Report: 12/31/2013, from 9/30/2013
Final Report: 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, awaiting further direction from WRI and FHWA.

Work Completed: Comments on draft final report were received 5/7/2013. Research team revised report to address comments and summarized response in a memo. Revised report and memo are currently under internal review.

Work Planned: Complete internal review of report and submit final version to FHWA.

Delivery Dates
Draft Report: 12/31/2011 (Submitted)
Final Report: 7/30/2013, extended from 6/30/2013.

REPORT S: MOLECULAR DYNAMICS RESULTS FOR MULTIPLE ASPHALT CHEMISTRIES

This report can be delivered in non-508 format.

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 publication that disseminates new proposed compositions for AAA-1, AAK-1, and AAM-1 was submitted to the journal *Fuel* during the winter 2013 quarter. Requests for revisions were received in May 2013 and were returned to the journal at the end of the quarter. News that the manuscript was accepted was received the day after the quarter ended.

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.

Work continued on conducting molecular simulations of model asphalts and analyzing the results to obtain physical insights and free energy parameters. Results from past quarters for molecular simulation predictions of $|G^*|$ and phase angle δ, calculated from the spontaneous fluctuations in the stress tensor, had been filtered to obtain a better signal, i.e. more smooth and trustworthy G^* and δ results. Interpretations were completed during the quarter, and a manuscript will be submitted during the upcoming quarter while finalizing the report. A second manuscript to be submitted will quantify the raw dynamics results. These efforts have focused on the new AAA-1, with results for other model asphalts set aside as the methods and understanding are refined.

Interpretations using time-temperature superposition have advanced relative to their status in the prior quarter. The prior report included a surprising finding that changes in storage and loss modulus with frequency do not show good superposition. (This was indicated by a Black [or van Gurp-Palmen] plot of G* vs δ over the different temperatures showing similar shapes but poor overlap.) The conclusion reached then was that the model system is not thermorheologically simple over this temperature range. Ongoing interpretation during the past quarter indicates more subtle results. The relationship between |G*| and δ over less high frequencies appears to show superposition. A clear loss peak at particularly high frequencies – ca. $10^{12.5}$ rad/sec (more than 1 rad per ps) does not shift with temperature. Instead, it appears to reflect dynamics that are temperature-independent. The reasons for such a loss peak are still being investigated, including whether they are a simulation artifact or an intrinsic property of the model asphalts.

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 - On Schedule.

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.

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
Work Element F3a-4: Phase-field modeling of self-healing in asphalt binder
Subtask F3a-4.1 AFM results of phase separation
Subtask F3a-4.2 Phase dynamics
Subtask F3a-4.3 Mathematical model
Subtask F3a-5.4 A mechanical approach to model self-healing

Status and Work Planned
On Schedule

At this moment, this research progress is on time according to the plan. Subtasks F5a 5.1-5.3 have been finished. Work Element F5a-5.4 the mechanical approach to modeling self-healing is still under research and will be conducted in the next quarter.

Based on Troy Pauli *et al.* (2012)'s AFM results, it is confirmed that asphalt binder undergoes a phase separation to reach the equilibrium state. It is noticed that the phase separation occurs, while the two phases diffuse into each other and co-exist in the cooling process. In the classic thermodynamic theory, whether the co-existence of different phases occurs or not is dependent on the system free energy. There are two types of free energies: the Gibbs free energy at constant pressure and constant temperature (**NPT**) and Helmholtz free energy under at constant temperature and constant volume (**NVT**).

Consider **NPT**, the evolution of the microstructure is determined by the Gibbs free energy and driven by the chemical potential (non-conserved case) or gradient of chemical potential (conserved case). A simple free energy model is the double well potential as shown in Figure 1 (a). The system has two metastable energy states ϕ_1 and ϕ_2, which represent two different phases α_1 and α_2, respectively. Note that the region under the negative curvature between two spinodes A and B (where $\frac{\partial^2 G}{\partial \phi^2} = 0$) is unstable. Since a system always tends to reach a lower energy state, a homogenous mixture is unstable in this region and spinodal decomposition occurs. As a result, the mixed system spontaneously separates into the two co-existing phases (α_1 and α_2) In the region where $\frac{\partial^2 G}{\partial \phi^2} > 0$ the system remains metastable and phase separation does not happen unless the perturbation is large enough. The phase kinetic information can be intuitively codified into the phase diagram as shown in Figure 1(b).

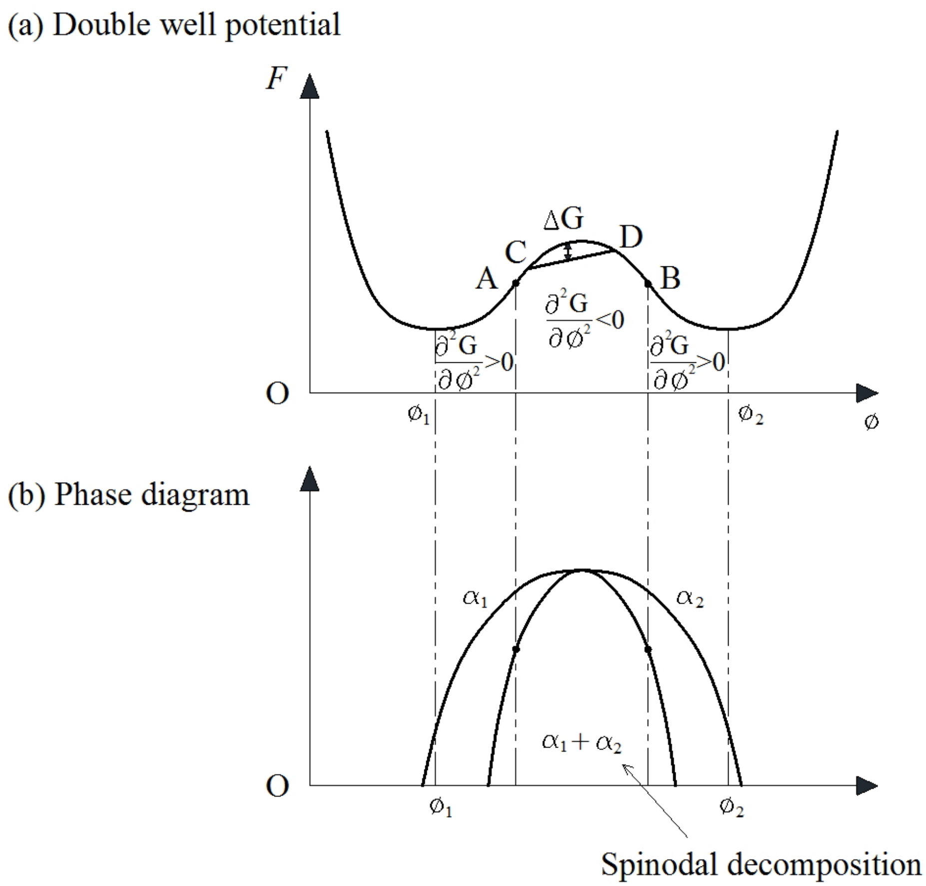

Figure 1. Schematic view of phase separation in terms of free energy and phase diagram.

Consider a cooling process, the phase separation and the corresponding von Mises stress distribution contour can be seen in Figure 2. Note that von Mises stress has a large gradient along the interface between two different phases.

<u>Included work elements/subtasks</u>
Subtask F3a-4. Overall integration for multiscale modeling (VT, URI, and WRI)
Subtask F3a-5. Experimental verification and validation (VT, URI, and WRI)

<u>Status and Work Planned</u>
Preparation of Report T, entitled “Progress Toward a Multi-scale Model of Asphalt Pavement-Including Test Methods for Model Input Parameters”-in progress.

On Schedule

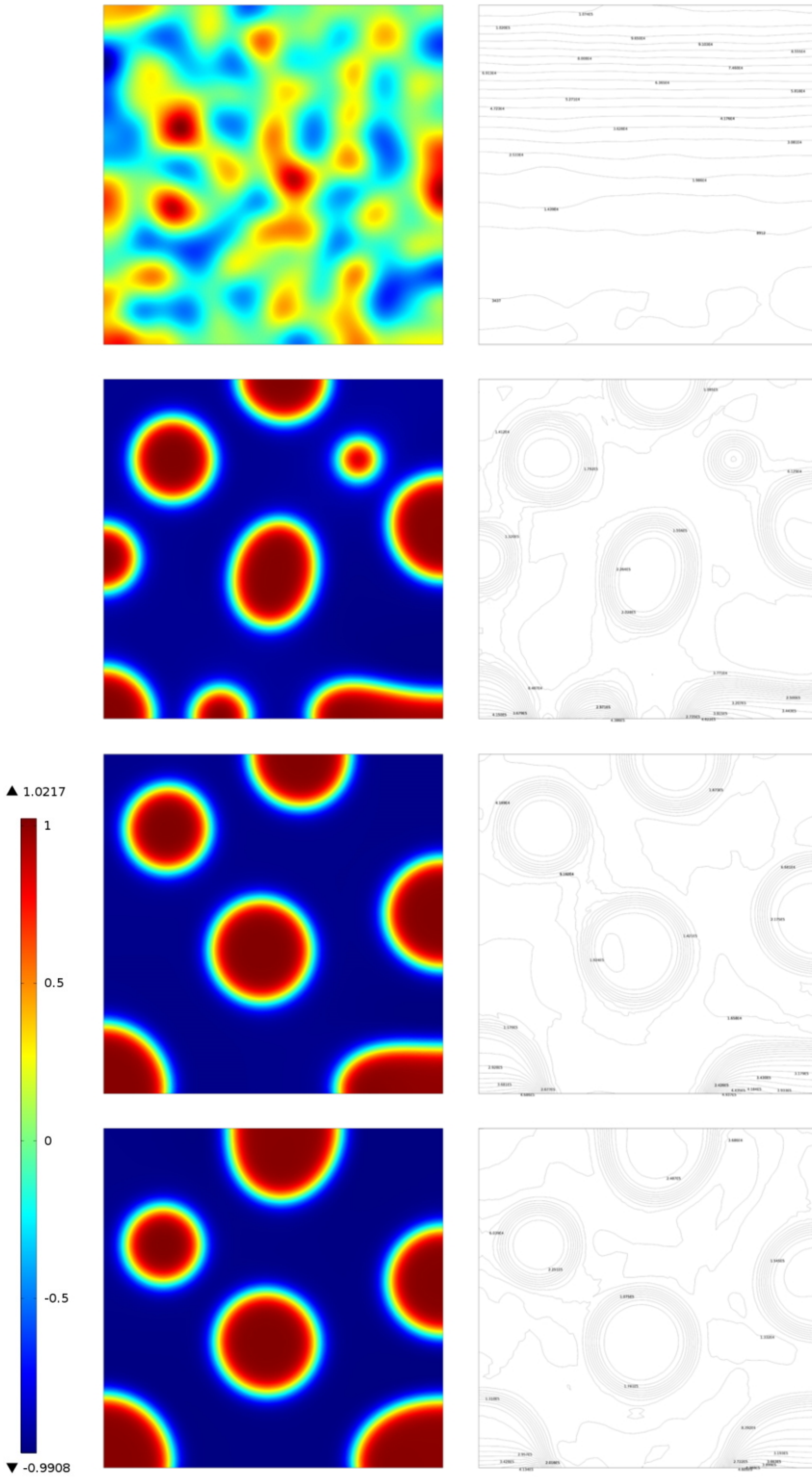

Figure 2. Phase separation during the cooling process and the corresponding von Mises stress distribution.

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 is progressing according to the year six work plan. Analysis of the data and refinement of the four models is continuing: (1) Hirsch model for dynamic modulus, (2) resistivity rutting model, (3) reduced cycles fatigue model, and (4) permeability model. After discussions with FHWA it was decided that Report U would consist of two components: (1) research report submitted to NTIS thoroughly documenting the refinement of the four models, and (2) a Technical Brief demonstrating how the models can be used to improve during mixture design to improve the rutting and fatigue resistance of mixtures. Work on the NTIS report continued this quarter. The revised delivery date for the NTIS report is September 30, 2013.

Next quarter, data analysis and refinement of all four models will continue. Work on the NTIS report will continue.

REPORT V: 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: on schedule.

The Level 2 Report V "Continuum Damage Permanent Deformation Analysis for 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 Report V has been submitted to the Federal Highway Administration for review.

REPORT W: 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: on schedule.

The Level 2 Report W "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 Report W has been submitted to the Federal Highway Administration for review.

REPORT X: 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: on schedule.

The Level 2 Report X "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 Report X has been submitted to the Federal Highway Administration for review.

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

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

Status and Work Planned
Status: on schedule.

The Level 2 Report Y "Model Water Vapor Diffusion in Pavement and Its Effects on the Performance 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 Report Y has been submitted to the Federal Highway Administration 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 Report Z in NTIS format to FHWA for review.

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 than expected.

The draft practice will be completed next quarter. The revised delivery date for the draft practice is September 30, 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: on schedule.

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: on schedule.

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: on schedule.

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: on schedule.

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: on schedule.

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:
Efforts mainly focused on identifying the RAP sources and sampling materials for the testing experiment.

- Two sources of RAP were identified for the validation of proposed mix design of CIR.
    - California 299 (Old Cedarville Hwy), Alturus, CA
    - Matterhorn Blvd, Lemon-valley, NV
- Both identified RAP materials were sampled along with PASS-R emulsion from Western Emulsions.
- Prepared the draft experimental plan

The following list describes the work planned for next quarter:

- Characterization of RAP materials.
- 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
On Schedule

Work Completed: Results of initial mix design experiment completed, two separate methodologies were developed for calculating mixture volumetric properties based on if the moisture content of the aggregate is below or at/above the SSD condition. A study was designed and initiated to evaluate the effects of replacement of filler with cement on volumetric properties and resistance to moisture.

Work Planned: Additional activities are planned to verify the proposed accelerated curing protocol (72 hours at 60°C) and evaluate mixture performance properties of CMA using current test methods. Validation of the accelerated curing protocol will be conducted by conditioning samples at laboratory conditions for a number of days and comparing tensile strength values with those obtained from samples subjected to accelerated curing.

Delivery Dates
Draft AASHTO Practice: 9/30/2013
Final AASHTO Practice: 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.

Completed Report Z, "Effect of Extraction Methods on the Properties of Aggregates in Reclaimed Asphalt Pavement," in NTIS format and submitted to FHWA for review and input.

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:

- Testing of the field validation samples to relate the thermo-viscoelastic properties of asphalt mixtures to the thermal cracking field performance.
- Testing control specimens for validation of the presented approach for determination of thermo-viscoelastic properties of asphalt mixtures using ATCA device. The approach has been validated for the test results obtained by ATCA.
- Continuous revision of the UTSST draft AASHTO procedure.

The following list the work planned for next quarter:

- Testing the standard aluminum specimens to calibrate the UTSST and ATCA set ups.
- 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: Red-line version of standard detailing suggested revisions to AASHTO TP-91 standard was completed and sent to AASHTO Subcommittee on Materials Tech Section 2a. Revisions to standard were made based on Tech Section 2a comments and new recommendations from the research team based on new research findings.

Work Planned: None, this item is considered 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
Delayed (procedure completed, ruggedness on schedule)

Work Completed: The ruggedness testing plan was completed between the 5 participating labs and the results were reported to the Binder ETG meeting. A revised procedure was also to the Binder ETG. Work is in progress with NCSU on finalizing the procedure used for data analysis procedure and selection of testing temperatures.

Work Planned: Work will be completed on LAS final analysis method and temperature selection. The AASHTO procedure will be updated to include this work and results of ruggedness testing. The final AASHTO procedure and updates will be presented at the Sep 2013 ETG meeting.

Reasons for Delay: Investigate the effects of test temperature and finalize ruggedness study. All revisions are expected to be finalized by the Sep 2013 ETG meeting, without additional delay.

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 (Added based on request by ETG for additional work).
Final AASHTO Method: 9/30/2013, 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: The combined AASHTO standard including the BYET procedure and the DSR Elastic Recovery (ER-DSR) was presented to the Binder ETG in the May 2013 meeting. Appropriate revisions were made and a context document was drafted for support of the document. Furthermore, two meeting were held with WisDOT technical bureau of material after which WisDOT formally declared their support for the implementation of this procedure in an official letter. Submitted draft standard and context document to FHWA.

Work Scheduled: All work is completed, 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
Delayed

Work Completed: Draft AASHTO procedure was submitted to FHWA Mixture ETG for consideration. Context document detailing technical reasons for the need for AASHTO method was prepared.

Work Planned: No further work, will address comments from FHWA/ETG as needed.

Revised Delivery Dates
Draft AASHTO Method: Complete (1/31/2013).
Final AASHTO Method: 6/30/2013. Pending ETG/FHWA comments.

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.

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: Completion of other standards due 6/30/2013 and follow up with the ETG/AASHTO SOM on standards previously submitted required a significant amount of effort. These issues have been addressed, work on the standard will continue next quarter.

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

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: Draft AASHTO procedure was submitted to FHWA Mixture ETG for review and possible presentation.

Work Planned: Present at September FHWA Mixtures ETG meeting if request for review is approved. Revise as needed after review.

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): 9/20/2013
Final AASHTO Standard: 9/30/2013

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
Behind Schedule

Work Completed: Draft standard procedure in AASHTO format was completed and is under internal review.

Work Planned: Complete internal review of draft standard and submit to FHWA Mixture ETG for consideration for inclusion in September 2013 meeting.

Reason for Delay: Internal review of standard was not completed at the time of this quarterly report. The standard will be finalized and distributed next quarter.

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

DRAFT AASHTO TEST METHOD: RAP BINDER PG TRUE GRADE DETERMINATION

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

<u>Status and Work Planned</u>
Completed.

Work Completed: Presented results summarizing application of RAP mortar grading procedure to quantify the effects of time and temperature on blending between virgin and recycled binder to the FHWA Mixture ETG. The procedure represents an improved method of measuring the actual blending that occurs during mixing and compaction relative to current practice, which assumes the same value of blending regardless of recycled material source or type (RAP vs. RAS). Revised standard based on results to state that mortar grading is significantly impacted by mixing temperature and time, thus it is recommended that conditions of the field are used in preparation of laboratory samples. The ETG decided to suspend decision on recommending the procedure for consideration of the AASHTO SOM and requested an update presentation at the next meeting. Received materials from two ARC field validation sites (AZ and CO) for application of the procedure to field produced materials.

Work Planned: Standard is complete and has been presented to ETG. Will address future comments as necessary.

<u>Delivery Dates</u>
Draft AASHTO Test Method: Completed (9/30/2012)
Presentation at Mix ETG Meeting: Completed (4/30/2013).
Presentation at Mix ETG Meeting: 9/20/2013
Final AASHTO Test Method: 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: Analytical work with use of pseudo strain and numerical FEM analysis was performed to investigate energy mechanisms contributing to SENB failure and use of these parameters as the SENB characterization index. Testing was also expanded to mastics and mortars to investigate applicability of time-temperature superposition to SENB failure.

Work Planned: Based on request of the ETG a small study will be performed to investigate the cooling fluids used in the SENB, specifically comparing Ethanol and Potassium Acetate. Furthermore a inner-laboratory ruggedness testing will be performed to investigate the effect of various setup parameters and conditions. A follow-up presentation may be given at the September 2013 Binder ETG meeting if requested.

Reasons for Delay: Scope of work was increased due to request of ETG to determine effect of cooling fluids and run inner-laboratory ruggedness test.

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: 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: Completed draft AASHTO Standard. Document was submitted to FHWA for presentation to FHWA Binder ETG.

Work Planned: Presentation at Sep 2013 Binder ETG Meeting if 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: The mixture glass transition temperature is complete and has been incorporated in the combined ATCA-UTSST standard procedure developed in conjunction with 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)

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: The draft AASHTO standard was submitted to FHWA Mixture ETG. Additional research was performed on the mechanisms through which the derived indices out of image analysis can lead to design of mixtures with better performance.

Work Planned: Conduct sensitivity analysis of selected threshold filter ranges on aggregate imaging results. Develop context document to justify inclusion as a draft AASHTO standard and submit to FHWA. Present at FHWA Mixture ETG September meeting as requested.

Delivery Dates
Draft AASHTO Method: 3/31/2013
Presentation to Mix ETG (if necessary): 9/20/2013
Final AASHTO Standard: 9/30/2013 (6 months after initial submittal)

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: Comments from ASTM committee reviewing standard were received. Memo summarizing current status of ASTM standard including proposed revisions to standard, improved data analysis procedures, and action items was submitted to equipment manufacturer. Video summarizing test procedure was developed. Conference call with equipment manufacturer and University of Arkansas was held to discuss ASTM comments and develop a plan to address them.

Work Planned: Address ASTM comments and submit for review. Conduct initial precision and bias statement in cooperation with University of Arkansas. Based on results design ILS study for development of complete precision and bias statement.

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: 9/30/2013 (extended from 6/30/2013).

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: on schedule.

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 equipment problems with one of our AFM systems only minimal imaging work was conducted on this subtask this past quarter. However, significant progress was made working with archival data. 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
The need to share equipment is delaying progress on this subtask. To accommodate equipment sharing and add stress rate to the method we anticipate a six month delay for this deliverable. Some additional work is being conducted to demonstrate the effect of stress-rate on this important parameter. A draft AASHTO to determine the ductile-brittle transition temperature *as a function of stress rate* is the expected product.

Development of this test method will continue in the next quarter. An AFM-based direct tension test is being employed to assess ductile-brittle properties of asphalt binders. Results indicate that the transition is sensitive to stress rate as well as temperature. Work next quarter will be directed toward variable stress rate testing using our AFM direct tension test with smaller temperature increments. 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

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: FHWA Mixture ETG declined review of draft AASHTO standard, coordination efforts with FHWA to identify other venues for review of the standard were pursued. Verification of standard procedure was conducted on additional mixes for a related research project.

Work Planned: Continue to pursue other opportunities for review. At a minimum, the procedure will be included as 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:

- Completed the subroutine to predict the pavement temperature profile. The pavement temperature profile model has been validated using LTTP data.
- Completed the subroutine to predict asphalt pavement oxidation. The laboratory aging and field aging validations 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.

The following list the work planned for next quarter:

- Validate the software to predict the carbonyl area growth as a function of time by comparing the prediction with the laboratory measured values.
- Develop the full package for calculation of thermal stress in asphalt pavement considering the effects of aging and nonlinear thermal coefficient of contraction.
- Evaluate the feasibility of including the effect of physical hardening to thermal cracking predictions.

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.

Most of the work done in this quarter focused on the following: (1) Releasing 3D-Move Analysis version 2.1; (2) Developing new platform for next 3D-Move version (Ver. 3); and (3) maintained the 3D-Move Forum.

Releasing 3D-Move Version 2.1
After releasing the last beta-version of the *3D-Move Analysis* (ver. 2.0) in February 2013, there have been some problems and questions related to pavement responses and performance models. There were some bugs in the software that were inadvertently overlooked. The *3D-Move Analysis* (ver. 2.1) was released in June 2013 and this version addressed those issues. Important problems which were fixed in this new version are listed below:

1. Displaying of error messages when using performance calculation option with the International System of Units (SI);
2. Improper use of the dynamic modulus (E*) master curve developed in SI units with the performance models;
3. Installation of the software on 64 bit Windows operation system;
4. The slight differences in responses calculated by 3D-Move version 1.2 and version 2.0 for dynamic load analysis cases;
5. Modification of traffic information input section (eliminating unnecessary input values which created confusion to users).

New Platform for Next Version (Ver. 3)
The other work done in this quarter includes developing a new platform for next version of 3D-Move (Ver. 3). The main features of this platform are:

- Capability of running two or more projects simultaneously by using parallel processing technology (40% progress);
- Incorporation of additional empirical procedures that are available to calculate asphalt dynamic modulus (5% progress);
- Interchangeability between SI and US unit systems, in the middle of a 3D-Move run (10% progress);
- Use of Artificial Neural Network in the interpolation of non-uniform tire contact pressure distribution from the database (60% 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:

- 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 addition of RAP binder influences binder properties, the rheological parameter G'/(η'/G') at 15°C and 0.005 radians/second developed by Glover (Glover et al. 2005) was employed to investigate the cracking potential of the virgin asphalt/RAP blends. Blends of RTFO-aged virgin asphalt with various percentages of extracted RAP asphalt were prepared and rheological properties obtained. Two different virgin asphalts and two different extracted RAP asphalts were used. Glover's study suggests that the pavement will tend to initiate fatigue cracking, due to aging, when the parameter of G'/(η'/G') exceeds 9.00E-04 MPa·s. The results show that when about 20% RTFO-aged asphalt AAA-1 mixes with about 80% extracted South Carolina RAP asphalt, the blend will be at the limit for the cracking potential parameter. On the other hand, when RTFO-aged asphalt AAA-1 is blended with extracted Manitoba RAP asphalt, the blends do not reach the limit for the cracking potential parameter in any proportion.

Similar blends were prepared using RTFO-aged asphalt AAC-1 and extracted RAP asphalts from South Carolina and Manitoba. In this case, the results show that the blends with South Carolina RAP asphalt reach the cracking parameter limit at a lower concentration than the blend with RTFO-aged asphalt AAA-1. When RTFO-aged asphalt AAC-1 is mixed with extracted Manitoba RAP binder, the results indicate that the cracking parameter value (G'/(η'/G')) is less at all concentrations than the cracking parameter value for the RTFO AAA-1/Manitoba RAP binder blends. Even though both the AAA-1 and AAC-1 blends with extracted Manitoba RAP binder never reach the limit of the cracking parameter value at any concentration, the AAC/ Manitoba RAP blends exhibit lower values at the same concentration. This is just opposite from what the extracted South Carolina RAP binder blends show with these two asphalts. These results suggest that the same RAP binder interacts with different asphalts differently.

Work Planned Next Quarter

Work will continue on obtaining rheological and blend data on virgin asphalt/extracted RAP asphalt blends.

A technical paper on the influence of RAP contents to chemical and rheological properties of neat asphalts will be prepared.

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

Work Done This Quarter

Extensive work was completed at the low, intermediate, and high temperatures, as well with regards to moisture damage resistance. Extender modified materials were prepared with two base binders and a range of petroleum based, bio-based, re-refined waste oil extenders and subjected to SENB, BBR, and extended BBR testing (physical hardening) to fully assess effect at low temperatures. LAS testing were also performed for both based on binders and the effect of the extenders on fatigue resistance was assessed. BBS and the mixture boiling test were used to investigate any possible effect of extenders on moisture damage susceptibility. DSC and GPC tests were also carried out to determine nature and mechanisms of effect of extenders binder chemical structure and behavior.

Work Planned Next Quarter

Efforts will continue to complete the experimental plan established for E3a in the coming quarter. The results of this work will be integrated into Report N.

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: 9/30/2013
Due Date for Final Report Submittal: 6/30/2014

Significant Problems, Issues and Potential Impact on Progress

None.

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

Development of the evaluation framework for fresh emulsion and emulsion residue properties was completed. The framework uses three devices: the Brookfield Rotational Viscometer and BBS test for fresh emulsions, and the DSR and BBS test for emulsion residues. A total of 20 emulsions have been tested including those applied to chip seals, spray seals, and micro-surfacing. The approach used in development of the framework was presented at the P3 symposium.

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-MARC 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: 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

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.

Work Element E3c: Laboratory Assessment of Mixture Long Term Aging

Work Done This Quarter

Experimental and theoretical work continued this semester to define the critical properties of mineral aggregates that affect aging, through evaluation of asphalt mastics. Additional emphasis was placed on evaluation of effect of diffusion and aging film thickness, especially as used in the PAV, thus additional aging processes were performed using two techniques to calculate the film thickness: 1. holding total material thickness constant, and 2. holding binder film thickness constant. Aging evaluation was carried out both by looking at the aging index as defined by the ratio of complex shear modulus before and after aging as an indicator of effect on mechanical properties, and change of glass transition temperature through dilatometric Tg measurements as a measure of brittleness changes through aging.

Work Planned Next Quarter

Work plan testing will be completed over the next two quarters and used to develop either a long term mixture aging test using asphalt mastics, or modifying current binder aging models with practical aggregate specific factors to enable aging potential prediction. Team will collaborate with UNR on mixture and field validation of concepts using long term aged mixtures.

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 Z."

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

Significant Problems, Issues and Potential Impact on Progress

Work is ongoing with WRI to validate the adsorption of asphaltenes mechanism identified in the preliminary findings of this work. An extension of three months is requested to provide more time for this work.

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

Work Done This Quarter

The project team at WRI and NCAT prepared for and sampled a field project on I-70 between Eagle and Wolcott, Colorado. The four mixtures used for these sections were based on two mix designs with 20% and 30% RAP. Each mix design was produced hot and warm with foaming WMA. This project was also a demonstration project for using the IR bar on the paver to collect real-time mat temperatures. NCAT continued laboratory testing of the materials sampled from the I-84 project in CT and the CR 159 in AL. The testing is almost complete. Laboratory testing for other projects is underway at NCAT.

Work Planned Next Quarter

The NCAT team will continue testing the materials sampled from the field projects. In addition, the team is preparing for a field project that is planned to be built in Indianapolis, IN in the third week of August. The four mixes used in these sections are based on the same mix design but produced hot and warm in two plant types (a counter flow drum plant and a patch plant). Data from this field project will be shared between this task and NCHRP 9-52.

WRI personnel are planning to monitor the Manitoba WMA site in the next quarter. This will occur in coordination with the monitoring of the Manitoba RAP site.

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.

Work Planned

The NCAT team is preparing for construction of three sections on Route 7 in Cass County, MO. The mix used in the control section is a 30% RAP mix with a PG 70-22 binder. The second section will be constructed with a PG 70-22 mix design that has 40% AC replacement from RAP and a rejuvenator. The third section will be built with another PG 70-22 binder that has 40% AC replacement from RAP and RAS and a rejuvenator. The rejuvenator used in the mixes is HydroGreen at the manufacturer’s recommended rates.

The WRI team is planning to monitor the Manitoba RAP project. This will occur in coordination with the Manitoba WMA site monitoring.

If the schedule permits, the Minnesota site will be monitored.