Western Research INSTITUTE

Asphalt Research Consortium

Quarterly Technical Progress Report
April 1 – June 30, 2008

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By
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TABLE OF CONTENTS

INTRODUCTION

This document is the Quarterly Report for the period of April 1 to June 30, 2008 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, and Advanced Asphalt Technologies.

The Quarterly Report is grouped into seven areas, Moisture Damage, Fatigue, Engineered Paving Materials, Vehicle-Pavement Interaction, Validation, Technology Development, and Technology Transfer. The format of the report is based upon the Research Work Plan that is grouped by Work Element and Subtask.

This Quarterly Report summarizes the work accomplishments, data, and analysis for the various Work Elements and Subtasks. This report is being presented in a summary form in response to a request from the FHWA Agreement Officer's Technical Representatives (AOTR's) Dr. Jack Youtcheff and Mr. Eric Weaver. The more detailed information about the research such as approaches to test method development, data collection, and analysis will be reported in research publications as part of the deliverables. Reviewers may want to reference the Year 2 Work Plans in order to obtain background information on specific areas of research. An updated version of the Year 2 Work Plan with additional information that was requested by the reviewers of the Year 2 Work Plan is being prepared and will be posted on the ARC website, www.arc.unr.edu, in the Fall of 2008.

The Year 1 and Year 2 Work Plans, quarterly reports, and other related documents and information about the Asphalt Research Consortium can be found at the ARC website, www.arc.unr.edu.

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.

GENERAL CONSORTIUM ACTIVITIES

PROGRESS THIS QUARTER

A substantial amount of time and effort was spent by Consortium members during the quarter preparing revised work plans for some Work Elements/Subtasks, additional background information, responding to reviewers questions, and preparing additional material requested including white papers and Gantt charts. The Year 2 Work Plan was submitted to FHWA Co-AOTR's Dr. Jack Youtcheff and Mr. Eric Weaver on January 30, 2008 followed by presentation at the ETG meetings in February 2008 and review by ETG members and FHWA personnel. After several conference calls and delivery of the additional material, the Year 2 Work Plan was approved in early August 2008.

ARC members attended the RILEM meeting in Chicago in June and made extensive presentations at the subsequent Fundamental Properties and Advanced Models ETG meeting. The Models ETG presentations were directed at comparing and explaining the different modeling efforts in the Consortium work plan and providing the rationale in using different modeling approaches.

WORK PLANNED FOR NEXT QUARTER

ARC members will attend the Binder and Mix & Construction ETG meetings in Reno, Nevada in mid-September. The University of Wisconsin team will present new findings in the binder fatigue testing area.

PROGRAM AREA: MOISTURE DAMAGE

CATEGORY M1: ADHESION

Work Element M1a: Affinity of Asphalt to Aggregate (UWM)

<u>Work Done This Quarter</u>

The team has continued to conduct stress sweep experiments following the proposed testing matrix. Two base binders from two different sources, containing different asphaltene percentages, are being evaluated: a Flint Hills PG 64-22 binder containing 16% wt asphaltenes and a Milwaukee tank farm blend, CRM PG 58-28 binder containing 9% wt asphaltenes. The tests are being conducted in both dry and wet conditions. The aggregates used in this quarter's work were limestone disks. The team has also prepared granite aggregate disks which it will begin testing for the next quarter. During this quarter the team also investigated the possibility of using only one rock disk paired with a steel plate for parallel plate testing rather than two rock disks. This line of investigation was intended to improve the test method and to help answer some of the critical questions raised by reviewers.

<u>Significant Results</u>

Notable results obtained this quarter provided an insight on different testing configurations employed in the dynamic shear rheometer (DSR) instrument. The team has tested and compared the repeatability of a rock and steel parallel plate geometry (figure M1a.1). In this setup the rock disk was the lower plate.

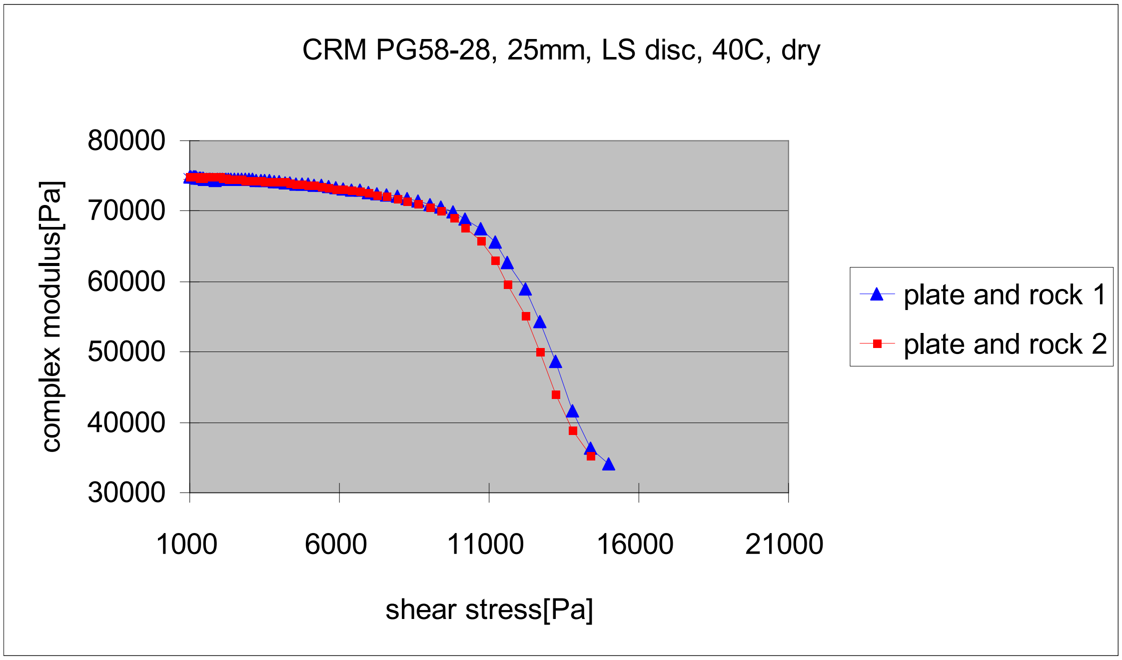


Figure M1a.1. Graph. Repeatability of metal and rock parallel pate geometry testing, using a limestone disk as the lower plate.

When testing and comparing two rock plates in parallel plate geometry versus one rock disk and one steel plate, the results are very similar but not identical. This is shown in figure M1a.2.

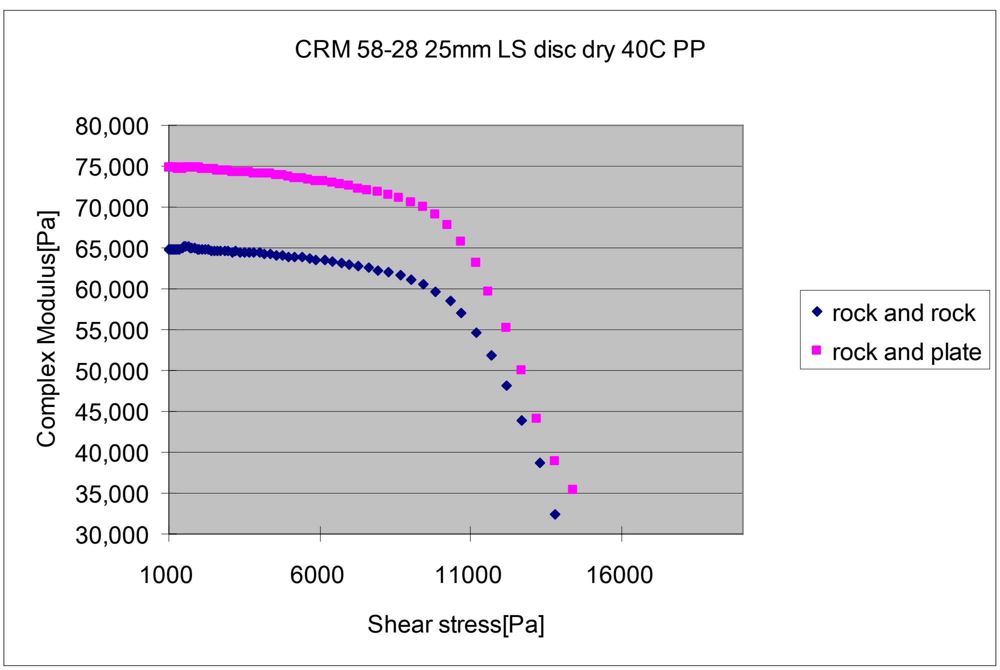


Figure M1a.2. Graph. Two rock disks versus one rock disk and one steel disk, using a parallel plate geometry.

This leads the team to believe that it should be able to rank the materials similarly using just one rock disk rather than two per test. Further testing is needed and will be performed in order to confirm this theory.

Materials were tested in wet versus dry conditions; a sample test is shown in figure M1a.3. As Cho and Bahia (2007) have shown previously, the wet-tested sample exhibited a shorter linear domain and showed signs of failure earlier than the same material tested in dry conditions. The summary results collectively indicate that using the modified DSR procedure for testing moisture damage resistance of binders will help provide valuable insight on characterization of binder damage resistance.

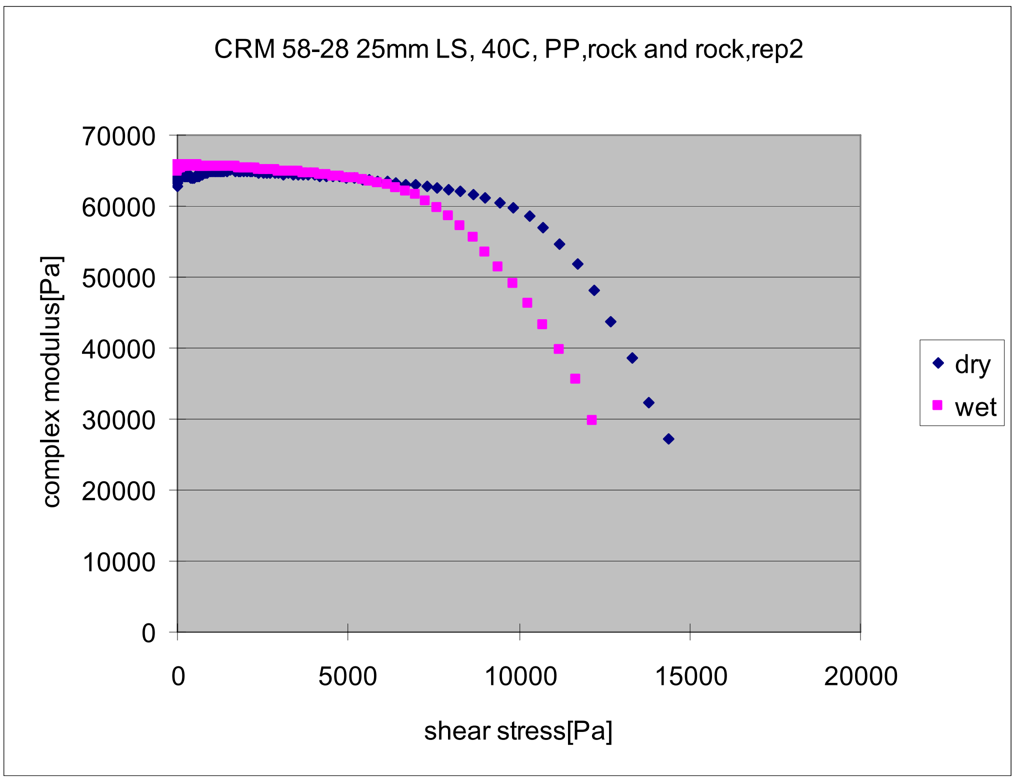


Figure M1a.3. Graph. Stress sweep testing in dry versus wet conditions.

Also during this quarter, research was performed on running the tack test in the DSR utilizing 25 mm parallel plates. This was done with the purpose of using aggregate disks as one of the plates in the test. The information obtained in this fashion will be similar to that sought from the modified Pneumatic Adhesion Tensile Testing Instrument (PATTI) device. As summarized in table M1a.1 and table M1a.2, conditioned and unconditioned samples can be run in both wet and dry environments. In the tables, **Tf** stands for the tack factor, which is the area under the stress versus deformation curve from the DSR.

Table M1a.1. Summary of tack test results using 25 mm diameter geometry, unconditioned.

Test Temp ºC	**Speed (mm/s)**		
	0.007	0.01	0.007 w/ watercup
50 ºC	Tf = 140 Tf = 154 Tf = 126	Tf = 171	Tf = 121 x x
70 ºC	Tf = 25		Tf = 20

Table M1a.2. Summary of tack test results using 25 mm diameter geometry, conditioned.

Test Temp ºC	Condition Temperature ºC	
	40 ºC	60 ºC
50 ºC	x x	Tf = 100
70 ºC	Tf = 12	

Significant Problems, Issues and Potential Impact on Progress

No significant problems have been encountered for this quarter. However, the team is waiting for a final response from the AOTR regarding the required work plan modification based on review of the Year Two Work Plan.

Work Planned Next Quarter

Work during the next quarter will focus on completing the experimental matrix as described in the submitted Year Two Work Plan. If approved by the AOTR, the team will start cone-rock testing for comparison purposes.

Cited References

Cho, D. W. and H. U. Bahia, 1998, Effects of Aggregate Surface and Water on Rheology of Asphalt Films. *Transportation Research Record 2007*, (-1), 10-17.

Work Element M1b: Work of Adhesion Based on Surface Energy

Subtask M1b-1: Surface Free Energy and Micro-Calorimeter Based Measurements for Work of Adhesion (TAMU)

<u>Work Done This Quarter</u>

No activity was planned for this quarter.

<u>Significant Results</u>

None.

<u>Significant Problems, Issues and Potential Impact on Progress</u>

None.

<u>Work Planned Next Quarter</u>

Work on this subtask is planned for the last quarter.

Subtask M1b-2: Work of Adhesion at Nano-Scale using AFM (WRI)

<u>Work Done This Quarter</u>

The detailed work plan was submitted as part of the Year 2 Work Plan.

<u>Significant Results</u>

None.

<u>Significant Problems, Issues and Potential Impact on Progress</u>

None.

<u>Work Planned Next Quarter</u>

Begin work at WRI and start subcontract approval process through the AO.

Subtask M1b-3: Identify Mechanisms of Competition Between Water and Organic Molecules for Aggregate Surface (TAMU)

<u>Work Done This Quarter</u>

This subtask investigates the mechanisms responsible for adhesion and debonding of model organic compounds (representing functional groups in asphalt binder) to minerals and representative aggregates. We are measuring the heat of reactions of the chemical mechanisms using a dual-mode flow adsorption calorimeter. Differences in molar heats of reaction of different organics bonding to the same absorbent are indicative of differences in the bonding strength of each absorbate with the absorbent of interest.

Work during this quarter focused on continued development of the instrument. In particular, we integrated a ultraviolet-visible spectrophotometer with the dual-mode flow adsorption calorimeter to provide continuous monitoring of the solution concentration of the organic compounds. In addition, we established the reproducibility and accuracy of the calorimeter by repeated measurements of the molar heats of reactions of benzoic acid adsorption and desorption to silica at pH 3 during flow-through experiments.

Significant Results

Our calorimeter exhibited excellent reproducibility and accuracy (table M1b.1) as shown by repeated measurements of the molar heats of reactions of benzoic acid adsorption and desorption to silica at pH 3 during flow-through experiments (figure M1b.1 and M1b.2). Standard deviations were less than 10% of the mean molar heats of reactions for repeated experiments.

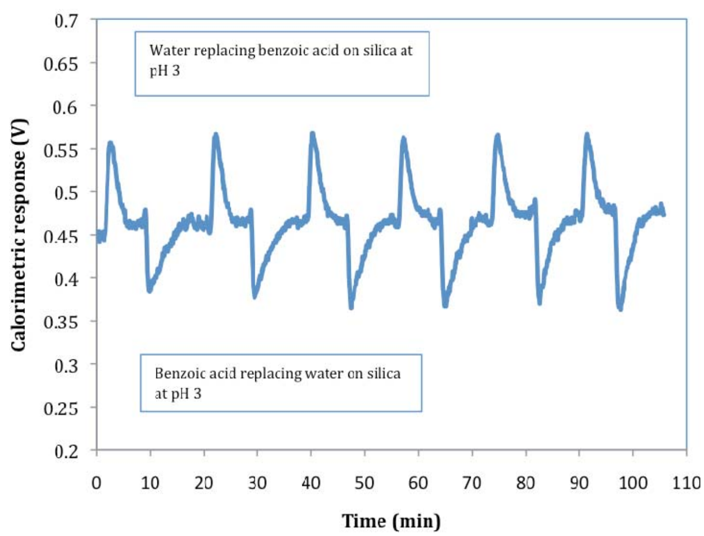


Figure M1b.1. Response (volts) of the calorimeter during repeated cycles of the adsorption and desorption of benzoic acid to silica (>150 micron). Experimental conditions include 200 mg Si reacting at pH 3.

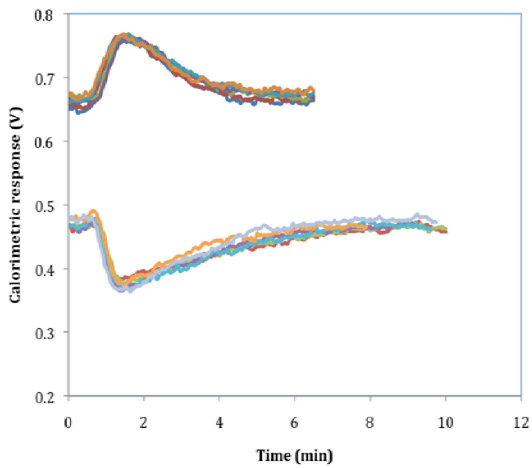


Figure M1b.2. Repeatability of the calorimeter response during repeated cycles of the adsorption and desorption of benzoic acid to silica (>150 micron). Experimental conditions include 200 mg Si reacting at pH 3.

Table M1b.1. Heat of reaction of the adsorption and desorption of benzoic acid to silica (>150 micron). Experimental conditions include 200 mg Si reacting at pH 3.

	Heat of Reaction (mJ/g silica)	
Run	Water/Benzoic Acid	Benzoic Acid/Water
1	-109.0	128.5
2	-96.0	132.5
3	-95.5	154.0
4	-93.5	136.5
5	-105.5	113.5
6	-88.5	141.0
Mean	**-98.0**	**134.3**
Std Dev.	**7.0**	**12.3**

Significant Problems, Issues and Potential Impact on Progress

There are no significant issues.

Work Planned Next Quarter

We plan on initiating flow through experiments to measure the molar heat of reaction of the adhesion of model organic compounds that represent asphalt to minerals and aggregates, as well as the molar heats of reactions of water adsorption to organic-coated minerals and aggregates. Adhesion will be modeled in the flow-through calorimeter by organic sorption from nonaqueous phase solvents. Experimental variables include the chemistry of the model organic, single versus mixtures of model organics, ionic salt content of the nonaqueous phase solvent, and the surface chemistry of the mineral or aggregate.

Competition of water and the model organics for the mineral or aggregate surfaces will be characterized through flow-through experiments that introduce small amounts of water to the systems created during the adhesion studies above.

Work Element M1c: Quantifying Moisture Damage Using DMA (TAMU)

Work Done This Quarter

No activity was planned for this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Work on this task will start in year 3 of the project.

CATEGORY M2: COHESION

Work Element M2a: Work of Cohesion Based on Surface Energy

Subtask M2a-1: Methods to Determine Surface Free Energy of Saturated Asphalt Binders (TAMU)

Work Done This Quarter

No activity was planned for this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Work on this task is anticipated to start in year 4 of the project.

Subtask M2a-2: Work of Cohesion Measured at Nano-Scale using AFM (WRI)

Work Done This Quarter

The detailed work plan was submitted as an addendum to the Year 2 Work Plan. The preparation of the detailed work plan was the first planned activity for Year 2.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Begin work at WRI and start subcontract approval process through the AO.

Work Element M2b: Impact of Moisture Diffusion in Asphalt Mixtures

Subtask M2b-1: Measurements of Diffusion in Asphalt Mixtures (TAMU)

Work Done This Quarter

Significant advances were made towards the development of a test method to measure the diffusivity of water through a thin film of asphalt binder using an FTIR. Recent advances include, development of a method to fabricate thin films with optimal thickness (figure M2b.1), a procedure to measure thickness of the bitumen film and its refractive index (figure M2b.2), and a procedure to measure diffusivity of water through thin films of asphalt binders (figure M2b.3).

Figure M2b.1. Spin coater being used to cast thin films of the binder on a Zn-Se FTIR window.

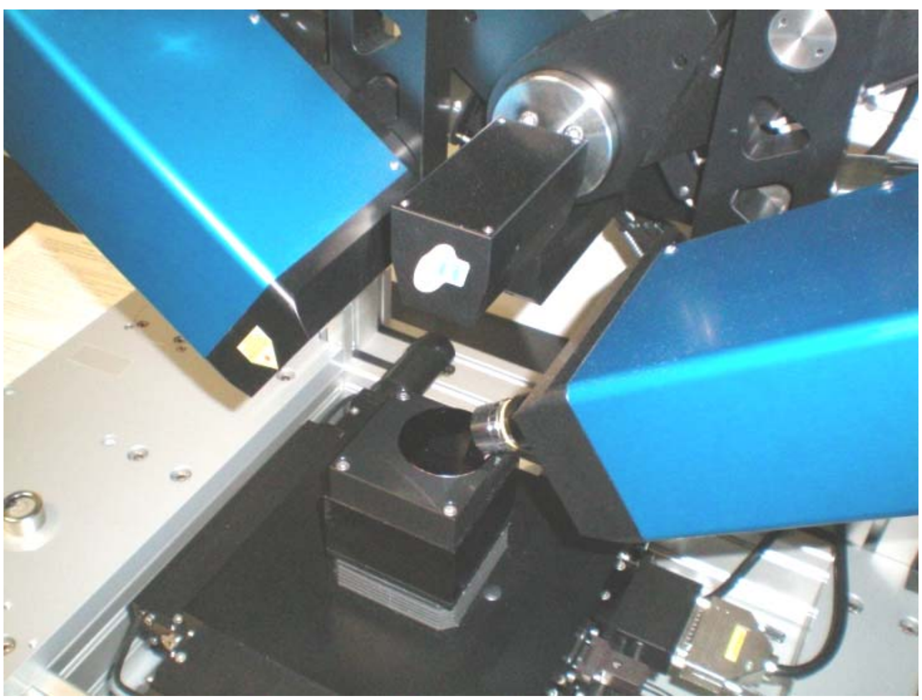


Figure M2b.2. Ellipsometer being used to measure the thickness of the thin film and its refractive index.

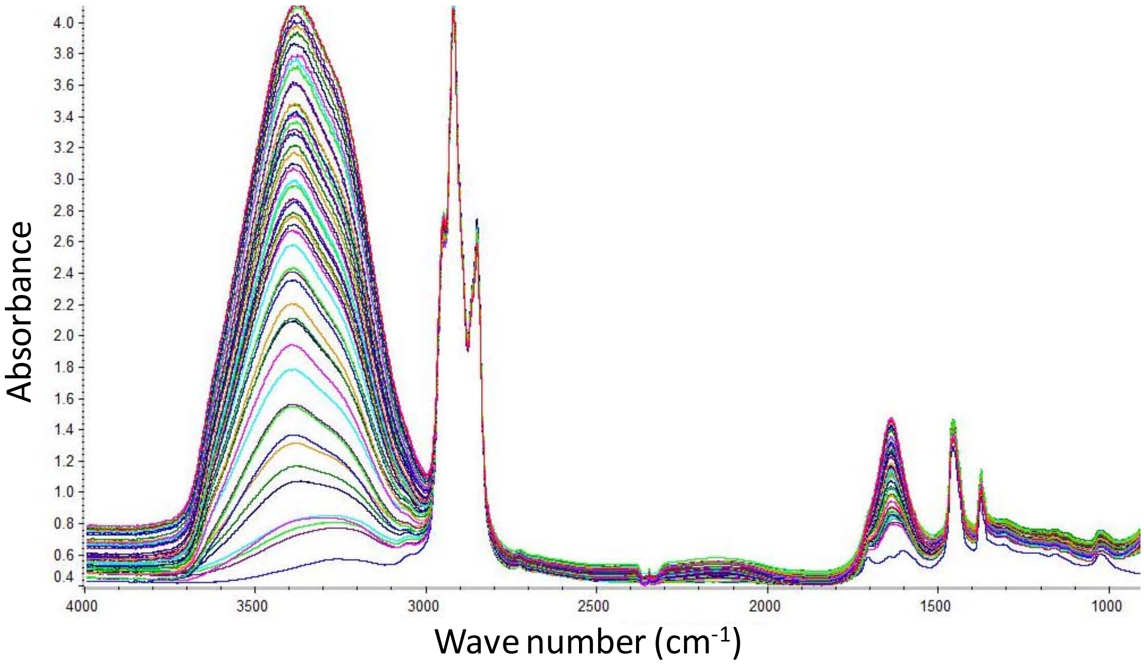


Figure M2b.3. Typical spectra indicating the increase in moisture concentration over time obtained for asphalt binder AAD (film thickness of about 1600 nm).

Significant Results

Determining the optimal film thickness for use with the FTIR to measure the diffusivity of water was found to be a critical step for the following reasons. Diffusivity of very thin films (typically thinner than 100 nanometers) can decrease by orders of magnitude with the decrease in film thickness as compared to the diffusivity of the bulk material (Vogt 2007). Therefore, it is important to use a film thickness that is representative of the properties of the bulk. However, the use of very thick films has two limitations. First, thicker films will result in longer testing time for the film to get saturated. Second, the film thickness should not exceed the effective depth of penetration for the IR beam on the ATR-IR cell. Therefore, it was critical to determine the optimal film thickness that should be used to prepare specimens. Based on some preliminary trials, it appears that a film approximately 1 to 2 microns thick is optimal for use with the FTIR. Initial data from the FTIR indicates that the diffusion characteristics of water through thin films of the asphalt binder appear to be as expected (figure M2b.4).

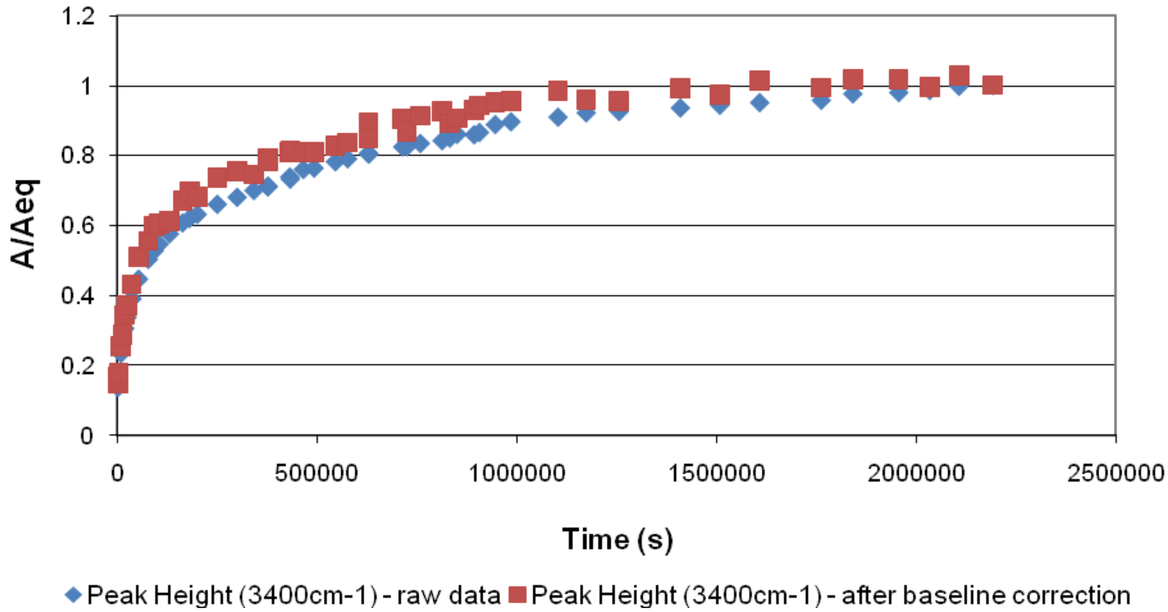


Figure M2b.4. Normalized absorbance for the peak corresponding to water over time (binder AAD with 1600 nanometer thick film)

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Measurements using the FTIR to determine the diffusivity of water through asphalt binders will be continued through the next quarter. Emphasis in the next quarter will be to, establish the repeatability of the test method; evaluate sensitivity of the test method to changes in film thickness and type of binder; establish a method to test multiple specimens at the same time using a single FTIR; and conduct preliminary analysis of the data.

Cited References

Vogt, B.D., 2008, Moisture Distribution and Transport in Polymers in Confined Spaces. *Proc.*, 2nd International Workshop on Moisture Damage, College Station, Texas, September 2008.

Subtask M2b-2: Kinetics of Debonding at the Binder-Aggregate Interface (TAMU)

Work Done This Quarter

Most of the work accomplished under subtask M2b-1 also directly relates to this subtask. The most significant difference in this subtask is that a portion of the binder-ATR window interface will be purposefully exposed to be in direct contact with the water. This will allow the water to diffuse through the film as well as propagate along the binder-ATR window interface.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Preliminary tests will be conducted to develop a test procedure by which the rate of debonding at the binder-window interface will be determined.

Work Element M2c: Measuring Thin Film Cohesion and Adhesion Using the PATTI Test and the DSR (UWM)

Work Done This Quarter

During this quarter, the research team focused its activities on the following issues:

1. Evaluation of displacement history in the modified pullout system response and validation of the modified Pneumatic Adhesion Tensile Testing Instrument (PATTI) test methodology
2. Parametric study of the system sensitivity for the evaluation of adhesion and cohesion of different mineral aggregate and neat and modified binder systems
3. Evaluation of the methodology to characterize adhesive and cohesive failures

The following set of parameters was included in testing:

- Three different surfaces: granite, limestone, and clean glass
- Three different binders: neat Flint Hills (FH) performance grade (PG) 64-22 binder, PG 70-22 styrene butadiene styrene (SBS)-modified binder, and PG 70-22 Elvaloy-modified binder
- Two different bonding temperatures: 65 °C and 135 °C
- Different pullout rates: slow and fast

Combinations of parameters were tested and analyzed (over 200 tests were run). A draft report was completed summarizing all the results and analysis.

Significant Results

- A modification of the pullout test was proposed to allow measuring pullout tension and deformation histories. The methodology included a detailed procedure for specimen preparation and testing (shown in figures M2c.1 and M2c.2).
- The aim of the test was to improve the evaluation of the mineral-binder adhesive and binder cohesive properties and the effects of moisture damage within the binder and at the mineral-binder interface.
- The test and methodology was used for a number of different binders, mineral surfaces, pressure rates, and binding temperatures. Figures M2c.3 through M2c.6 present examples of the evaluation of some of these parameters.
- The methodology was found reliable in evaluating maximum pressure at failure but was unable to give reliable displacement measurements, as the coefficient of variation was extremely large. Figures M2c.7 and M2c.8 summarize the problems encountered during testing including large coefficients of variation in the calculated energy of deformation.
- Experimental results show significant effects of binding temperatures and types of binders. These phenomena should be further explored.

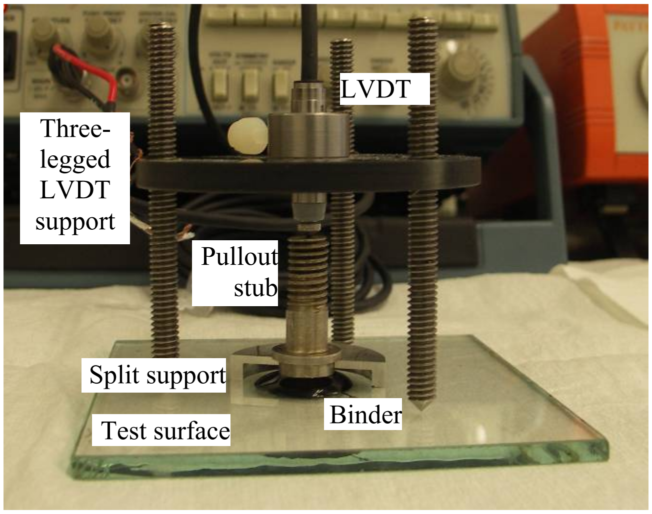


Figure M2c.1. Photograph. The ensemble modified PATTI test setup (the PATTI pressure ring is not shown).

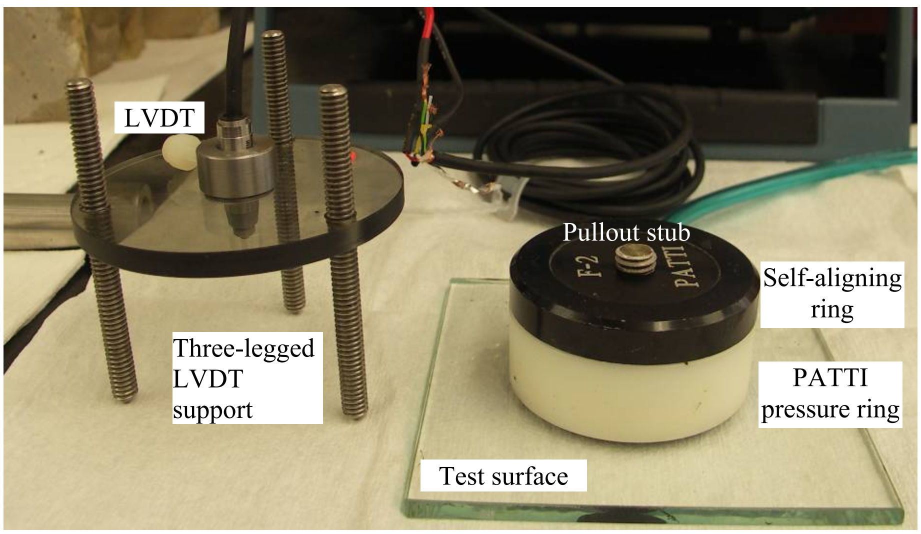


Figure M2c.2. Photograph. The ensemble modified PATTI test setup (the PATTI pressure ring is not shown).

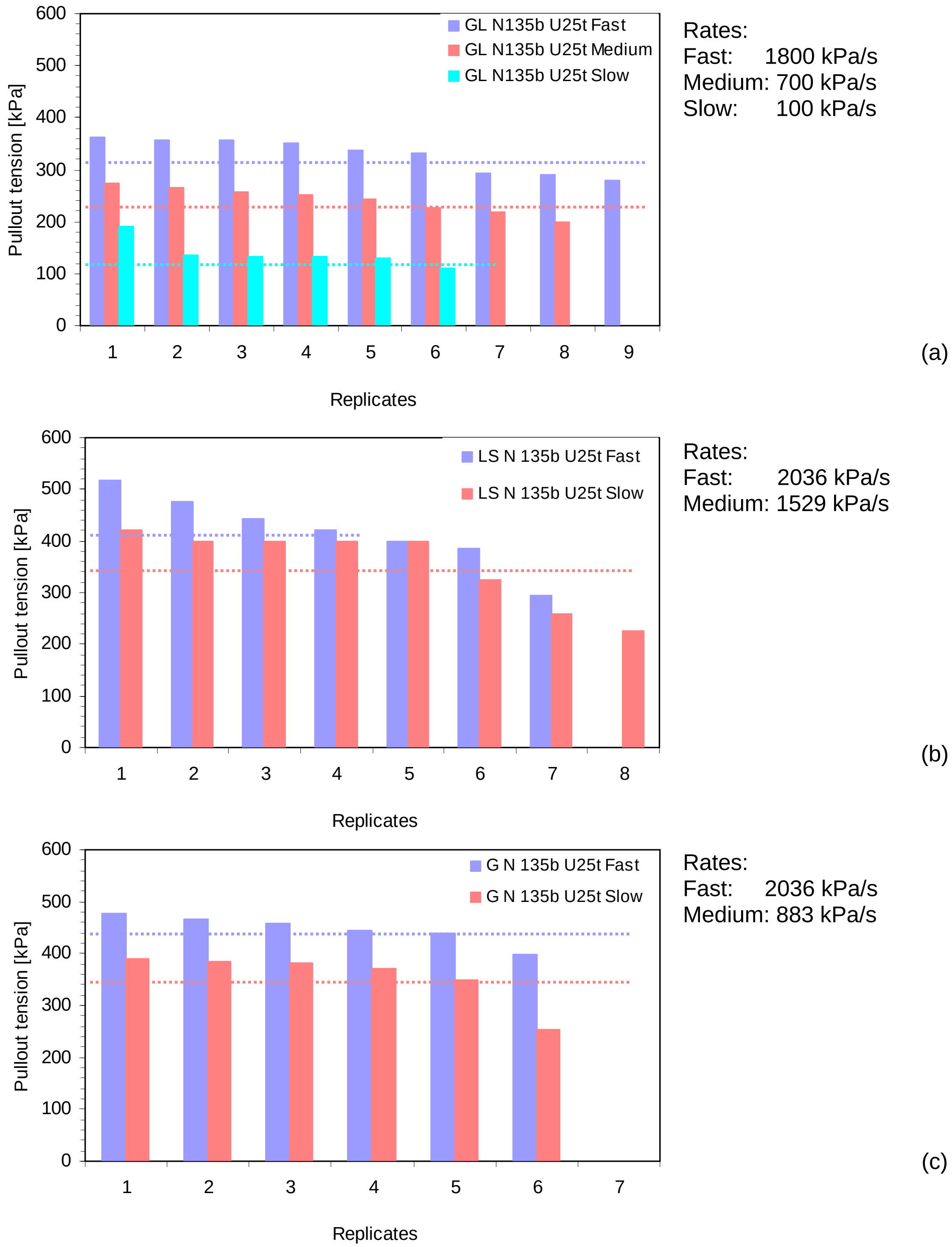


Figure M2c.3. Graphs. Effect of pressure rates on pullout tensions: (a) glass, (b) limestone, and (c) granite. The rate of pressure applied on the aggregate-binder system does increase the deformation rate and therefore the measured pullout tension.

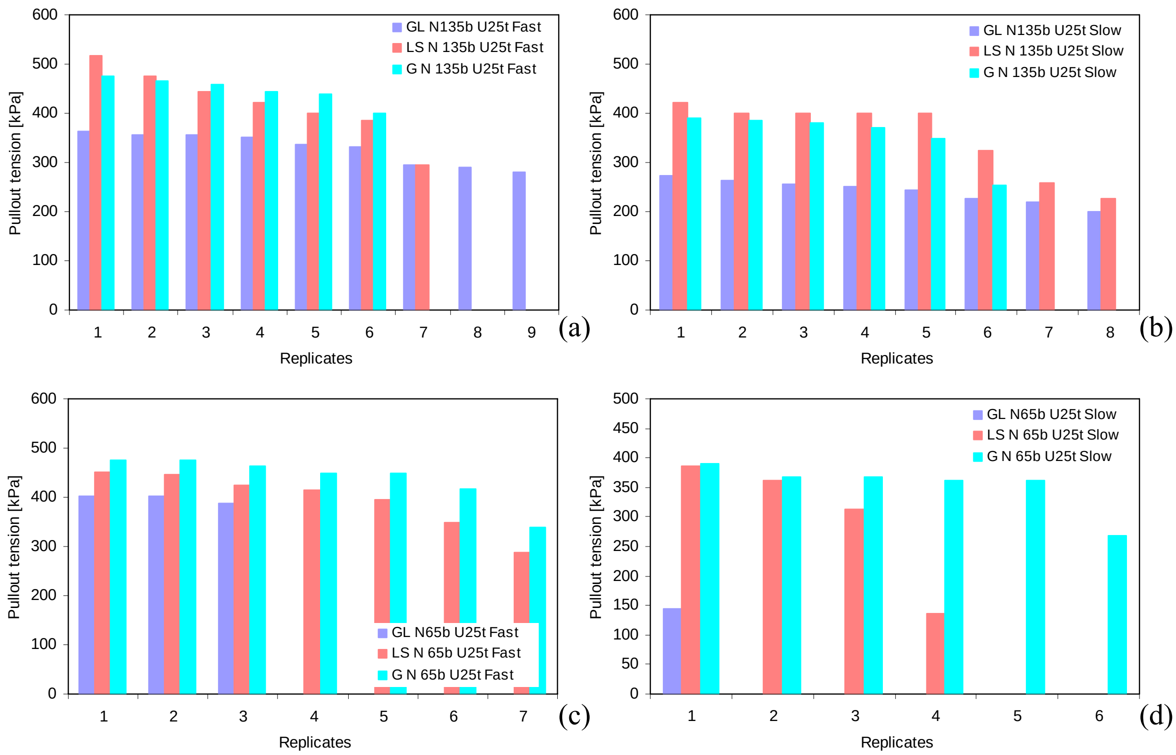


Figure M2c.4. Graphs. Effect of mineral surfaces on the pullout tension response of neat binder: (a) fast loading rate and 135 ºC bonding temperature, (b) slow loading rates and 135 ºC bonding temperature, (c) fast loading rate and 65 ºC bonding temperature, (d) slow loading rate and 65 ºC bonding temperature.

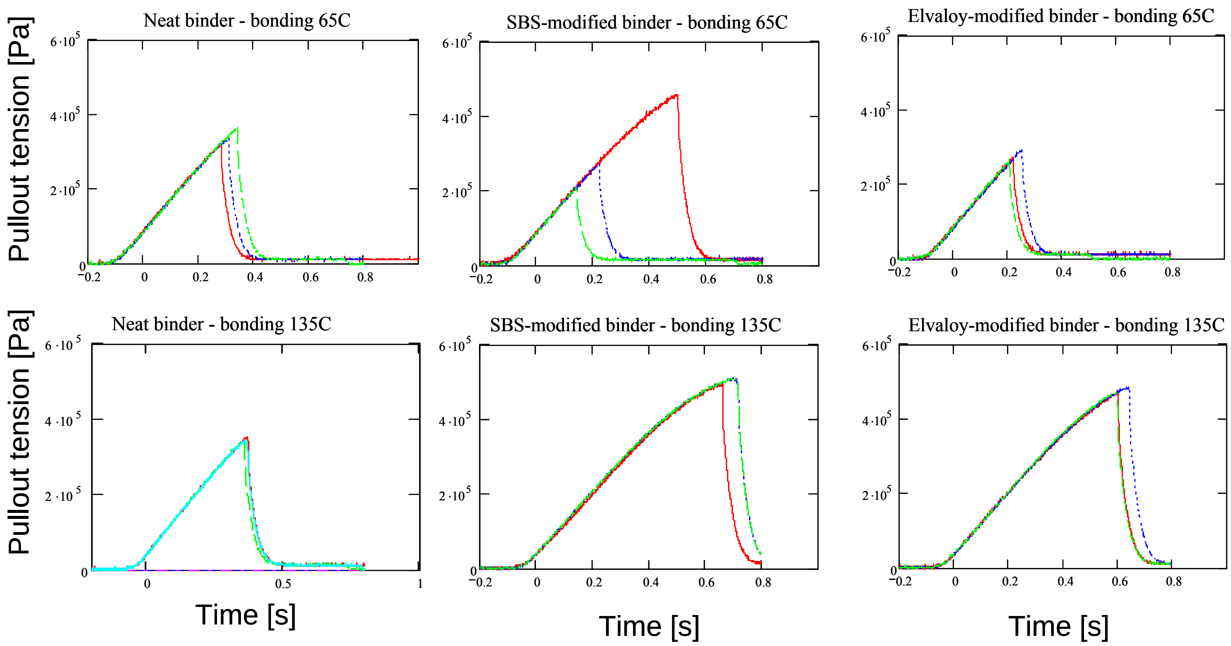


Figure M2c.5. Graphs. Pullout history curves for neat, SBS-modified and Elvaloy modified binder on glass surfaces. The top row presents results for specimens prepared at 65 ºC while the bottom row presents results for specimens prepared at 135 ºC (Pressure rates equal to 891 kPa/s).

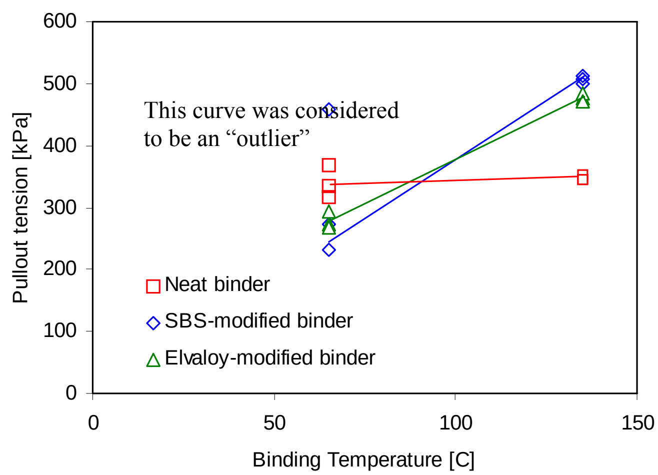
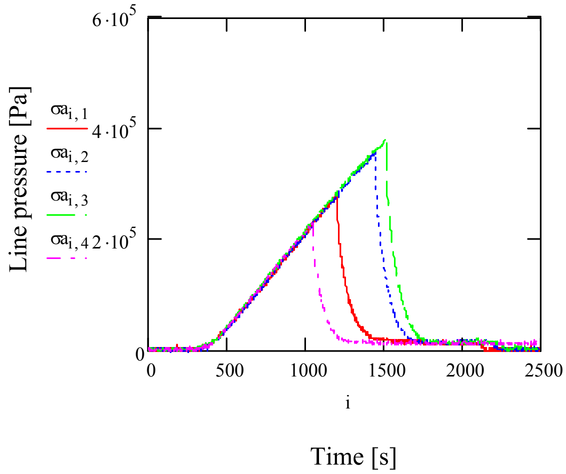
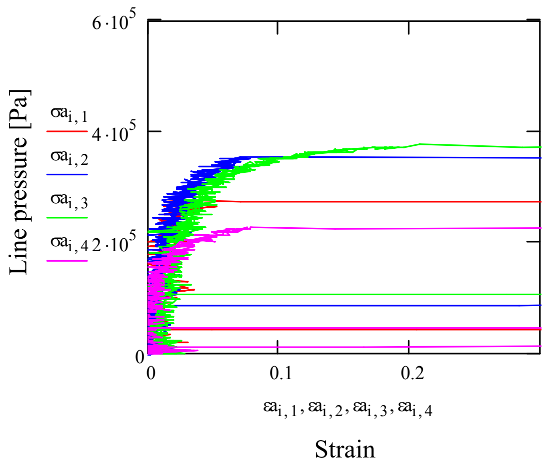


Figure M2c.6. Graph. Summary pullout tension test results for neat, SBS-modified and Elvaloy modified binder on glass surfaces. All specimens were tested at pressure rates equal to 891 kPa/s.



Max pullout tension [kPa]:	Deformation energy [kPa]:
281	4.5
358	16.4
381	41.3
231	12.7

Adhesive at stub
Failed on rock



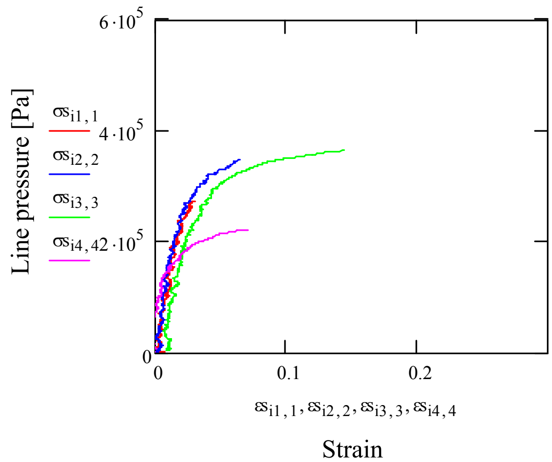
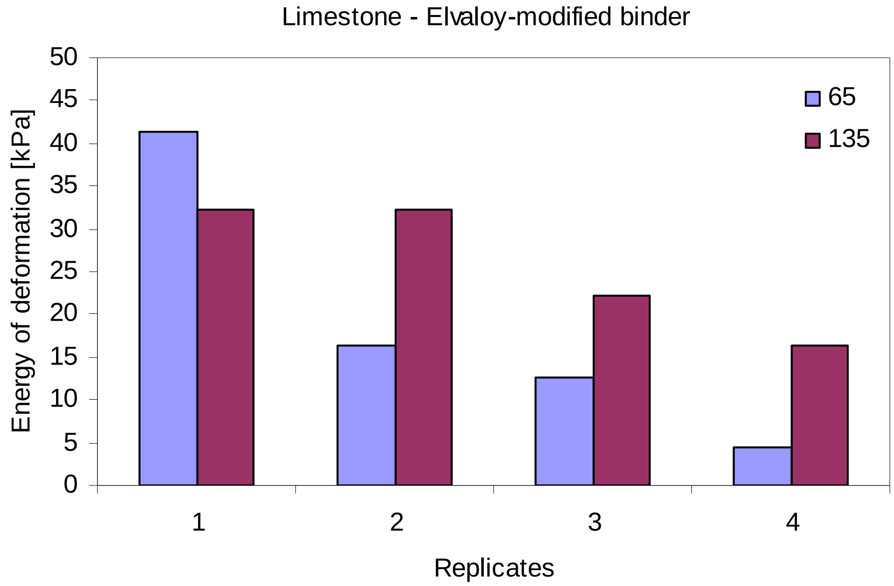
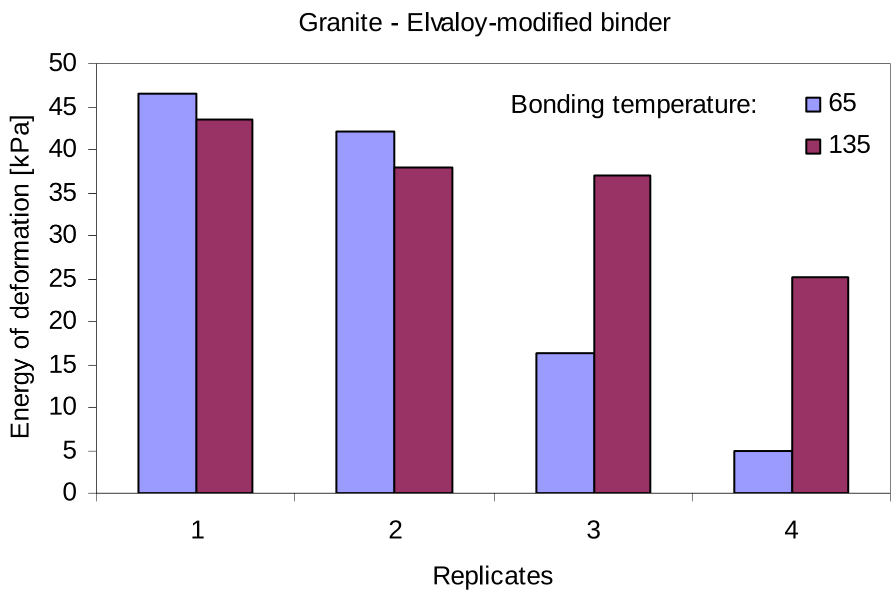


Figure M2c.7. Graphs and photographs. Pullout tension vs. deformation history: Elvaloy-modified binder on limestone surface with binding temperature of 65 ºC and pressure rate of 870 kPa/s.



	65 C	135 C
Average	18.7	25.8
St. deviation	15.85	7.8
Coef. Variation	0.846	0.3034



Temperature	65 C	135 C
Average	27.4	35.85
St. deviation	20.06	7.7
Coef. Of Variation	0.7315	0.215

Figure M2c.8. Graphs and analysis tables. Summary of results–energy of deformation (all slow pressure rates ~ 850 kPa/s).

Significant Problems, Issues and Potential Impact on Progress

The research team encountered several problems related to the displacement measurements. The small deformation and fine resolution needed during the observed brittle failure compromised the collected data. However, even when this problem was solved over this last quarter, the quality of the data was quite poor, and the obtained coefficients of variation were so large that there was not confidence in the results. For this reason, the pullout deformation was dropped as viable measurement alternative and the team will focus on pullout pressure alone.

Work Planned Next Quarter

The research team will focus on evaluating moisture damage using the pullout tension results. Also, the research team will use an alternative pullout tester. The PosiTest Pull-Off Adhesion Tester (per http://www.defelsko.com, $1,950 plus $95 for the recording software) will be purchased. This tester measures the peak pull-out strength and controls pressure rates. The instrument is portable and it does not require an external pressure source. Additionally, the setup allows for the self alignment of the pull-out stub. Finally the team plans to summarize the results compiled in the draft document in a manuscript documenting its experience with the testing.

CATEGORY M3: AGGREGATE SURFACE

Work Element M3a: Aggregate Surface Characterization (TAMU)

Work Done This Quarter

Physical and chemical properties of aggregates at the macro and molecular scale influence the performance of asphalt mixes. These properties control the nature and durability of the bond between aggregates and asphalt in wet and dry conditions and its resistance to moisture induced damage and fatigue cracking. Recent research by Dr. Little and colleagues have shown that surface energy of the aggregate-asphalt interface is a reliable predictor of engineering properties of the asphalt mixture. Current understanding of the aggregate and bitumen properties that control and shape surface energy is limited, limiting our ability to *a priori* predict surface energy of any given aggregate-asphalt combination.

Current tasks are organized around the (1) characterization of the chemical composition of the surfaces of reference minerals and aggregates through electron beam spectroscopes, including electron microprobe, backscatter electrons and electron-dispersive spectroscopy (EDS), and (2) the characterization of the surface energies of reference minerals and aggregates through the universal sorption device and microcalorimetry. The results from these tasks will support the development of a predictive model of aggregate surface energies based upon the surface energies of the minerals that compose the aggregate.

Tasks completed this quarter include additional chemical and mineralogical analysis for the following aggregates: Lithonia granite (RA), basalt (RK), and Gulf Coast Gravel (RL). In addition, mineralogical samples were obtained for kaolinite, montmorillonite and chlorite. Specific accomplishments are highlighted in the tables below.

Surface energy measurements for quartz, microcline, calcite, labradorite, biotite, and olivine have been collected using the universal sorption device. The components of surface energy were calculated on replicates of the samples.

Sample preparation and aggregate surface characterization tasks completed this quarter are shown in the table below.

Table M3a.1. Status of tasks associated with mineralogical and chemical characterization of aggregates.

SHRP	Name	08 Qtr	Thin Section Prep Status	Microprobe Analysis Status
RA	Lithonia Granite	1	1 aggr sample prepared, 2 more in progress	1 set of X-ray maps, 1 set of BSE images, 1 preliminary set of WDS quant analyses
		2	2 more aggregate samples prepared	2 sets of X-ray maps, BSE images are not needed because of grain size
RC	Limestone (higher absorption)	1	2 aggr samples prepared	1 set of X-ray maps, 1 set of BSE images, 1 preliminary set of WDS quant analyses
		2	-	No additional analyses
RD	Limestone (low absorp.)	1	4 aggr samples prepared,	4 sets of X-ray maps, 1 set of BSE images, 1 preliminary set of WDS quant analyses
		2	-	No additional analyses
RK	Basalt	1	2 aggr samples prepared, 1 more in progress	1 set of X-ray maps, 1 set of BSE images, 1 preliminary set of WDS quant analyses
		2	1 sample in progress	3 additional sets of X-ray maps, 13 set of BSE images, 1 set of WDS quant analyses for pyroxene, olivine, amphibole
RL	Gulf Coast Gravel	1	5 aggr samples prepared, 9 more in progress	3 sets of X-ray maps, 1 set of BSE images, 1 preliminary set of WDS quant analyses
		2	9 more in progress	9 sets of X-ray maps

Sample preparation and mineral surface characterization tasks completed this quarter are shown in the tables below.

Table M3a.2. Status of tasks associated with mineralogical and chemical characterization of mineral components of aggregates.

Mineral	**Group**	**08 Qtr**	**(1) Acquisition Status (2) Microprobe Mount Status**	**Microprobe Analysis Status**
Quartz	Silica Mineral	1	(1) > 200 grams acquired (Arkansas, RNG specimen) (2) Polished microprobe mount in preparation	In progress
		2	In progress	In progress
Microcline	Alkali Feldspar	1	(1) > 160 grams acquired (G&G collection, B0434) (2) Preliminary polished mount prepared	Preliminary homogeneity and quantitative chemical analysis acquired.
		2	In progress	In progress
Albite	Plagioclase Feldspar	1	(1) > 100 grams acquired (G&G collection, B0469) (2) Polished mount to be prepared	In progress
		2	In progress	In progress
Andesine	Plagioclase Feldspar	1	(1) > 65 grams acquired (G&G collection, B0513) (2) Preliminary polished mount prepared	Preliminary homogeneity and quantitative chemical analysis acquired.
		2	In progress	In progress
Labradorite	Plagioclase Feldspar	1	(1) > 160 grams acquired (Naim, Labrador; RNG specimen) (2) Preliminary polished mount prepared	Preliminary homogeneity and quantitative chemical analysis acquired.
		2	In progress	In progress
Anorthite	Plagioclase Feldspar	1	Samples to be acquired	NA
		2	NA	NA

Table M3a.2 (continued). Status of tasks associated with mineralogical and chemical characterization of mineral components of aggregates.

Mineral	Group	08 Qtr	(1) Acquisition Status (2) Microprobe Mount Status	Microprobe Analysis Status
Hornblende	Amphibole	1	(1) > 350 grams acquired (G&G collection, B0545) (2) Preliminary polished mount prepared	Preliminary homogeneity and quantitative chemical analysis acquired.
		2	In progress	In progress
Hornblende	Amphibole	1	(1) > 70 grams acquired (G&G collection, Room 008) (2) Polished mount to be prepared	In progress
		2	In progress	In progress
Augite	Pyroxene	1	(1) > 0 (?) grams acquired (G&G collection, B1007) (2) Preliminary polished mount prepared	Preliminary homogeneity and quantitative chemical analysis acquired.
		2	In progress	In progress
Augite	Pyroxene	1	(1) > 80 grams acquired (G&G collection, Room 008) (2) Polished mount to be prepared	In progress
		2	In progress	In progress
Forsteritic Olivine	Olivine	1	(1) > 280 grams acquired (San Carlos, AZ) (2) Polished mount to be prepared	In progress
		2	In progress	In progress

Table M3a.2 (continued). Status of tasks associated with mineralogical and chemical characterization of mineral components of aggregates.

Mineral	Group	08 Qtr	(1) Acquisition Status (2) Microprobe Mount Status	Microprobe Analysis Status
Muscovite	Mica	1	(1) > 65 grams acquired (G&G collection, Room 008) (2) Polished mount to be prepared	Preliminary quantitative chemical analysis acquired.
		2	In progress	In progress
Biotite	Mica	1	(1) > 175 grams acquired (G&G collection, B0857) (2) Polished mount to be prepared	In progress
		2	In progress	In progress
Biotite	Mica	1	(1) > 150 grams acquired (G&G collection, Room 008) (2) Polished mount to be prepared	Preliminary quantitative chemical analysis acquired.
		2	In progress	In progress
Calcite	Carbonate	1	(1) > 100 grams acquired (Mexico; RNG specimen) (2) Polished mount to be prepared	In progress
		2	In progress	In progress
Dolomite	Carbonate	1	Samples to be acquired	NA
		2	NA	NA

Table M3a.2 (continued). Status of tasks associated with mineralogical and chemical characterization of mineral components of aggregates.

Mineral	Group	08 Qtr	(1) Acquisition Status (2) Microprobe Mount Status	Microprobe Analysis Status
Hematite	Iron Oxide	1	Samples to be acquired	NA
		2	NA	NA
Magnetite	Iron Oxide	1	Samples to be acquired	NA
		2	NA	NA
Goethite	Iron Oxyhydroxide	1	Samples to be acquired	NA
		2	NA	NA
Kaolinite (KGA-1B)	Clay Mineral	1	Samples to be acquired	NA
		2	Samples acquired	In progress
Montmorillonite (SAz-2)	Clay Mineral	1	Samples to be acquired	NA
		2	Samples acquired	In progress
Chlorite	Clay Mineral	1	Samples to be acquired	NA
		2	Samples acquired	In progress

Significant Results

No significant results at this time.

Significant Problems, Issues and Potential Impact on Progress

No significant problems at this time.

Work Planned Next Quarter

Work planned in the next quarter includes continued analysis of the aggregates and minerals, with specific reference to surface energies.

CATEGORY M4: MODELING

Work Element M4a: Micromechanics Model (TAMU)

Work Element M4b: Analytical Fatigue Model for Mixture Design

Work Element M4c: Unified Continuum Model

Work Done This Quarter

The multi-scale virtual fabrication and lattice modeling (MS-VFLM) procedure is completely automated and tested. NCSU has also initiated the effort towards increasing the computational efficiency by optimizing the program flow and incorporating advanced analysis methods.

The finite element model to evaluate the effect of interfacial debonding on the macroscopic performance of the composite is under development at TAMU. The model utilizes cohesive elements to represent the asphalt binder-aggregate interface. The material properties for the bulk as well as the interface, rate of debonding, and rate of moisture diffusion will be obtained from tasks F1a and M2b. Preliminary runs are being conducted on this finite element model to evaluate its sensitivity to the various material property inputs.

Significant Results

None at this time.

Significant Problems, Issues and Potential Impact on Progress

None at this time.

Work Planned Next Quarter

NCSU will continue to work in the direction of increasing computational efficiency of the MS-VFLM program.

TAMU will continue the development of the finite element model for moisture damage at the binder-aggregate interface. We anticipate that in the next quarter some of the results from this model can be calibrated using actual test data obtained from Task F1a.

CATEGORY M5: MOISTURE DAMAGE PREDICTION SYSTEM

This area is planned to start later in the project.

Moisture Damage Year 2

		Year 2 (4/08-3/09)											
		4	5	6	7	8	9	10	11	12	1	2	3
Adhesion													
M1a	**Affinity of Asphalt to Aggregate - Mechanical Tests**												
M1a-1	Select Materials						DP						
M1a-2	Conduct modified DSR tests					P					P		
M1a-3	Evaluate the moisture damage of asphalt mixtures												DP
M1a-4	Correlate moisture damage between DSR and mix tests												
M1a-5	Propose a Novel Testing Protocol												
M1b	**Work of Adhesion**												
M1b-1	Adhesion using Micro calorimeter and SFE												
M1b-2	Evaluating adhesion at nano scale using AFM												
M1b-3	Mechanisms of water-organic molecule competition												JP,D
M1c	**Quantifying Moisture Damage Using DMA**												
Cohesion													
M2a	**Work of Cohesion Based on Surface Energy**												
M2a-1	Methods to determine SFE of saturated binders												
M2a-2	Evaluating cohesion at nano scale using AFM												
M2b	**Impact of Moisture Diffusion in Asphalt**												
M2b-1	Diffusion of moisture through asphalt/mastic films											JP,D	
M2b-2	Kinetics of debonding at binder-agreagte interface											JP,D	
M2c	**Thin Film Rheology and Cohesion**												
M2c-1	Evaluate load and deflection measurements using the modified PATTI test		DP		JP					D			F
M2c-2	Evaluate effectiveness of the modified PATTI test for Detecting Modification									D	DP		F
M2c-3	Conduct Testing												
M2c-4	Analysis & Interpretation												P
M2c-5	Standard Testing Procedure and Recommendation for Specifications												
Aggregate Surface													
M3a	**Impact of Surface Structure of Aggregate**												
M3a-1	Aggregate surface characterization												
Models													
M4a	**Development of Model**												
M4a-1	Micromechanics model development										JP		
M4a-2	Analytical fatigue model for use during mixture design												
M4a-3	Unified continuum model												

LEGEND

Deliverable codes	**Deliverable Description**
D: Draft Report	Report delivered to FHWA for 3 week review period.
F: Final Report	Final report delivered in compliance with FHWA publication standards
M&A: Model and algorithm	Mathematical model and sample code
SW: Software	Executable software, code and user manual
JP: Journal paper	Paper submitted to conference or journal
P: Presentation	Presentation for symposium, conference or other
DP: Decision Point	Time to make a decision on two parallel paths as to which is most promising to follow through
[x]	Indicates completion of deliverable x

Work planned

Work completed

Parallel topic

	Moisture Damage Year 2 - 5	Year 2 (4/08-3/09)				Year 3 (4/09-3/10)				Year 4 (04/10-03/11)				Year 5 (04/11-03/12)			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Adhesion																	
M1a	**Affinity of Asphalt to Aggregate - Mechanical Tests**																
M1a-1	Select Materials		DP														
M1a-2	Conduct modified DSR tests		P		P												
M1a-3	Evaluate the moisture damage of asphalt mixtures				DP		P			P							
M1a-4	Correlate moisture damage between DSR and mix tests						P		P								
M1a-5	Propose a Novel Testing Protocol				P				P				JP, F				
M1b	**Work of Adhesion**																
M1b-1	Adhesion using Micro calorimeter and SFE						JP				JP,F						
M1b-2	Evaluating adhesion at nano scale using AFM							JP					JP				JP, F
M1b-3	Mechanisms of water-organic molecule competition				JP,D	F					JP	D	F				
M1c	**Quantifying Moisture Damage Using DMA**										JP	D	F				
Cohesion																	
M2a	**Work of Cohesion Based on Surface Energy**																
M2a-1	Methods to determine SFE of saturated binders														JP		
M2a-2	Evaluating cohesion at nano scale using AFM							JP					JP				JP, F
M2b	**Impact of Moisture Diffusion in Asphalt**																
M2b-1	Diffusion of moisture through asphalt/mastic films				JP,D	F					JP	D	F				
M2b-2	Kinetics of debonding at binder-agreagte interface				JP,D	F											
M2c	**Thin Film Rheology and Cohesion**																
M2c-1	Evaluate load and deflection measurements using the modified PATTI test	DP	JP	D	F												
M2c-2	Evaluate effectiveness of the modified PATTI test for Detecting Modification			D	DP,F												
M2c-3	Conduct Testing						JP										
M2c-4	Analysis & Interpretation				P						D, JP		F				
M2c-5	Standard Testing Procedure and Recommendation for Specifications											D	P,F				
Aggregate Surface																	
M3a	**Impact of Surface Structure of Aggregate**																
M3a-1	Aggregate surface characterization																
Models																	
M4a	**Development of Model**																
M4a-1	Micromechanics model development				JP				JP				M&A	D	DP	F, SW	
M4a-2	Analytical fatigue model for use during mixture design															M&A,D	F
M4a-3	Unified continuum model								JP				M&A	D	DP	F, SW	

LEGEND

Deliverable codes	Deliverable Description
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SW: Software	Executable software, code and user manual
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P: Presentation	Presentation for symposium, conference or other
DP: Decision Point	Time to make a decision on two parallel paths as to which is most promising to follow througjh
[x]	Indicates completion of deliverable x

Work planned

Work completed

Parallel topic

PROGRAM AREA: FATIGUE

CATEGORY F1: MATERIAL AND MIXTURE PROPERTIES

Work Element F1a: Cohesive and Adhesive Properties

Subtask F1a-1: Critical Review of Measurement and Application of Cohesive and Adhesive Bond Strengths (TAMU)

Work Done This Quarter

During the previous quarter a white paper documenting the relationship between practical (or measured) and ideal (thermodynamic or based on surface free energy) work of fracture was developed. This white paper was based on the work of other researchers with materials other than asphalt binder on this topic for the last three decades. In this quarter, ARC member Dr. Masad had personal meetings and discussion with Dr. Kinloch and his colleagues from the Imperial College, London and Dr. Scarpas and his colleagues from TU-Delft. Dr. Kinloch is a world renowned expert on the topic of adhesion. During the discussion, Dr. Kinloch corroborated the findings from the white paper and the basic approach adopted by the ARC team to address this issue. The proposed white paper was further improvised during a joint discussion at TU-Delft with Dr. Scarpas and his group. While this white paper is still a work in progress, the most recent version was transmitted to FHWA for internal use.

Significant Results

Several improvements were made to the white paper relating the practical work of adhesion to the thermodynamic work of adhesion.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The white paper is a dynamic document and work will be continued to refine and update this document based on further discussions and findings from this project.

Subtask F1a-2: Develop Experiment Design (TAMU)

Work Done This Quarter

Based on some of the preliminary tests conducted on thin films of asphalt binder in dry condition, a tentative test matrix was developed for this task. We are currently refining the thin film transverse tensile test that will be used in this task. This tentative test plan will be revised as necessary to fulfill the overall objectives of this work element. Also note that this task will address the relationship between ideal work of fracture and practical work of fracture under both dry and wet conditions. Therefore, the findings from this task are also an integral part of the moisture damage work area, specifically the modeling effort in task M4a. These test results and the model in task M4a will be evaluated in conjunction with each other. The following is the tentative test plan developed for this work element n (table F1a-2.1). As the work progresses the test plan may be modified to accommodate the needs for the modeling effort in M4a.

Table F1a-2.1. Test plan to determine the mechanical work of adhesion for asphalt binders in dry and moisture conditioned states.

		Thin Film Adhesive - 25 um	**Film Thickness Sweep**						**Cohesive Failure[2]**	**Relaxation – DSR[3]**
			50 um	100 um	150 um	200 um	250 um	300 um		
Dry, Loading rate = 0.025 mm/sec		8	2	2	2	2	2	2	4	2
Moisture conditioned @ 35°C[1], Loading rate = 0.025 mm/sec	1 day	2								
	1 week	2								
	2 weeks	2							2	2
	1 month	2								
	2 months								2	2
	6 months								2	2
Dry, Loading rate = 0.01 mm/sec		8	2	2	2	2	2	2	4	2
Dry, Loading rate = 0.05 mm/sec		8	2	2	2	2	2	2	4	2
Dry, Loading rate = 0.1 mm/sec		8	2	2	2	2	2	2	4	2

Note: Grey boxes indicate the test combination that will be conducted and the number in the box indicates the estimated number of test replicates.

[1] A higher temperature will be used to accelerate the diffusion process. Results will be used in the modeling in Task M4a after correcting for the increased diffusivity. The correction will be estimated from some of the tests being conducted in M2a.

[2] The cohesive properties will be obtained on the thinnest film that yields a significantly cohesive failure from the film thickness sweep.

[3] The relaxation data is required as a material property input in the modeling effort.

Initially three different types of asphalt binders will be tested (AAD, AAB, and ABD). These binders were selected based on their use for method development and validation in other relevant components of this research. The tests will be conducted in two phases. In the first phase, the affect of moisture on the cohesive and adhesive properties will be evaluated (note that fatigue cracking of dry specimens is a special case with no extraneous moisture conditioning). Tests will be performed on all asphalt binders, room temperature, and one loading rate (0.025 mm/sec). In the second phase, the affect of changing the loading rate will be evaluated at one temperature using one asphalt binder.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The test plan will be revised based on the results from some of the initial tests.

Subtask F1a-3: Thermodynamic Work of Cohesion and Adhesion (Year 1 start)

Work Done This Quarter

The objective of this subtask is to provide the surface free energy of asphalt binders that will be used in other subtasks as a material property input or for the comparison with results from other test methods. Based on the requirements from other tasks, tests under this subtask will be ongoing through the remainder of this project.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Based on the requirements from other tasks, tests under this subtask will be ongoing through the remainder of this project.

Subtask F1a-4: Mechanical Work of Adhesion and Cohesion

Work Done This Quarter

Testing based on the plan described in table F1a-2.1 is in progress. Initially tests were conducted using the LVDTs mounted on top of the loading axis of the frame. Based on preliminary results it was found that the measured displacement until failure was several times the original film thickness even for very thin films where the mode of failure observed to be brittle adhesive. Further investigation revealed that the recorded displacement during the test included data that was due to the compliance of the loading frame itself. To remedy this effect, end plates were attached immediately above and below the fixtures used for testing. Two LVDTs were used on the either end of these plates and the difference was used as a measure of strain in the thin film (figure F1a-4.1). This eliminated the presence of any extraneous displacement in the final data. Currently, researchers are using a laser based LVDTs to further improvise the precision and accuracy of the test data. Figure F1a-4.2 indicates the transition in the mode of failure from adhesive to cohesive as the film thickness was gradually increased.

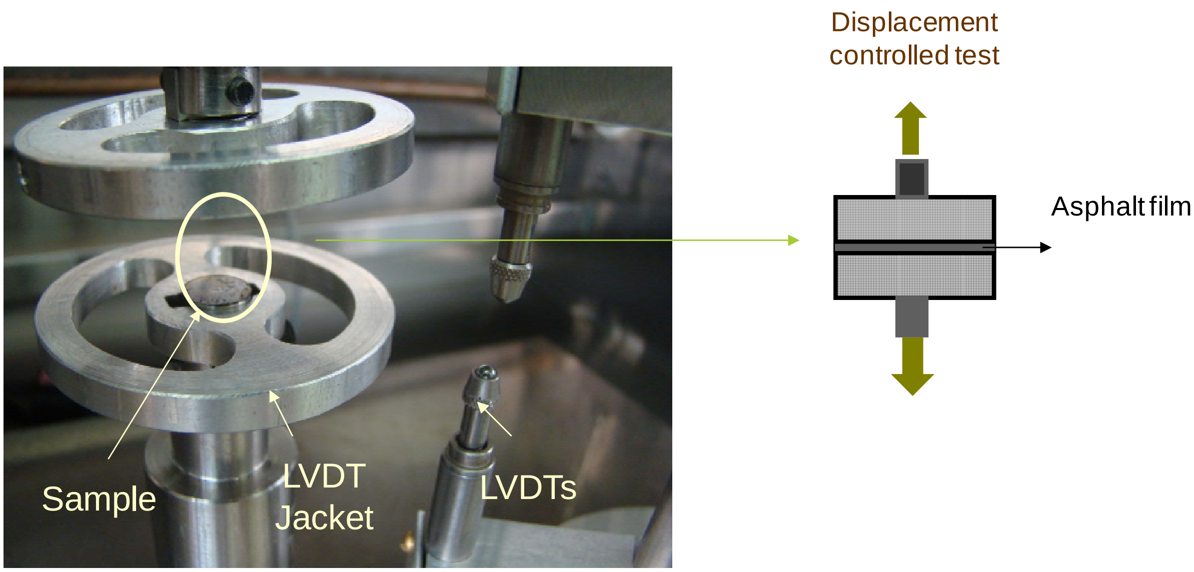

Figure F1a-4.1. Photo. Transverse tensile test geometry shown with the end plates and dual LVDT setup.

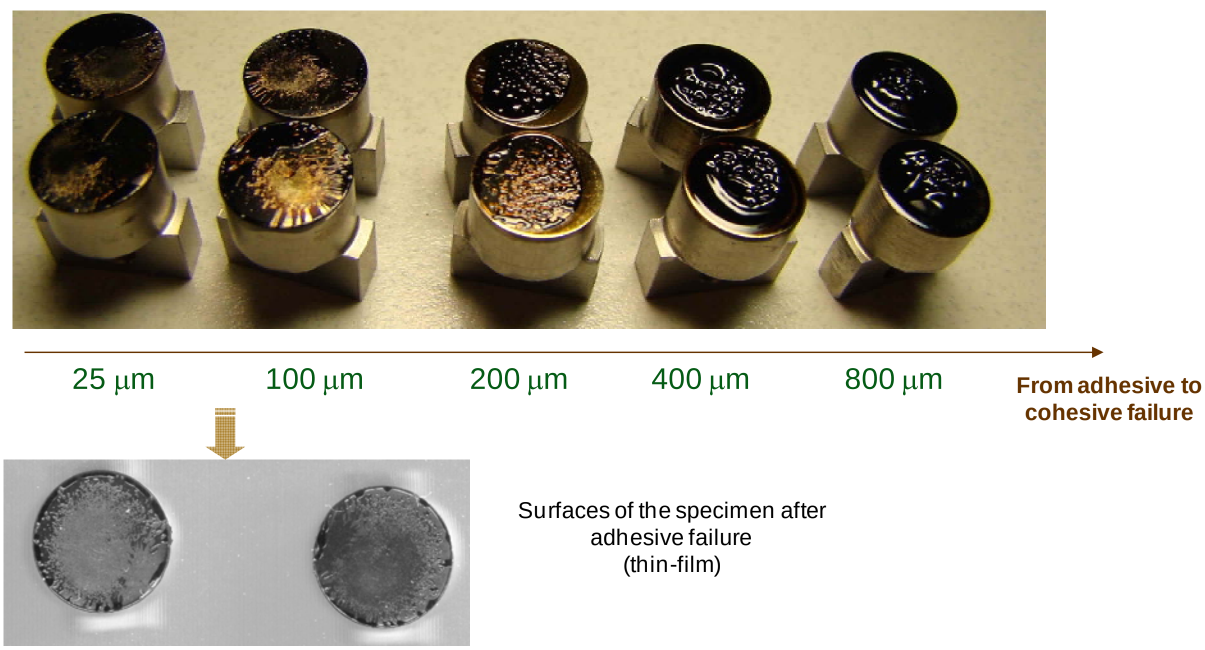

Figure F1a-4.2. Photo. Film thickness sweep using the transverse tensile test on thin films.

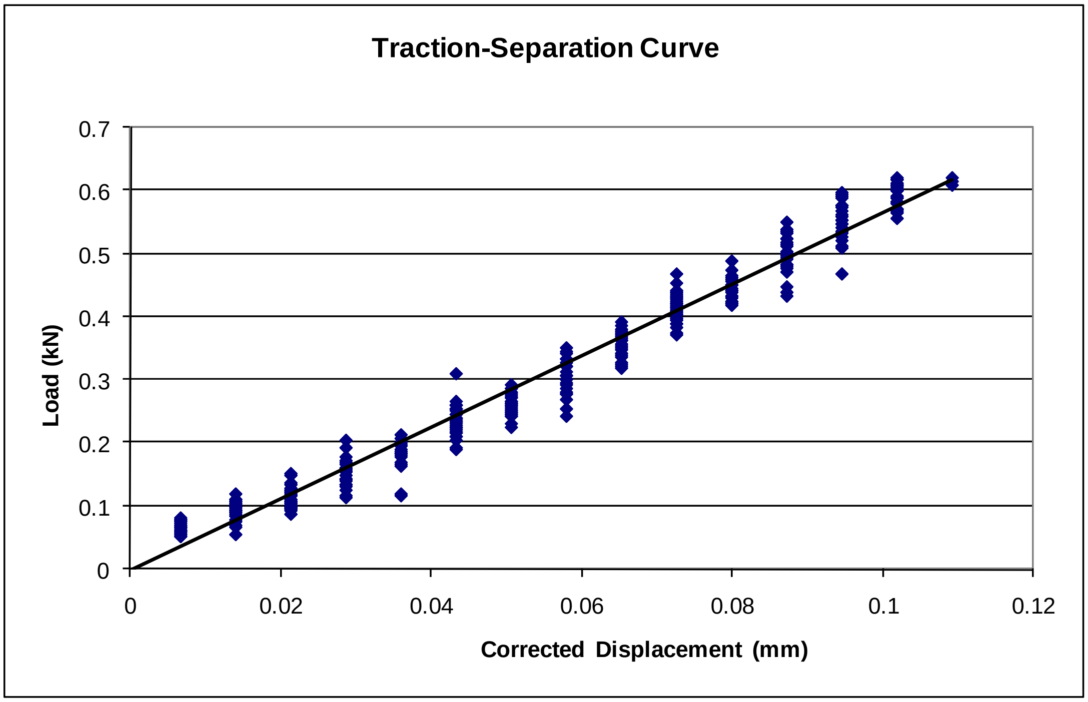

Figure F1a-4.3. Graph. Typical traction displacement curve for very thin film of a PG 64-22 binder failing in brittle adhesive mode (dry condition)

Significant Results

Testing in this subtask is currently in progress. Significant findings will be reported after completion of the initial test matrix.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Testing will continue as per the plan shown in F1a-2. Modifications to the test matrix are possible based on the accuracy and precision of results from some of the initial tests and requirements from the modeling effort.

Subtask F1a-5: Evaluate Acid-Base Scale for Surface Energy Calculations

Work Done This Quarter

No work was planned.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Work on this subtask is planned in the year 4 of this project.

Work Element F1b: Viscoelastic Properties (Year 1 start)

Subtask F1b-1: Separation of Nonlinear Viscoelastic Deformation from Fracture Energy under Cyclic Loading (TAMU)

Work Done This Quarter

One of the main objectives of this task was to conduct dynamic mechanical analysis on the fine aggregate matrix (FAM) specimens using different materials and develop an approach in order to:

i) Identify the limiting stress or strain amplitude that results in a nonlinear viscoelastic response without causing damage,

ii) Model and monitor the change in the nonlinear viscoelastic parameters with increasing number of load cycles, and

iii) Model and monitor the change in the nonlinear viscoelastic parameters within each cycle.

Testing of six different types of FAM (combinations of three aggregates and two different asphalt binders) was accomplished. Resulting data were analyzed to accomplish objectives (i) and (ii) described above. A statistical model and excel based program was developed to use data from the DMA and compute the limiting or maximum stress (or strain) amplitude that results in a non linear viscoelastic response without causing incremental damage to the specimen. The test data were further analyzed to determine the nonlinear viscoelastic properties and damage characteristics for different materials subjected to controlled stress and controlled strain modes of loading. The data analysis is based on modified Schapery theory for damage in viscoelastic materials. The analysis provides model parameters for quantifying the levels of nonlinear viscoelastic and damage responses of the material.

Significant Results

1) Develop a statistical method for separating nonlinear viscoelastic response from damage.
2) Develop an experimental protocol for evaluating the resistance of fine aggregate mixtures to fatigue damage under stress or strain controlled tests.

The detailed test protocols and findings from this subtask will be included in a detailed technical report.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The available test data will be analyzed in the following two quarters to accomplish the third objective of this sub task, i.e. to model and analyze the nonlinear viscoelastic response within each load cycle during a cyclic load test.

Subtask F1b-2: Separation of Nonlinear Viscoelastic Deformation from Fracture Energy under Repeated and Monotonic Loading

Work Done This Quarter

The theory used in Subtask F1b-1 has been formulated for the analysis of mixtures tested using repeated and monotonic load. The method follows the same concept of subjecting the material to different stress and strain levels. Consequently, a statistical method will be used to identify the load levels that induce non linear viscoelastic response without causing incremental damage to the specimen.

Significant Results

The main result is developing the formulation for the analysis of nonlinear viscoelastic response and damage of asphalt mixtured subjected to monotonic and repeated loads.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Asphalt mixtures will be tested at different monotonic stress levels to evaluate the nonlinear viscoelastic properties. Then, mixtures will be subjected to repeated loading to determine the damage functions of the mixtures.

Work Element F1c: Aging

Subtask F1c-1: Critical Review of Binder Oxidative Aging and Its Impact on Mixtures (TAMU)

<u>Work Done This Quarter</u>

Review on Pavement Temperature Prediction Models
The rate of binder oxidation is temperature dependent. In order to assess binder oxidation, it's important to obtain accurate pavement temperature as a function of time and depth. A review of research work on the prediction of pavement temperature profiles was conducted. The reviewed methods and models fall into three types.

The first type uses a heat transfer model, and is based on a simplification that daily and annual pavement temperatures are sinusoidal functions of time with a surface periodic temperature boundary condition (Won Jun 2006). The resulting model yields an analytical solution of pavement temperature versus depth over time. However, this model requires pavement surface temperature data as an input, which is usually not available.

The second type is a statistical model, the parameters of which are obtained using regression methods (Brian K. Diefenderfer et al. 2006; Peter J. Bosscher et al. 1998) to establish pavement maximum and minimum temperatures as a function of depth. This model takes into account solar radiation and ambient air temperature. Complete hourly temperature profiles, however, are not obtained. In addition, this model assumes a linear dependence of pavement temperature on depth, which is fundamentally wrong and experimentally inconsistent with measured data.

The third approach also uses a heat transfer model, but assumes a surface flux boundary condition and employs a finite different approximation to obtain a discrete solution; hourly temperature data are obtained (Ake Hermansson 2001; Ake Hermansson 2004; Manuel J. C. Minhoto et al. 2005; Jooseng Gavin Gui et al. 2007). The prediction results show good agreement with measured data from the Long Term Pavement Performance (LTPP) database, which contains pavement temperature data as a function of both time and depth.

Review of Binder Oxidation Fast Rate Kinetics
While reaction kinetics of binder oxidation during the constant-rate period has been studied extensively in laboratory, details of the fast-rate reaction period kinetics are rarely reported. Although one can assure that the fast-rate period of oxidation is passed in laboratory aging studies at elevated temperatures, it is uncertain when the fast-rate period ends under field aging conditions. Using constant-rate period kinetics to evaluate or predict field aging without knowing if the fast-rate period has even been passed will lead to suspect results and conclusions. Therefore, it is important to understand oxidation kinetics during the fast-rate period.

Recent literature data provide insight to fast-rate aging times in pavements. Data suggest that binder in a Texas location passed the fast-rate aging period in about two to three years, while for a binder in a MnRoad pavement it may take more than 12 years (Woo et al. 2007). The following figure shows the DSR function (a measure of binder stiffness) growth due to subsequent 60 C environmental room aging for up to eight months of binders recovered from Texas and Minnesota pavements. For the Texas binder, subsequent aging of the recovered binder form a consistent trend with the recovered binder. For the Minnesota binder, subsequent laboratory aging (which evidently is past the fast-rate period) forms a trend that is apart from the aging level of the initial state of the recovered binder. The tentative conclusion is that for Texas pavements, the fast-rate period is a relatively small portion of the binder's lifetime. By contrast, for the Minnesota binder the fast-rate period may cover a much longer fraction of the binder's pavement life.

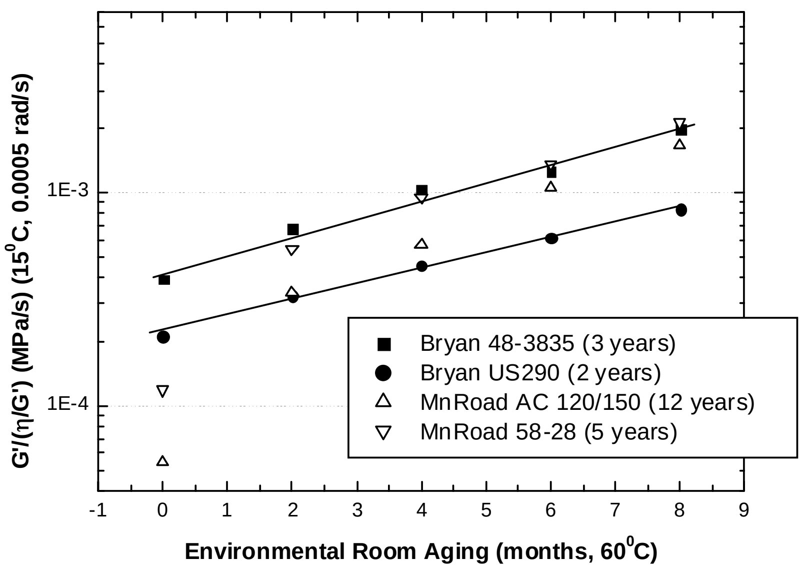

Figure F1c.1. DSR function growth of recovered binders from Texas and Minnesota aged in environmental room (60 °C)

Pioneering research work investigated oxygen absorption by tar oils (Dickinson and Nicholas 1949). Two parallel reactions were suggested, one is a first-order reaction with respect to phenol and the other is zero order reaction with respect to aromatics. The combined effect of these two reactions yielded a fast-rate period of oxygen absorption at the beginning, followed by a constant-rate period after the limiting reactant phenol depleted. The proposed reaction kinetics for tar oil is as follows:

$$M = k \cdot t + M_2 \cdot [1 - \exp(k_2 \cdot t)]$$

M is total amount of oxygen absorbed by tar oil. *k* and k_2 are reaction constants for the two reactions. *k* is temperature and oxygen pressure dependent, $k = A \cdot P^{\alpha} \cdot \exp(-Ea / RT)$ and k_2 is independent of temperature and pressure for tar oil. M_2 is maximum oxygen absorption due to the first reaction, which depends linearly on oxygen pressure, $M_2 \propto P$.

A similar relation was observed by Van Oort (1956) for binder oxygen absorption. Initially, oxygen was absorbed at a high rate, which then decreased until a constant-rate period was reached.

Despite the obvious similarity of kinetics between asphalt and tar oil, three deviations are identified. First, it's quite possible that k_2 for asphalt is temperature and pressure dependent. Second, M_2 might not be a linear function of oxygen pressure. Finally, neat binders will have an initial viscosity or carbonyl area, not included explicitly by the above equation.

Significant Results

Literature reports provide important insight to binder oxidation kinetics during both the fast-rate and constant-rate period binder kinetics and in both neat films and pavements. More data are needed, to understand specific binder kinetics and to provide a better understanding of hardening in pavements and as a function of climate and mixture parameters.

Significant Problems, Issues and Potential Impact on Progress

Existing literature results provide a good foundation and context for future experimental and modeling progress.

Work Planned Next Quarter

Review of previous work will be an ongoing effort. A white paper of pavement temperature modeling is being prepared.

Cited References

Bosscher, Peter J., et al., 1998, Relationship between Pavement Temperature and Weather Data: Wisconsin Field Study to Verify Superpave Algorithm. *Transportation Research Record 1609*, Paper No. 98-0944.

Dickinson, E. J., and J. H. Nicholas, 1949, The Reaction of Oxygen with Tar Oils, Road Research Technical Paper, No. 16.

Diefenderfer, B.K., A.M. ASCE, I.L. AL-Qadi, and S.D Diefenderfer, 2006, Model to predict pavement temperature profile: development and validation. *Journal of Transportation Engineering*, 132: 162-167.

Fromont, G. F., and K. B. Bischoff, 1979, *Chemical Reactor Analysis and Design*, John Wiley and Sons, New York, NY.

Gui, Jooseng Gavin, et al., 2007, Impact of Pavement Thermophysical Properties on Surface Temperatures. *Journal of Materials in Civil Engineering*, August 2007, 683-690.

Hermansson, Ake, 2001, Mathematical Model for Calculation of Pavement Temperatures. Comparison of Calculated and Measured Temperatures, *Transportation Research Record 1764*, Paper No. 01-3543.

Hermansson, Ake, 2004, Mathematical model for paved surface summer and winter temperature: comparison of calculated and measured temperatures, *Cold Regions Science and Technology*, 40.

Lau, C.K., K.M. Lunsford, C.J. Glover, R.R. Davison, and J.A. Bullin, 1992, Reaction Rates and Hardening Susceptibilities as Determined from POV Aging of Asphalt. *Transportation Research Record 1342*, 50.

Martin, K.L., C.J. Glover, R.R. Davison, and J.A. Bullin, 1990, Asphalt Aging in Texas Roads and Test Sections. *Transportation Research Record 1269*, 9.

Minhoto, Manuel J.C., et al., 2005, Predicting Asphalt Pavement Temperature with a Three-Dimensional Finite Element Method, Journal of the Transportation Research Board, *Transportation Research Record 1919*, 96–110.

Reid, R.C., J.M. Prausnitz, and T.K. Sherwood, 1983, *The Properties of Gases and Liquids*, McGraw-Hill, 4th ed., New York, NY.

Van Oort, W. P., 1956, Durability of Asphalt. *Industrial and Engineering Chemistry*, 1196-1201.

Woo, W.J., E. Ofori-Abebresse, A. Chowdhury, J. Hilbrich, Z. Kraus, A. Epps Martin, and C.J. Glover, 2007, Polymer Modified Asphalt Durability in Pavements. Report FHWA/TX-07/0-4688-1, Texas Transportation Institute, College Station, TX.

Subtask F1c-2: Develop Experimental Design (TAMU)

Work Done This Quarter

In this quarter, experimental design was completed for a pilot experiment and continued for an expanded experiment aimed at achieving the following three objectives associated with this Work Element F1c:

(1) Determine fundamental mixture parameters that control the decline of mixture fatigue resistance with aging (Subtask F1c-4 including polymer modified asphalt materials in Subtask F1c-5)

(2) Develop enhanced mixture testing protocol (Work Element F2c)

(3) Validate transport model of binder oxidation (Subtask F1c-3 including polymer modified asphalt materials in Subtask F1c-5)

For both the pilot experiment and the expanded experiment, the following elements are included:

- Materials

- Specimens (LMLC, Field Cores)
- Aging Protocol
- Laboratory Testing Protocols and Measured Properties
- Analysis Methods

The pilot experiment design addresses both objectives (1) and (2), and utilizes only LMLC specimens. This pilot experiment is also being used to provide data to verify the forward/inverse analysis proposed for quantitatively capturing the effect of aging on mixture stiffness in Work Element E1a. The selected materials are two SHRP MRL unmodified asphalt binders (AAD and AAM) and a common Texas Limestone (Colorado Materials) with a TxDOT Type C dense aggregate gradation. The LMLC specimens 6" in diameter and more than 7" in height are fabricated using the SGC and then cored and cut to 4" in diameter by 6" in height. Total AV contents of 4% and 7% are selected, and the optimum AC content by TxDOT standards is utilized. The aging protocol requires STOA (AASHTO R30) and 0 or 6 months in the 60C environmental room. Laboratory testing includes surface energy measurements of the separate component materials (binder and aggregate) and AV content (total and water accessible) and distribution determinations using specific gravities and X-ray CT image analysis. In addition the direct tension testing (TS, RM, and RDT) protocols used in previous TxDOT research projects will be expanded to include multiple temperatures (10, 20, and 30C) in the TS test and additional measurement of radial deformation in the RM test at 10, 20, and 30C in both tension and compression to allow for determination of Poisson's ratio. The RDT test at 20C will also be enhanced to include multiple 1000 cycle loading periods after different healing times of 1000, 500, 250, 120, 60, 30, 15, and 10 seconds. In addition to these mixture testing protocols, DSR and ductility testing of neat and recovered binders will also be included. With the properties measured with these testing protocols as inputs, the enhanced Calibrated Mechanistic with Surface Energies (CMSE*) analysis method with improved techniques to account for healing, anisotropy, and aging will be utilized to determine mixture fatigue resistance by either fatigue life or crack growth index.

Also in this quarter the expanded experiment design continued. This primary experiment in this Work Element F1c utilizes both LMLC specimens and field cores, and the laboratory testing protocols and the CMSE* analysis will also be used for this experiment. The selected materials are the four core unmodified asphalt binders (to be selected by the entire ARC team with FHWA approval) and an additional four non-core polymer modified asphalt binders (Subtask F1c-5) to be combined with two core aggregates (moisture resistance CA granite and either moisture sensitive AR/TX gravel or moisture sensitive NV andesite). Common dense graded aggregate gradations from the corresponding states will be selected subsequently. LMLC specimens will be fabricated using the same process as for the pilot experiment, but three total AV contents (4%, 7%, and 9%) and three AC contents (optimum, optimum ± 0.5%) will be utilized. Two different AV distributions will also possibly be explored. A similar aging protocol that requires STOA (AASHTO R30) and 0, 3, 6, and 9 months in the 60C environmental room will be used. Field cores will also be gathered at field validation sites (to be selected by the entire ARC team with FHWA approval and probably including WRI sections in AZ, NV, WY, KS, and MN). Coring is planned for these sections on three different dates; and AC content, AV content, and AV distribution will be measured to characterize these sections.

Significant Results

The pilot experiment design was completed, and material procurement and specimen fabrication (Subtask F1c-4) commenced.

Significant Problems, Issues and Potential Impact on Progress

Input from the entire ARC team with approval from FHWA is needed with respect to the core asphalt binder materials and the field validation sections. The component materials are needed to fabricate LMLC specimens that will be aged in the 60C environmental room for up to a year prior to material characterization and estimation of mixture fatigue resistance. The field validation sections are needed to allow for cores to be collected on three different dates to assess the effect of aging on mixture fatigue resistance.

Work Planned Next Quarter

Next quarter the expanded experimental design will be finalized with input from the entire ARC team and approval from FHWA with respect to the core asphalt binder materials and the field validation sections.

As the experiment design process is completed, a draft and final report will be submitted to FHWA that includes the complete experiment design for this Work Element F1c.

Subtask F1c-3: Develop a Transport Model of Binder Oxidation in Pavements (TAMU)

Work Done This Quarter

Work on developing a transport model of binder oxidation in pavements continues. To obtain a better understanding of the relative rates of oxygen diffusion and reaction in pavements, oxidative aging has been calculated using the transport-oxidation model. According to the results, when pore-to-pore spacing is less than approximately 200 micron, the oxygen diffusion limitation in the asphalt binder is fairly small. In other words, the oxygen concentration in the binder and thus the oxidation rate of the binder are both calculated to be quite uniform at an instant in time. Experimentally, literature reports of binder aging in pavements suggests that in some cases, such a low diffusion resistance effect may, in fact, be the case; however, in other pavements (typically those with low air voids, less than about two percent) there is a definite diffusion resistance. Improved, higher resolution X-ray CT observations (imaging) of pavement mixtures are planned to determine approximate field interpore spacing to compare to these modeling efforts.

Additionally, the asphalt oxidation model was non-dimensionalized and a number of dimensionless groups were determined. The dimensionless groups that play significant roles in the asphalt oxidation model include reaction rate, diffusivity, temperature, and interpore spacing in the mixture. A detailed study of the importance of each dimensionless group was initiated.

Significant Results

Significant progress on modeling binder oxidation in pavements has been made. This progress includes work on both temperature modeling and oxygen transport modeling. This modeling effort provides the basis for planning both laboratory and field experiments.

Significant Problems, Issues and Potential Impact on Progress

The principal issue with the transport model is the question of how accurately the cylindrical continuum transport model can represent the situation that exists in pavements. If the model captures the essential elements, then it will be able to provide very valuable insight for pavement design and maintenance planning.

Work Planned Next Quarter

Higher resolution of X-ray CT scan will be performed on field core samples to evaluate the average size of air voids and estimate asphalt film thickness in the pavement. The resolution of the images should be at least as small as 50 micron per pixel in order to detect smaller air voids.

Subtask F1c-4: The Effects of Binder Aging on Mixture Viscoelastic, Fracture, and Permanent Deformation Properties (TAMU)

Work Done This Quarter

In this quarter, material procurement and specimen fabrication for the pilot experiment (Subtask F1c-2) commenced.

Significant Results

None to report at this time.

Significant Problems, Issues and Potential Impact on Progress

In this quarter the MTS equipment used for direct tension testing experienced significant problems with respect to accurate measurement of deformation and successful testing in direct tension with failure in the middle of the specimen. These problems took time to diagnose and then required substantial upgrading of the equipment with new LVDTs and calibration of the load cells. These upgrades were completed in this quarter.

In addition, ARC researchers submitted an estimate to TTI Administration of the demand for testing with the MTS equipment over the next four years from all researchers in the Materials and Pavements Division that share this equipment. The demand is substantial with 9100 specimens to be tested over the next four years and 3800 specimens projected for the next fiscal year. This estimate was forwarded with a request to: (1) upgrade a second MTS system for mixture testing and (2) purchase a third MTS system.

These MTS equipment problems hampered the efforts to develop the expanded mixture testing protocol for both LMLC specimens and prismatic specimens cut from field cores and the associated enhanced CMSE* analysis method.

Work Planned Next Quarter

Next quarter, material procurement and specimen fabrication for the pilot experiment (Subtask F1c-2) will continue.

As core asphalt binder materials and the field validation sections are selected, material procurement and specimen fabrication for the expanded experiment will commence.

After checking that the MTS equipment is operating correctly, mixture characterization will commence and the expanded mixture testing protocol (with changes in the TS, RM, and RDT direct tension testing protocols) for LMLC specimens and prismatic specimens cut from pavement cores will be finalized (Work Element F2c). At the end of the protocol, extracted binder property measurements will also commence. Specifically, AV characterization (total and water accessible) through determination of specific gravities and X-ray CT and image analysis will commence.

Subtask F1c-5: Polymer Modified Asphalt Materials (TAMU)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

No work planned.

Work Element F1d: Healing

Subtask F1d-1: Critically Review Previous Work on Healing under FHWA Contracts DTFH61-C-92-00170 and DTFH61-C-99-00022 (TAMU)

Work Done This Quarter

The literature review was continued in this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

No work planned.

Subtask F1d-2: Select Materials with Targeted Properties (TAMU)

Work Done This Quarter

In the previous quarter, it was reported that the molecular modeling techniques were used to investigate the material properties the influence the healing process. The effect of molecular morphology and surface free energy of asphalt binders was investigates. The results reported in the previous quarter were promising. This work was continued in this quarter. The time scale used for molecular simulations was significantly increased from the previous simulations (from 5 pico seconds to 100 to 500 pico seconds). Longer time scales for simulation provide a more robust estimate for properties such as the diffusivity of molecules. Simulations were also performed at elevated temperatures so that the results could be extrapolated to determine the diffusivity of molecules at lower temperatures (room temperatures). The results from the simulation were compared to the expected long term and short term healing characteristics of the asphalt binders from the previous studies.

Significant Results

The results from this exercise will be documented in the form of a journal paper in the following quarter.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The findings from the molecular simulations conducted in this subtask will be reported in the form of a journal paper. Also, the FTIR measurements will be conducted on select few asphalt binders in order to determine the relevant molecular characteristics of these binders. These characteristics include the chain length and chain branching and will follow the approach originally proposed by Kim, Little and Benson (1990).

Cited References

Kim, Y. R., D. N. Little, and F. C. Benson, 1990, Chemical and Mechanical Evaluation on Healing Mechanism of Asphalt Concrete. *Proc.*, Association of Asphalt Paving Technologists, 59: 240-275.

Subtask F1d-3: Develop Experiment Design (TAMU)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

We plan to conduct some review on the test methods and models to determine properties related to healing and the rate of healing in bituminous materials. This information is necessary before developing a full scale experiment design to validate the model for healing in asphalt mixtures.

Subtask F1d-4: Investigate Test Methods to Determine Material Properties Relevant to Asphalt Binder Healing (TAMU)

Work Done This Quarter

In the previous quarter a test method based on the use of a DSR was developed to determine the parameters that describe the intrinsic healing properties of an asphalt binder. In this quarter, additional binders using this test method were developed. The intrinsic healing characteristics of these binders were determined using the DSR based test method. A plot of the intrinisic healing characteristics of five different binders is shown in figure F1d-4.1.

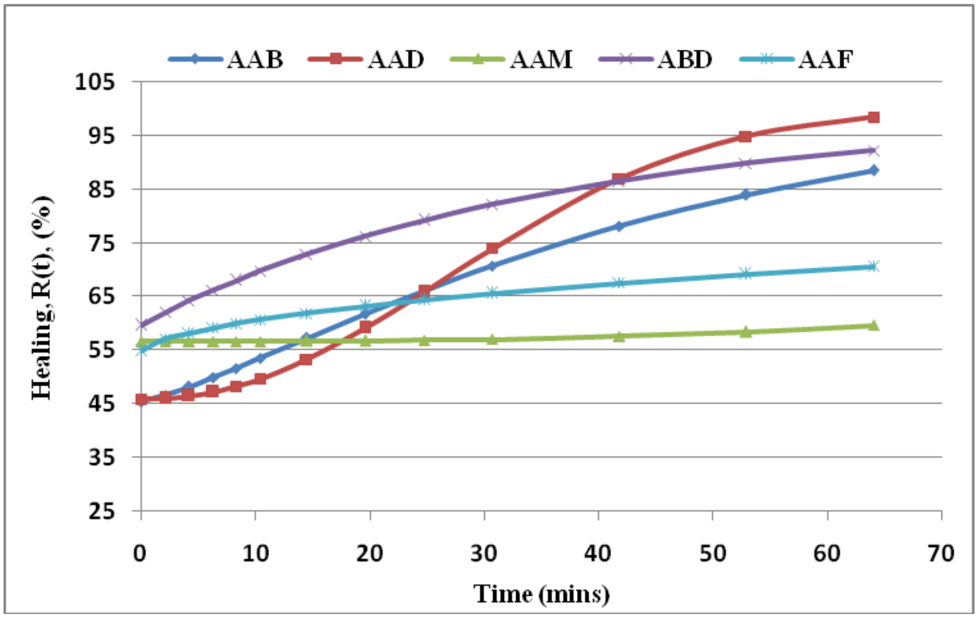

Figure F1d-4.1. Intrinsic healing characteristics of five different asphalt binders

Significant Results

Based on the phenomenological explanation behind the model for the intrinsic healing function, the instantaneous healing parameter R_0 must bear a correlation with the thermodynamic work of cohesion or surface free energy. This was confirmed by comparing the results from this study to the surface free energy of selected asphalt binders measured using the Wilhelmy plate device (figure F1d-4.2). This provides limited validation for the proposed methodology. Results from this study also indicate that the intrinsic healing on a long term and short term for different asphalt binders need not follow the same rank order. Therefore, it is quite likely that in experiments related to healing, the rank order of the tendency of different mixtures to heal will depend on the duration of rest periods used during the test.

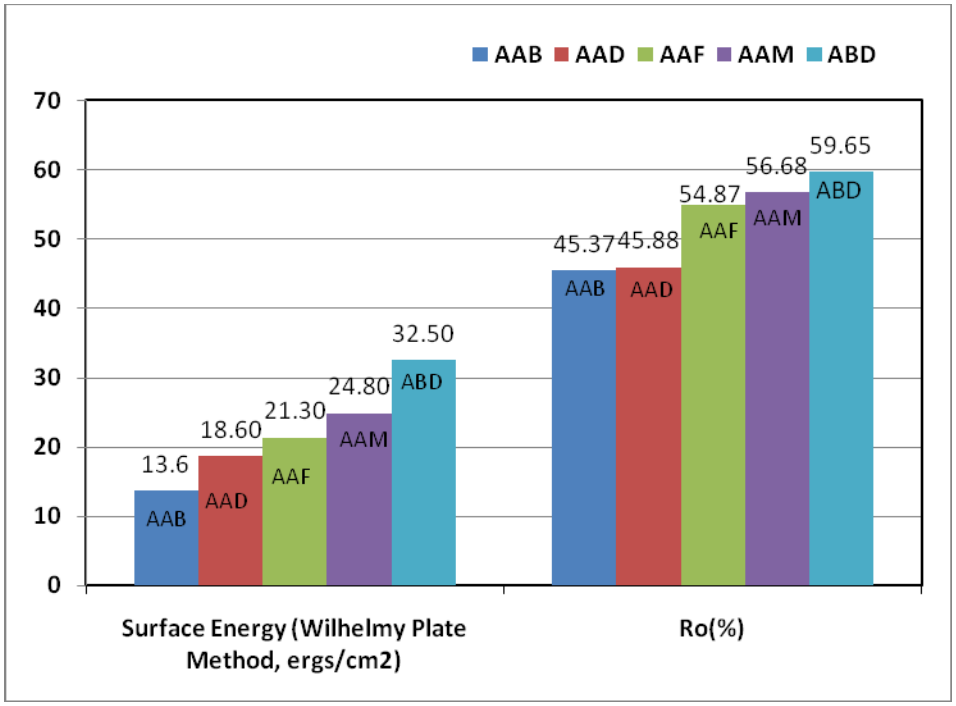

Figure F1d-4.2. Comparison of the instantaneous healing from the DSR test to the surface free energy for different binders.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Other methods to determine the intrinsic healing function for asphalt binders will be explored. Preliminary tests will be conducted to determine whether or not this test protocol using the DMA can be used with modified asphalt binders and mastics in lieu of neat asphalt binders.

Subtask F1d-5: Testing of Materials (TAMU)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Work on this subtask is planned for the last quarter of this year.

Subtask F1d-6: Evaluate Relationship Between Healing and Endurance Limit of Asphalt Binders (UWM)

Work Done This Quarter

During this quarter, the main focus of this subtask was to address the repeatability of the fatigue healing tests on binders. Sample preparation proved to be of substantial significance, and the procedure for binder time sweep testing sample preparation and conditioning has been adjusted as follows:

1. Asphalt binder is heated and poured into 8-mm silicone molds.
2. Plates in the dynamic shear rheometer (DSR) are preheated to the performance grade (PG) high temperature for the specific binder being tested.
3. Once the binder specimen has cooled to a temperature where it can be handled, it is placed on the bottom plate of the DSR, and the upper plate is lowered until it reaches the trimming gap of 2.05 mm.
4. The temperature in the DSR is held at the PG grade high temperature for 15 minutes in order to ensure adequate adhesion to the plates.
5. The temperature is then lowered to the testing temperature, and the sample is trimmed.
6. Upon trimming, the gap is lowered to 2 mm, and the specimen is conditioned at the testing temperature for thirty minutes until loading is applied.

It is noted that this procedure largely follows steps outlined by Bonnetti (2001) with some adjustments. Repetition of the tests yielded far more reliable results, which are shown in the next section.

Significant Results

Time sweep testing with rest periods has continued using the above procedure. Improved repeatability is apparent in the shape of normalized modulus versus number of cycles plots, but it also can be seen numerically as the average number of cycles to reach a predetermined reduction in stiffness contains significantly less variation than previously measured. Currently, time sweep testing with and without rest periods using the improved sample preparation procedure has been completed on the two base binders at 3% controlled-strain amplitude (shown in figures F1d-6.1 and F1d-6.2). Testing has begun on linear styrene butadiene styrene (SBS)-modified (at 2% by weight of binder).

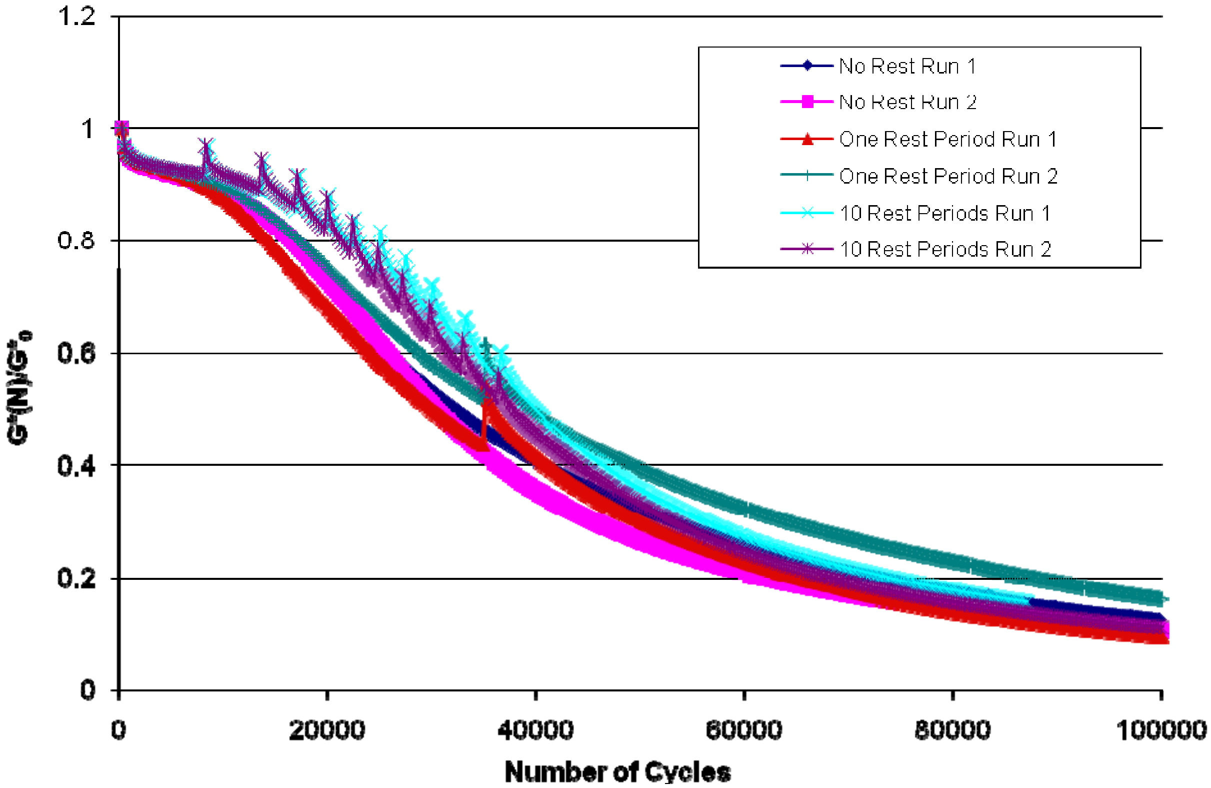

Figure F1d-6.1. Graph. Time sweep test results for lower asphaltene base binder.

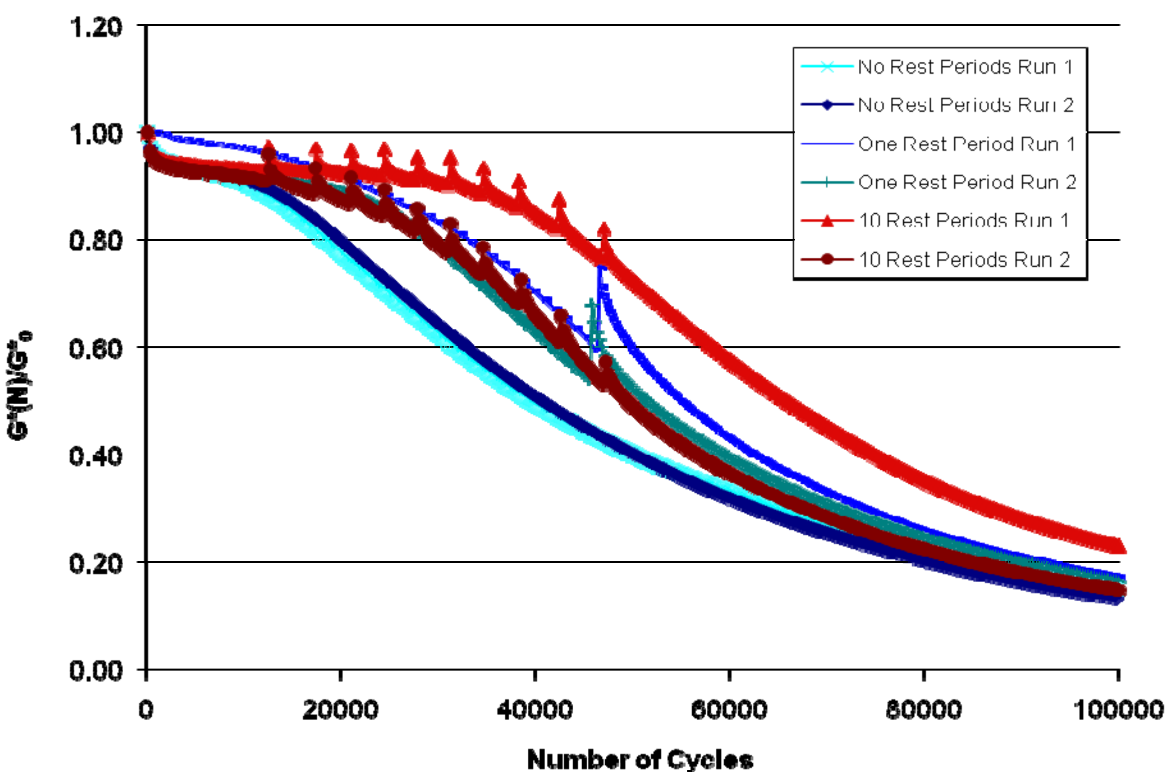

Figure F1d-6.2. Graph. Time sweep test results for higher asphaltene base binder.

Significant Problems, Issues and Potential Impact on Progress

The initial problem of time sweep test repeatability appears to have been sufficiently resolved. Haversine load pulse testing in the DSR does not appear to be possible with the existing equipment; however an adjusted procedure is currently under evaluation for use within the capabilities of test equipment. Once the feasibility of this procedure has been established, a decision will be made on which test protocol to use for the evaluation of factors affecting the healing of binders. It is planned to make this decision next quarter.

Work Planned Next Quarter

As the data become available for the rest of the binders in the testing matrix, the Healing Potential Index, as introduced by Kim, et al. (2002), will be evaluated and compared among the neat and modified binders.

Cited References

Bonnetti, Karen S., 2001, *Fatigue behavior of modified asphalt binders*. Master's thesis, University of Wisconsin-Madison.

Kim, Yong-Rak, D. N. Little, and R. L. Lytton, 2002, Use of dynamic mechanical analysis (DMA) to evaluate the fatigue and healing potential of asphalt binders in sand asphalt mixtures. Asphalt Paving Technology: Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions, 71: 176-206.

Subtask F1d-7: Coordinate with Atomic Force Microscopic (AFM) Analysis (WRI)

Work Done This Quarter

The detailed work plan was submitted as an addendum to the Year 2 Work Plan. The preparation of the detailed work plan was the first planned activity for Year 2.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

No work planned.

Subtask F1d-8: Coordinate Form of Healing Parameter with Micromechanics and Continuum Damage Models. (TAMU)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Work on this subtask is scheduled for later years of this research.

Subtask F1d-9: Design Experiment on Selected Binders with Synchrotron (TAMU)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

No work planned.

CATEGORY F2: TEST METHOD DEVELOPMENT

Work Element F2a: Binder Tests and Effect of Composition (UWM)

Work Done This Quarter

Binders modified with polyphosphoric acid (PPA), Elvaloy and Styrene-Butadiene-Styrene (SBS) have been prepared. The level of modification has been chosen such that it provides one performance grade (PG) bump and two PG grades bump for the polymer modification, in accordance with the proposed experimental matrix. The base binders used (Flint Hills [FH] and Payne & Dolan labeled CRM) have 16% wt and 9% wt asphaltene contents, respectively.

Neat and modified binders were subjected to rolling thin film oven (RTFO) and pressure aging vessel (PAV) aging techniques. The resulting materials have been tested for fatigue and creep and recovery as proposed in the experimental matrix.

Significant Results

The most significant finding of the work performed during this quarter is the verification of the testing procedures and methods with good repeatability and consistency in the measurements.

The Binder Yield Energy Test (BYET) discriminates easily between different ages of the binder as shown in figure F2a.1. Representative results for calculations are presented in table F2a.1.

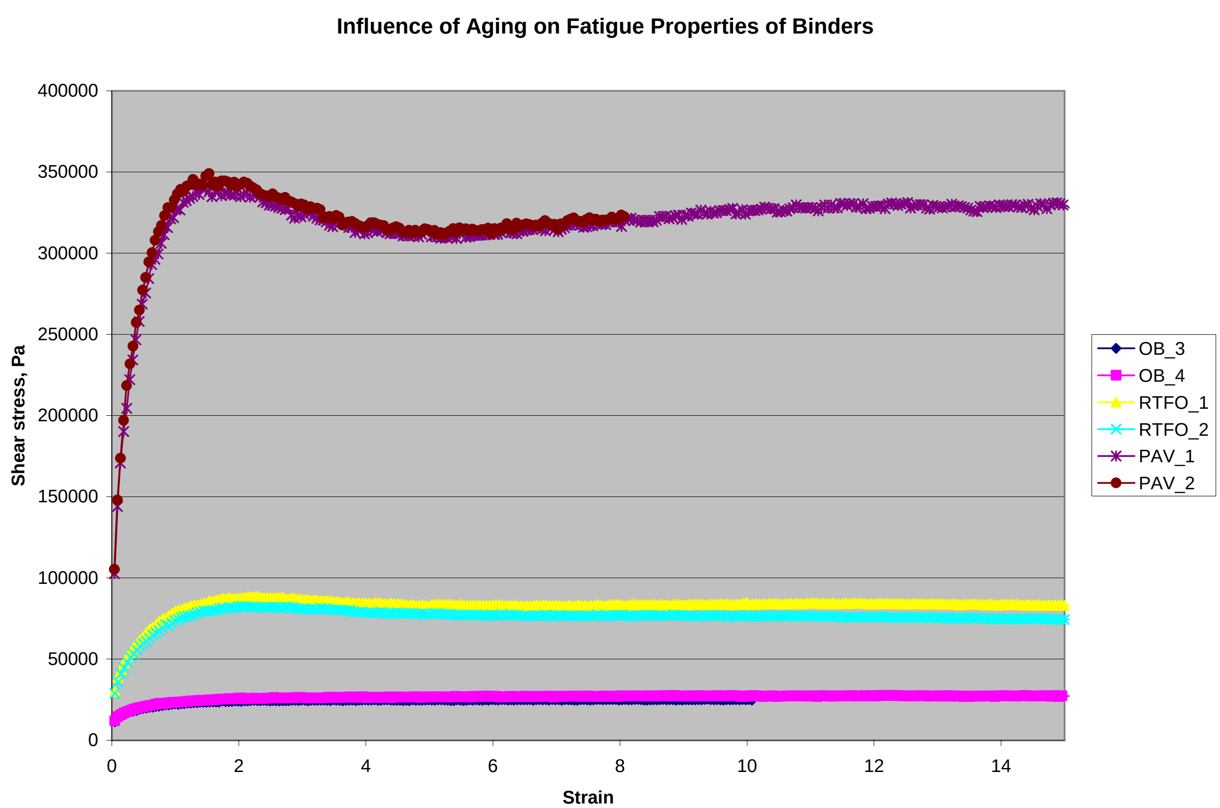

Figure F2a.1: Influence of binder age on fatigue properties for Flint Hills PG 70-22 2% linear styrene-butadiene-styrene (LSBS) modified binder. (OB: Original binder. RTFO: Rolling thin film oven. PAV: Pressure aging vessel.)

Table F2a.1. Representative results for the influence of binder age on fatigue.

	Original Binder			
	RUN1	RUN2	Standard Deviation	Coefficient of Variation%
Yield Energy (kPa)	224.99	321.11	67.97	24.89
Strain at Max Stress	9.38	12.31	2.07	19.10
	Rolling Thin Film Oven aged			
	RUN1	RUN2	Standard Deviation	Coefficient of Variation%
Yield Energy (kPa)	170.81	139.02	22.48	14.51
Strain at Max Stress	2.30	2.05	0.18	8.13
	Pressure Aging Vessel aged			
	RUN1	RUN2	Standard Deviation	Coefficient of Variation%
Yield Energy (kPa)	391.15	439.61	34.27	8.25
Strain at Max Stress	1.43	1.53	0.07	4.78

The BYET test also discriminates between different binder compositions (asphaltene contents) as shown in figure F2a.2, with data summarized in table F2a.2.

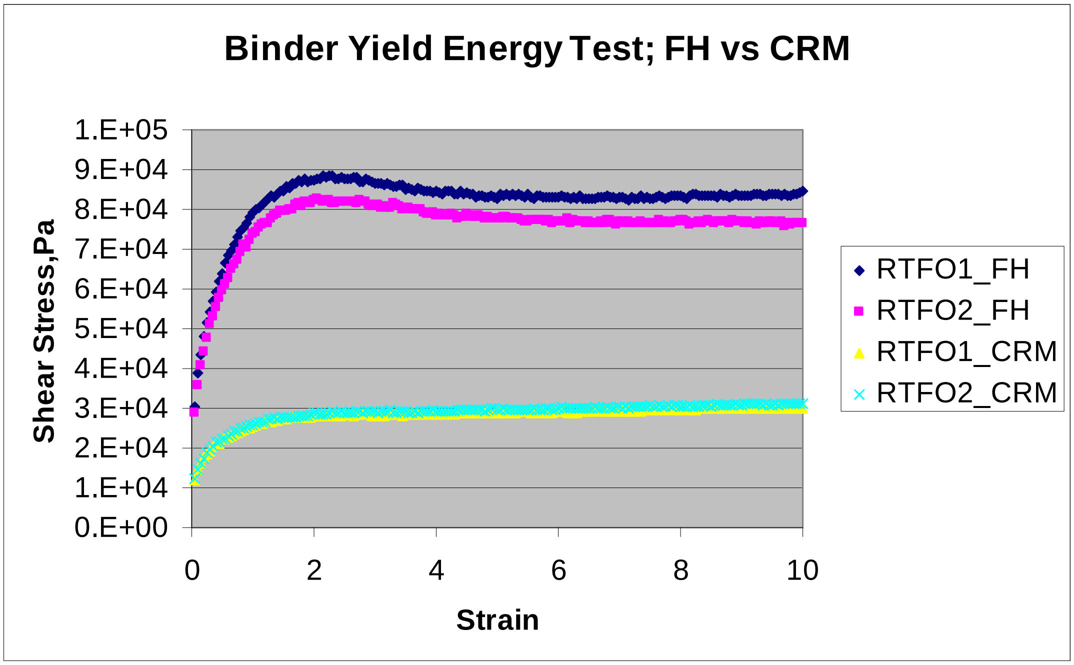

Figure F2a.2. Graph. Influence of asphaltene content on fatigue properties; CRM has 9% asphaltenes, FH has 16% asphaltenes. (RTFO: Rolling thin film oven. FH: Flint Hills.)

Table F2a.2. Representative results for the influence of asphaltene content on binder fatigue.

	Flint Hills Rolling Thin Film Oven				CRM Rolling Thin Film Oven			
	RUN1	RUN2	STDEV	COEF OF VAR,%	RUN1	RUN2	STDEV	COEF OF VAR,%
Yield Energy (kPa)	170.81	139.02	22.48	14.51	283.97	290.71	4.76	1.66
Strain at Max Stress	2.30	2.05	0.18	8.07	12.10	14.05	1.38	10.53

A representative sample of data for the multiple stress creep recovery test is shown in table F2a.3.

Table F2a.3. Multiple stress creep recovery test results for CRM 2% linear styrene-butadiene-styrene modified binder.

Average %Recovery @	Original Binder				Rolling Thin Film Oven			
	RUN1	RUN2	STDEV	COEF OF VAR%	RUN1	RUN2	STDEV	COEF OF VAR%
100Pa	70.52	76.42	4.17	5.68	78.12	79.47	0.96	1.21
3200Pa	0.62	0.61	0.01	1.42	1.59	1.79	0.14	8.54

Also frequency sweep measurements are being collected for the purpose of building master curves for the tested materials (see example in figure F2a.3).

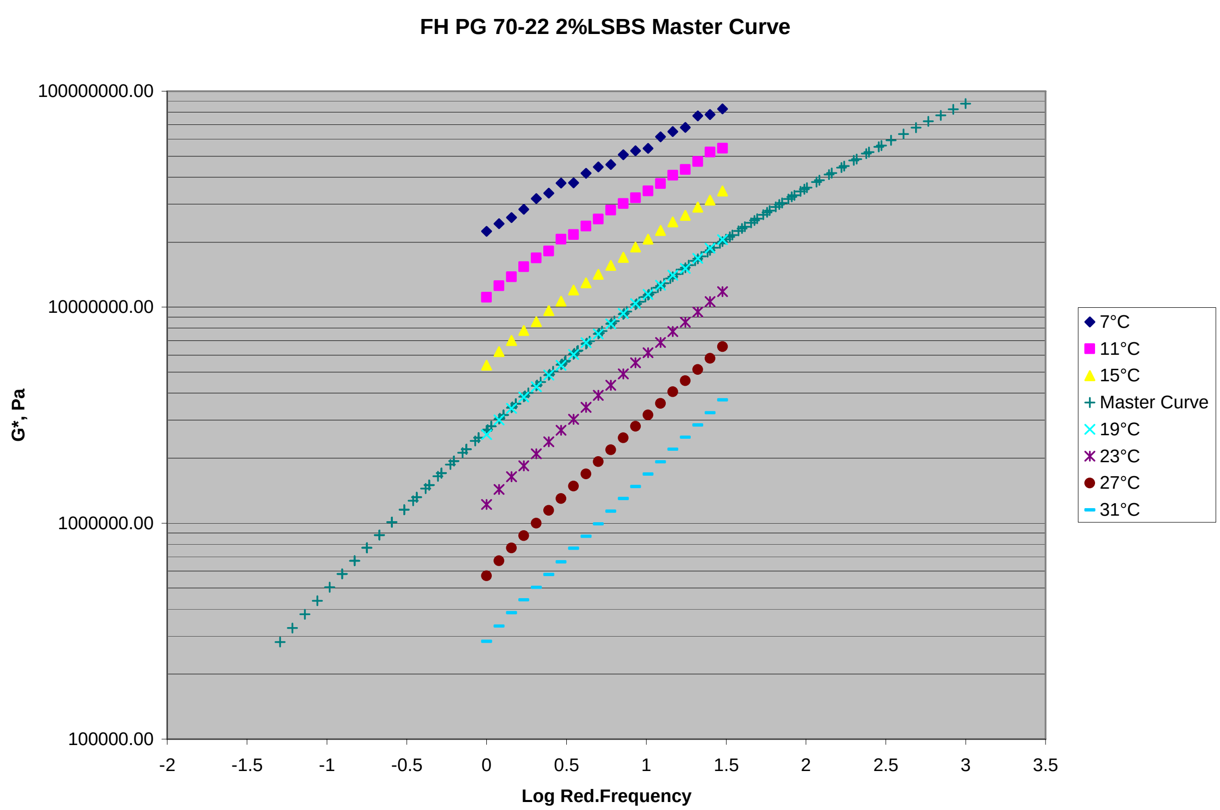

Figure F2a.3. Graph. Master curve for Flint Hills PG 70-22 modified 2% linear styrene-butadiene-styrene.

Stress sweep tests are being conducted on these materials in order to determine the linear domain for their behavior. Sample data are plotted in figure F2a.4.

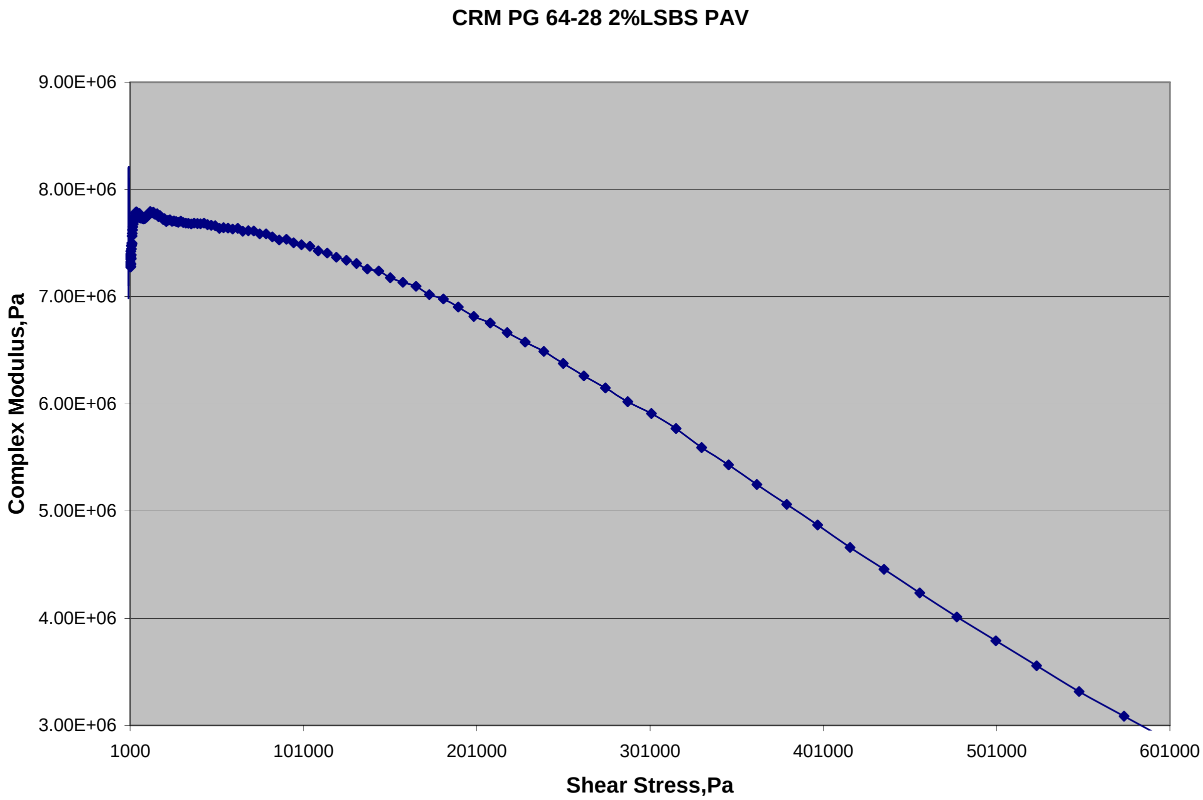

Figure F2a.4. Graph. Typical stress sweep test results on CRM PG-28 modified 2% linear styrene-butadiene-styrene, aged with pressure aged vessel technique.

Significant Problems, Issues and Potential Impact on Progress

No significant problems have been encountered this quarter.

Work Planned Next Quarter

For the next quarter the team will continue testing following the proposed experimental matrix and will begin analyzing the experimental data.

Work Element F2b: Mastic Testing Protocol (TAMU)

Work Done This Quarter

In the previous quarter, a preliminary procedure for testing of FAM using the DMA was developed and documented using the AASHTO format. Further work on the evaluation of the repeatability and ruggedness of this method will be conducted as a part of the technology development area.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Further work on the development of the test procedure will be coordinated with the technology development work area. While the specimen preparation and basic test procedure for fatigue is not expected to change, some modifications to the test protocols may be required based on the requirements for the models developed in the F1b.

Work Element F2c: Mixture Testing Protocol (TAMU)

Work Done This Quarter

In this quarter, outputs from the mixture testing protocol were used in four different versions of the CMSE fatigue analysis approach utilized in previous TxDOT and FHWA research projects. These four different versions of the CMSE analysis approach were applied to mixture data gathered as part of other ongoing research projects for comparison of the key parameter that indicates the rate of damage accumulation. These different versions include: (1) the original CMSE utilized by Walubita et al., (2) the modified CMSE utilized by Arambula et al. to account for changes in stiffness due to damage and intact mixture, (3) the modified CMSE that separates the different mechanisms of energy dissipation during damage due to repeated loading into 3 parts for use with the DMA fatigue analysis of mastics and fine mixtures, and (4) the modified CMSE that separates the different mechanisms of energy dissipation during damage due to repeated loading into 2 parts.

In addition, development of a mixture testing protocol for prismatic specimens cut from pavement cores continued. This development is necessary to transform the older CMSE testing protocols that utilized only LMLC specimens to ones that will allow testing of pavement cores with relatively thin asphalt concrete layers, specifically to monitor aging and validate pavement performance and aging models.

Significant Results

The following two draft documents were produced: (1) testing sequences for field cores and (2) descriptions of the four different versions of the CMSE fatigue analysis approach.

Significant Problems, Issues and Potential Impact on Progress

In this quarter the MTS equipment used for direct tension testing experienced significant problems with respect to accurate measurement of deformation and successful testing in direct tension with failure in the middle of the specimen. These problems took time to diagnose and then required substantial upgrading of the equipment with new LVDTs and calibration of the load cells. These upgrades were completed in this quarter.

In addition, ARC researchers submitted an estimate to TTI Administration of the demand for testing with the MTS equipment over the next four years from all researchers in the Materials and Pavements Division that share this equipment. The demand is substantial with 9100 specimens to be tested over the next four years and 3800 specimens projected for the next fiscal year. This estimate was forwarded with a request to: (1) upgrade a second MTS system for mixture testing and (2) purchase a third MTS system.

These MTS equipment problems hampered the efforts to develop the expanded mixture testing protocol for both LMLC specimens and prismatic specimens cut from field cores and the associated enhanced CMSE* analysis method.

Work Planned Next Quarter

Next quarter assuming the MTS equipment is operating correctly, development of the expanded mixture testing protocol (with changes in the TS, RM, and RDT direct tension testing protocols) for LMLC specimens and prismatic specimens cut from pavement cores will be finalized by testing dummy specimens. For the corresponding enhanced CMSE* analysis method, output parameters of fatigue life in terms of number of cycles to failure and crack growth index as a measure of fatigue resistance will both be explored.

As the expanded mixture testing protocol that includes healing, anisotropy, and aging is completed; a draft report and journal paper will be submitted to FHWA that documents the development effort. A summary of this report and/or journal paper will also be included in the draft and final reports on the experiment design (Subtask F1c-2).

Work Element F2d: Tomography and Microstructural Characterization (TAMU)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Work in this area is scheduled for start in the last quarter of year 2.

Work Element F2e: Verification of the Relationship between DSR Binder Fatigue Tests and Mixture Fatigue Performance (UWM)

Work Done This Quarter

In the previous quarter, the team attempted to simulate the fatigue behavior of binders in time sweep tests from the monotonic tests based on viscoelastic continuum damage mechanics. However, there is a discrepancy between simulated and measured fatigue life of binders in time sweep tests. After discussing this issue with peers, the group at UW-Madison believes that lack of consideration of nonlinearity and visco-plasticity in the analysis might be the cause of the discrepancy between predicted and measured fatigue behaviors. These two aspects are being addressed at UW-Madison.

Nonlinearity of Asphalt Binder

Following testing procedures developed by the Texas A&M team, the isolation of the nonlinearity effect is being investigated using a step-wise approach. The binders are first tested at a low strain level within the linear viscoelastic (LVE) range, then tested at a higher strain, followed by a repeated test at the original low strain level. If there is no difference in complex modulus at different strain levels, the responses are considered to be within the LVE range. If the complex moduli at the various strains are different from LVE complex modulus, nonlinearity and/or damage might be induced. A way to differentiate between nonlinearity and damage is that if moduli at the initial LVE strain level change after the strain increase step, then damage has occurred; otherwise it is nonlinearity. The variation in the current testing compared to Texas A&M is that multiple frequencies are used at each strain level to capture non-linearity and damage across wide range of loading times.

Figures F2e.1 and F2e.2 illustrate the approach to identify nonlinearity in characterizing the fatigue behavior. Figure F2e.3 shows sample of the testing results to identify the nonlinearity. It seems that for this binder, at 25ºC, 4% and 8% strain levels caused nonlinear response of binders while 12% caused damage in the materials.

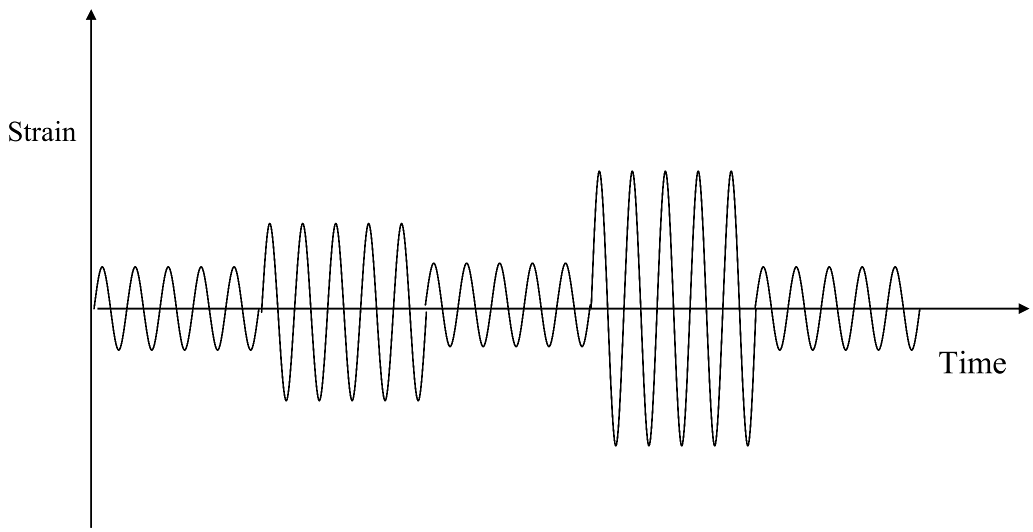

Figure F2e.1. Graph. Test sequence to identify nonlinearity and damage of binders in the DSR.

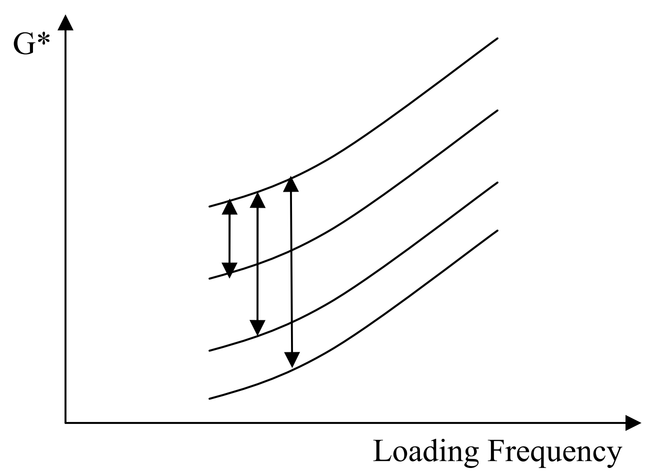

Figure F2e.2. Graph. Schematic of approach to characterize nonlinearity.

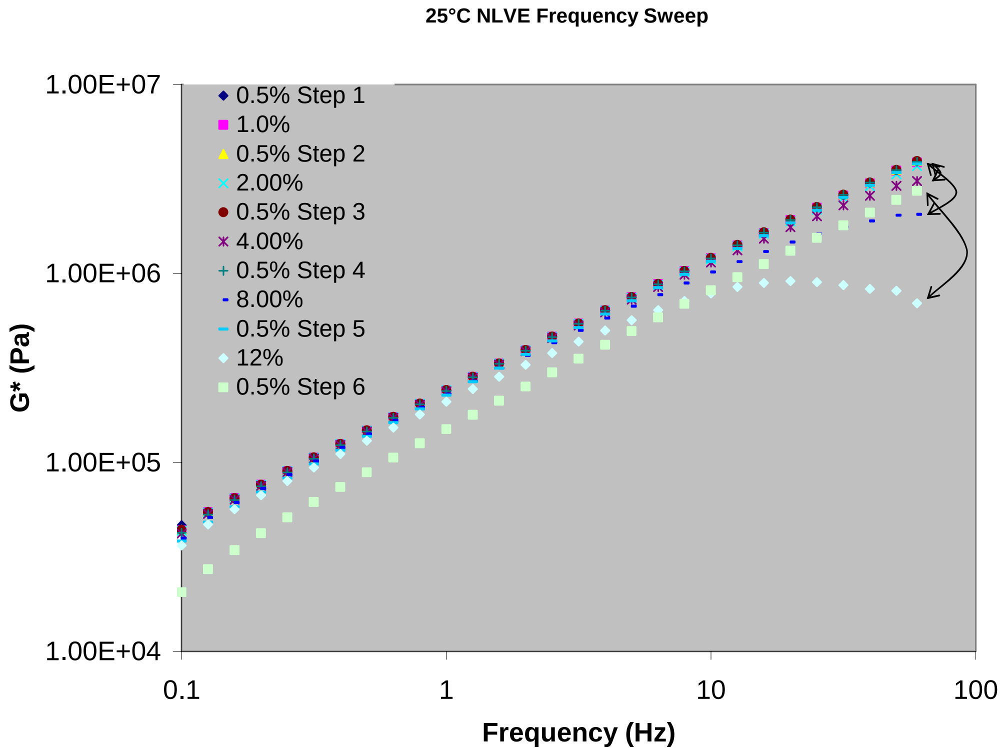

Figure F2e.3. Graph. Test results showing nonlinearity.

Visco-plasticity of Asphalt Binders

The team has conducted detailed literature review on the subject as applied for mixtures by Chehab et al. (2004). Based on the review, testing is being conducted at lower temperatures at which the effect of visco-plasticity can be assumed negligible. Also, the mathematical formulation to account for the nonlinearity and the visco-plasticity is being developed.

<u>Significant Results</u>

In collaboration with the Texas A&M team, a procedure for isolating the nolinearity effects from damage effects has been successfully demonstrated. The nonlinearity of asphalt binder is found to depend on the strain levels, testing temperature, and testing frequency. Visco-plasticity of binders is under investigation by comparing results at varying temperatures. This work is following previous work on mixtures.

<u>Significant Problems, Issues and Potential Impact on Progress</u>

None.

Work Planned Next Quarter

The research team will finish the characterization of nonlinearity and work on visco-plasticity following the work by Chehab et al. (2003). An evaluation of the role of these behaviors in explaining the discrepancy in simulation of stress sweep will continue. Professor Chehab has been contacted to seek his help in applying the concepts of visco-plstcicity to binder testing results. He has expressed an interest in collaboration and a meeting will be scheduled next quarter.

Cited References

Chehab, G. R., Kim, Y. R., Schapery, R. A., Witczak, M. W., and Bonaquist, R., 2003, Characterization of Asphalt Concrete in Uniaxial Tension Using a Viscoelastoplastic Model, *J. Assoc. Asphalt Pavement Technology*, 72, 326–370.

CATEGORY F3: MODELING

Work Element F3a: Asphalt Microstructural Model (WRI)

Work Done This Quarter

The detailed work plan was submitted as an addendum to the Year 2 Work Plan for approval. The preparation of the detailed work plan was the first planned activity for Year 2.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Begin work at WRI and begin the process of subcontract approval with the AO.

Work Element F3b: Micromechanics Model (TAMU)

Subtask F3b-1: Model Development

Subtask F3b-2: Account for Material Microstructure and Fundamental Material Properties

Note: These two subtasks work together until such time as the development progresses. Subtask F3b-2 will begin in the latter part of the Year 2 Work Plan.

Work Done This Quarter

- Continued the review of literature related to the micromechanics-based computational modeling techniques and the cohesive zone modeling (CZM) approaches;
- Participated in the modeling ETG meeting at Chicago (June 2008) and presented work progress including research background of the CZM and the micromechanical model; and
- Completed RVE study of asphalt microstructure without considering damage.

Significant Results

Representative volume elements (RVE) of undamaged asphalt concrete mixtures were sought. Three widely-used asphalt concrete mixtures (two dense-graded Superpave mixtures with different nominal maximum aggregate sizes and one stone matrix asphalt mixture) were selected and evaluated. To properly address the significant heterogeneity of asphalt concrete mixtures in defining RVE, several geometrical factors such as volume fraction, gradation, orientation, and the number of aggregate particles were considered together. Analysis results indicated that typical dense-graded Superpave asphalt concrete mixtures can be characterized for their non-damage effective properties with the approximately 50 mm size RVE, which infers that current non-damage mixture property tests such as the dynamic modulus test and the low-temperature creep compliance test can reasonably identify mixture properties, since specimen size and gauge length of those tests is equal or greater than 2 inches. However, property measurements of stone matrix asphalt mixtures, where larger aggregates are involved, need to be performed at a larger scale for better accuracy. Geometrically-defined RVE were then validated by finite element simulations where effective material properties were obtained.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Laboratory tests will be performed to obtain key model parameters. These experiments will also be used to characterize length scales of cohesive zone. In addition, analysis will be conducted to determine the influence of damage on the size of the representative volume element (RVE). The results of this research will be documented in a research paper during the coming quarter.

Work Element F3c: Development of Unified Continuum Model (TAMU)

Work Done This Quarter

The continuum damage model developed at TAMU has been implemented in the finite element method. The UMAT subroutine of ABAQUS software was used to define the elastoviscoplastic constitutive relationship. The model accounts for the nonlinear viscoelastic response and permanent deformation of asphalt mixtures. It is also developed to account for the influence of stress state (extension versus compression) on material performance. Parametric analysis was conducted to determine the influence of model parameters on asphalt pavement response (nonlinear viscoelastic response and permanent deformation).

The research team members at NCSU have conducted literature review on non-local models in order to develop an extended continuum damage model that is capable of accounting for the material response after damage initiation.

Significant Results

The main result is the successful implementation of the continuum damage model in the finite element method.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The model will be extended during the next quarter to account for the influence of damage on the viscoelastic response of asphalt mixtures. In addition, the hardening/softening function of the yield surface will be examined in order to test the ability of the model to capture the response of asphalt mixtures during loading and unloading. In the current model, the material continues to harden during the application of the first loading cycle until it reaches a maximum level of viscoplastic strain. During the application of the second loading cycle, the model is not capable of producing viscoplastic deformation higher than the maximum level reached during the first cycle. However, it is known from experimental measurements that the material develops viscoplastic strain in the second cycle beyond the level in the first cycle. In order to overcome this limitation of the model, the research will evaluate the use of “kinematic hardening” function to model the change in material response during unloading. It is expected, based on findings in the literature review, that the use of the “kinematic function” will overcome the current limitation of the model.

Work Element F3d: Calibration and Validation

This work element is planned to start later in the project.

Fatigue Year 2

		Year 2 (4/08-3/09)											
		4	5	6	7	8	9	10	11	12	1	2	3
Material Properties													
F1a	**Cohesive and Adhesive Properties**												
F1a-1	Critical review of literature					JP							
F1a-2	Develop experiment design												
F1a-3	Thermodynamic work of adhesion and cohesion												
F1a-4	Mechanical work of adhesion and cohesion												
F1a-5	Evaluate acid-base scale for surface energy calculations												
F1b	**Viscoelastic Properties**												
F1b-1	Separation of nonlinear viscoelastic deformation from fracture energy under cyclic loading							JP		D			F
F1b-2	Separation of nonlinear viscoelastic deformation from fracture energy under monotonic loading							JP		D			F
F1c	**Aging**												
F1c-1	Critical review of binder oxidative aging and its impact on mixtures												
F1c-2	Develop experiment design					D	F						
F1c-3	Develop transport model for binder oxidation in pavements				P						P		JP
F1c-4	Effect of binder aging on properties and performance						JP						P
F1c-5	Polymer modified asphalt materials												
F1d	**Healing**												
F1d-1	Critical review of literature												
F1d-2	Select materials with targeted properties												
F1d-3	Develop experiment design												
F1d-4	Test methods to determine properties relevant to healing							JP					
F1d-5	Testing of materials												
F1d-6	Evaluate relationship between healing and endurance limit of asphalt binders			DP							P		
F1d-7	Coordinate with AFM analysis												
F1d-8	Coordinate form of healing parameter with micromechanics and continuum damage models												
Test Methods													
F2a	**Binder tests and effect of composition**												
F2a-1	Analyze Existing Fatigue Data on PMA						DP						
F2a-2	Select Virgin Binders and Modifiers and Prepare Modified Binder						DP						
F2a-3	Laboratory Aging Procedures												
F2a-4	Collect Fatigue Test Data				P						JP		
F2a-5	Analyze data and propose mechanisms												P
F2b	**Mastic testing protocol**												
F2b-1	Develop specimen preparation procedures						D						
F2b-2	Document test and analysis procedures in AASHTO format						D						
F2c	**Mixture testing protocol**					D, JP	F						
F2d	**Tomography and microstructural characterization**												
F2d-1	Micro scale physicochemical and morphological changes in asphalt binders												
F2e	**Verify relationship between DSR binder fatigue tests and mixture fatigue performance**												
F2e-1	Evaluate Binder Fatigue Correlation to Mixture Fatigue Data												
F2e-2	Selection of Testing Protocols				D, JP		DP,F						
F2e-3	Binder and Mixture Fatigue Testing												
F2e-4	Verification of Surrogate Fatigue Test				JP						P		
F2e-5	Interpretation and Modeling of Data				JP						P		
F2e-6	Recommendations for Use in Unified Fatigue Damage Model												
Models													
F3a	**Asphalt microstructural model**												
F3b	**Micromechanics model**												
F3b-1	Model development									JP			
F3b-2	Account for material microstructure and fundamental material properties												
F3c	**Develop unified continuum model**												
F3c-1	Analytical fatigue model for mixture design												
F3c-2	Unified continuum model						JP						
F3c-3	Multi-scale modeling												

LEGEND

Deliverable codes	**Deliverable Description**
D: Draft Report	Report delivered to FHWA for 3 week review period.
F: Final Report	Final report delivered in compliance with FHWA publication standards
M&A: Model and algorithm	Mathematical model and sample code
SW: Software	Executable software, code and user manual
JP: Journal paper	Paper submitted to conference or journal
P: Presentation	Presentation for symposium, conference or other
DP: Decision Point	Time to make a decision on two parallel paths as to which is most promising to follow througjh
[x]	Indicates completion of deliverable x

Work planned
Work completed
Parallel topic

	Fatigue Year 2 - 5	Year 2 (4/08-3/09)				Year 3 (4/09-3/10)				Year 4 (04/10-03/11)				Year 5 (04/11-03/12)			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Material Properties																	
F1a	**Cohesive and Adhesive Properties**																
F1a-1	Critical review of literature			JP													
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F1a-3	Thermodynamic work of adhesion and cohesion																
F1a-4	Mechanical work of adhesion and cohesion						JP	D	F								
F1a-5	Evaluate acid-base scale for surface energy calculations														JP		
F1b	**Viscoelastic Properties**																
F1b-1	Separation of nonlinear viscoelastic deformation from fracture energy under cyclic loading			D,JP	M&A, F				JP		JP		P		JP,M&A,D		F
F1b-2	Separation of nonlinear viscoelastic deformation from fracture energy under monotonic loading			D,JP	M&A, F				JP		JP		P		JP,M&A,D		F
F1c	**Aging**																
F1c-1	Critical review of binder oxidative aging and its impact on mixtures																
F1c-2	Develop experiment design		D, F														
F1c-3	Develop transport model for binder oxidation in pavements		P		P, JP		P		P, JP		P		P, JP			D, M&A	F
F1c-4	Effect of binder aging on properties and performance			JP	P		JP	D	F						JP	D	F
F1c-5	Polymer modified asphalt materials						P				P					D	F
F1d	**Healing**																
F1d-1	Critical review of literature																
F1d-2	Select materials with targeted properties																
F1d-3	Develop experiment design																
F1d-4	Test methods to determine properties relevant to healing			JP					JP	D	F						
F1d-5	Testing of materials						JP				JP			M&A,D	JP, F		
F1d-6	Evaluate relationship between healing and endurance limit of asphalt binders	DP			P	D,JP,F	P		D,F		P		DP,JP		P	D	F
F1d-7	Coordinate with AFM analysis																
F1d-8	Coordinate form of healing parameter with micromechanics and continuum damage models											JP				JP,D	F
Test Methods																	
F2a	**Binder tests and effect of composition**																
F2a-1	Analyze Existing Fatigue Data on PMA		DP														
F2a-2	Select Virgin Binders and Modifiers and Prepare Modified Binder		DP														
F2a-3	Laboratory Aging Procedures																
F2a-4	Collect Fatigue Test Data		P		JP		P		P				JP, D,F				
F2a-5	Analyze data and propose mechanisms				P			P				P			P	D	F
F2b	**Mastic testing protocol**																
F2b-1	Develop specimen preparation procedures		D														
F2b-2	Document test and analysis procedures in AASHTO format		D														
F2c	**Mixture testing protocol**		D, JP	F													
F2d	**Tomography and microstructural characterization**																
F2d-1	Micro scale physicochemical and morphological changes in asphalt binders						JP				JP	M&A,D	F				
F2e	**Verify relationship between DSR binder fatigue tests and mixture fatigue performance**																
F2e-1	Evaluate Binder Fatigue Correlation to Mixture Fatigue Data																
F2e-2	Selection of Testing Protocols	D, JP	F,DP														
F2e-3	Binder and Mixture Fatigue Testing																
F2e-4	Verification of Surrogate Fatigue Test		JP		P	JP				P	JP	D	F, DP				
F2e-5	Interpretation and Modeling of Data		JP		P	JP			DP	P	JP		M&A				
F2e-6	Recommendations for Use in Unified Fatigue Damage Model															D	F
Models																	
F3a	**Asphalt microstructural model**							JP					JP			M&A	F
F3b	**Micromechanics model**																
F3b-1	Model development				JP				JP				M&A	D	DP	F, SW	
F3b-2	Account for material microstructure and fundamental material properties										JP			D		F	
F3c	**Develop unified continuum model**																
F3c-1	Analytical fatigue model for mixture design														M&A,D		F
F3c-2	Unified continuum model			JP				JP					M&A	D	DP	F, SW	
F3c-3	Multi-scale modeling											JP	M&A	D		F	

LEGEND

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[x]	Indicates completion of deliverable x

Work planned

Work completed

Parallel topic

PROGRAM AREA: ENGINEERED MATERIALS

CATEGORY E1: MODELING

Work element E1a: Analytical and Micro-mechanics Models for Mechanical Behavior of Mixtures (TAMU)

Work Done This Quarter

During this quarter, we have programmed the forward and inverse methods of self-consistent micromechanics analysis and applied it to mixtures and binders that have been tested previously at Texas A&M. In the inverse analysis, we input the Young's Modulus and Poisson's Ratio of the mixture as it varies with frequency and the Shear Modulus of the binder as it varies with frequency. The output gives the Bulk Modulus and Shear Modulus of the aggregate as it varies with frequency. We were then able to put this same aggregate frequency-dependent Bulk and shear modulus data into the forward calculation mode, which uses a separate set of simultaneous equations, to calculate the mixture Bulk, Shear, and Young's moduli and Poisson's Ratio. In doing so, we found that the forward and inverse processes are true inverses of each other.

We also input mixture and binder properties of aged mixtures and binders which had been measured separately and found the resulting frequency dependent aggregate properties using the inverse analysis process. As before, we found that we could put the derived aggregate properties back into the forward analysis process and recover the original mixture properties-to six decimal places!

We also analyzed the results of inputting constant versus frequency-dependent Poisson's Ratios and found that the frequency-dependent approach gives a much less frequency dependent set of aggregate moduli. The resulting slope of the log Shear Modulus vs log frequency curve of aggregates was about what would be expected of hardened concrete and the stiffness was about 1/3 that of concrete at comparable testing frequencies.

In an attempt to determine if the derived aggregate properties were characteristic of the mineral skeleton of the aggregates instead of the aggregates themselves, we analyzed the compressibility test results of several dozen sets of unbound aggregate data, each of which were tested under a variety of stress states. We found that the stiffness of the aggregate mineral skeleton is much less stiff (10 to 20 times less stiff) than the aggregate values that we found in the inverse analysis of the mixtures.

The results of inputting aged mixture and binder data showed that this method can, indeed produce the aging shift of mixture properties with the input of aged binder properties. We also found a form of aging shift function that was suggested by Dr. Zach Grasley of the Texas A&M faculty in his work on the aging of concrete. This form of aging shift function makes it possible to include the aging effect within the Boltzmann superposition integral with which viscoelastic stress and pseudo strain are calculated.

As an effort to measure the properties of aggregates separately and independently, we collected samples of large aggregates (Limestone, River Gravel, Sandstone) and Dr. Bruce Herbert has cored these aggregates into small columns of a size that can be tested at various frequencies with the equipment in the Petroleum Engineering Department.

Significant Results

We have derived, programmed and proven that our forward and inverse self-consistent micromechanics models of a mixture are true inverses of one another.

We have derived from our inverse analysis the frequency –dependent properties of the aggregate and the results thus far demonstrate that we are, indeed getting the properties of the aggregate, itself, rather than the frequency response of the mineral skeleton of the aggregate. We are preparing to make an independent check on the frequency-dependent moduli of several types of aggregates.

We have shown that the forward calculation mode of our micro-mechanics model is capable of producing the frequency-dependent properties of a mix when the separately determined frequency-dependent properties of the aggregate and the binder (or mastic ?) are input to the analytical process.

We have found that the properties of an aged mixture can be predicted using the forward-calculation process by inputting the frequency-dependent properties of the binder (or mastic?) together with the frequency-dependent properties of the aggregate and can obtain the frequency-dependent properties of the mixture as it ages

We have also found, at the suggestion of Dr. Zach Grasley, an aging shift function that shift the frequency-dependent properties of the binder (or mastic?) very accurately and also can be included within the Boltzmann superposition integral for calculating viscoelastic stress and pseudo strain. These latter two are essential to calculating the dissipated pseudo strain energy that is responsible for both cracking and plastic deformation in the mixture. This suggests that we will be able with the use of this aging shift function to incorporate into computational models the effects of aging on the formation and growth of the two principal types of damage.

Significant Problems, Issues and Potential Impact on Progress

We need to determine independently whether the frequency-dependent properties of aggregates that we are inferring from the inverse self-consistent model are the genuine article. At present the results show an expected level of frequency dependence of aggregate moduli but unexpectedly show a stiffer property of the *aggregate* as the mixture ages. There are several possible reasons for this observation that we will need to identify. The possibilities are these: (1) we should be inputting the properties of an aged *mastic* rather than an aged binder; (2) the asphalt absorbed into the surface of the aggregates is providing the changing stiffness of the aggregate as the mixture ages; (3) the measurement of Poisson's Ratio of the mixture must be made accurately: if it varies as expected with aging, it will be important to be able to measure accurately the effect of aging on the stiffness properties of the mix. In this second case, we will need to characterize both the aggregate stiffness of the mineral aggregate and the degree of asphalt absorption that is characteristic of each aggregate source. In the third case, the measurement of the frequency-dependent of the Poisson's Ratio of a mix must be made much more accurately than in the past. We are receiving several sets of binder and mastic data that were measured by Dr. Bahia's group at the University of Wisconsin within the next few weeks in order to test the first two possibilities.

Work Planned Next Quarter

A series of relaxation moduli tests have been initiated in this past quarter and will continue into this quarter. The test protocol has been carefully determined to allow us to use the Laplace Transform method derived by Dr. Zach Grasley to arrive at the frequency-dependent Poisson's Ratio of a mixture. This method will make the crucial measurement of the frequency-dependent Poisson's Ratio of a mixture much more accurate than any of the methods that have been used in the past. This is part of the effort to identify the source of the unexpected dependence of the aggregate stiffness on the age of the mixture. We will develop, program, and apply this method of analysis of the frequency-dependent Poisson's Ratio of mixes.

We expect to run the frequency-dependent tests of the small aggregate columns in the Petroleum Engineering Department in the next quarter.

We will apply the forward and inverse micromechanics model to the DSR test results of binders and mastics that we receive from Dr. Bahia's group at the University of Wisconsin.

We expect to formulate our aging shift function for binders (or mastics?) and mixes into a presentation which we will prepare for presentation at an upcoming ETG meeting.

We expect to begin a series of repeated load tests on mixes at different temperatures, moisture conditions, aging conditions and rest periods to determine these effects on the properties of mixes that we can investigate with our forward and inverse self-consistent micromechanics method.

We expect to complete the analyses of the effect of aggregate particle size and shape as it interacts with the surface tension generated by different SHRP asphalts to produce the stiffness and tensile strength of mixtures. These computations have been made on approximately 150,000 combinations of aggregate size, shape, asphalt content, and surface tension with a variety of SHRP Reference Library asphalts with a recently developed micromechanics-level "particle model". We also expect to provide a hypothesis of how the fracture and healing bond energies of asphalt mixes, both adhesive and cohesive, are affected by the presence of different levels of relative humidity either on the aggregate-asphalt interface or within the binder. We will use these computations from the particle model and bond energy as altered by water vapor partial pressure to explain the results of the DMA tests which we will run after conditioning at different levels of relative humidity.

Presentations:

We will report on the self-consistent micromechanics forward and inverse mixture model at the Petersen conference in Laramie, Wyoming during the week of July 14-16, 2008.

Journal Papers:

We expect to write a paper on the forward and inverse self-consistent micromechanics mixture model for presentation and publication in the TRB annual Meeting in January 2009.

Work element E1b: Binder Damage Resistance Characterization (DRC) (UWM)

Subtask E1b-1: Rutting of Asphalt Binders

Work Done This Quarter

In the previous quarter it was found that geometry has an effect on the test results of the creep and recovery response of binders. The effect was further confirmed this quarter by testing at multiple temperatures and increased stresses. In addition, testing was conducted in another rheometer to rule out that the effect is rheometer-dependent. Since the parallel plate geometry is widely used, it was necessary to explore what causes the tertiary behavior in this geometry and what conditions can be changed to allow using it. It was speculated that varying film thickness could solve the problem, and thus, testing was conducted at various film thicknesses and varying stress levels. Also, since initial data indicated that the cone-and-plate geometry does not show tertiary flow at the same testing conditions as the parallel-plate, further testing was conducted at varying stresses and temperatures to investigate at what conditions tertiary flow could be measured.

To see the effect of film thickness in parallel plate, an unmodified binder, Flint Hills performance grade (PG) 64-22, was selected. One hundred cycles repeated creep and recovery test were run with different film thickness at 58 ºC and low stress level. The stress level in all of these tests was 1000 Pa and film thickness ranged from 125 microns to 1 millimeter.

Significant Results

Results showed that using the geometry of parallel plates with a 1 mm gap is not recommended when high stress and high temperature temperatures are used for testing binders in creep and recovery loading mode. This geometry allows a sudden increase in strain that appears as tertiary-like behavior, as shown in figure E1b-1.1. This sudden increase in flow could be mistakenly taken as material behavior, while it is clearly a testing artifact due to changing geometry. The flow is caused by the large gap (1.0 mm) which leads to flow of binder outside the gap at certain strains or temperatures.

The testing this quarter also confirmed that using the cone-and-plate geometry does not allow the sudden increase in shear strain (tertiary-like flow) that is seen when parallel plates are used, even at high stresses (up to 20 kPa) and high temperatures (70 ºC), as shown in figure E1b-1.1.

It was also found that reducing the film thickness in the parallel plates to 275 µm can stop this behavior and response measured for a number of asphalt binders matches very well with the results of the cone-and-plate geometry.

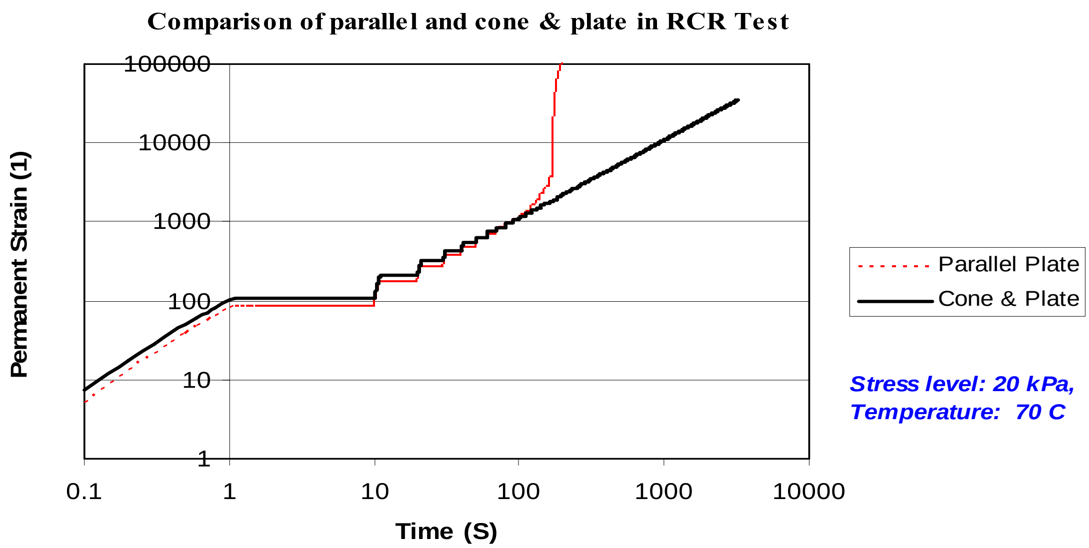


Figure E1b-1.1. Graph. Comparison of parallel plates and cone-and-plate in repeated creep and recovery (RCR) test at 70 ºC for a PG 64 grade.

The results of the cone-plate, however, did not rule out the existence of tertiary flow, as a true binder behavior. On the contrary, they indicate that for some modified binders tertiary flow does exist and is similar to such behavior in mixtures, particularly at high stress levels and high temperatures. Figure E1b-1.2 depicts an example of the tertiary flow for one of the binders tested in the study. The importance of tertiary flow varies from binder to binder and requires extended time of loading. Tertiary flow is found significant for the low asphaltenes binder and for binders with high concentration of modifier. It appears that binder molecular structure is an important factor for this tertiary behavior.

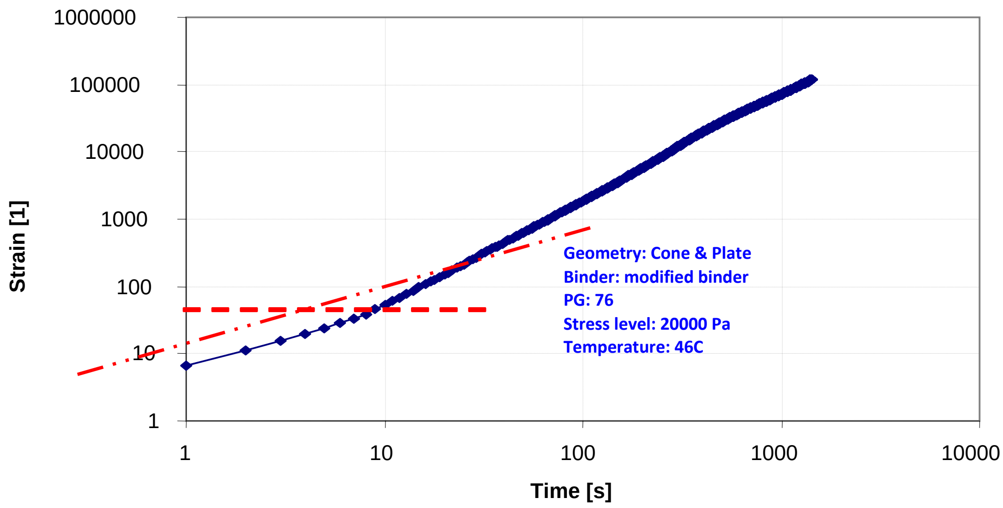


Figure E1b-1.2. Graph. Simple creep test at 46 ºC and 20 kPa stress level, on a modified binder.

Significant Problems, Issues and Potential Impact on Progress

Creep and recovery was found to be extremely sensitive to minor variation in temperatures. Extensive testing was required to understand that cause of lack of repeatability but repeated calibration of temperature led to consistent results.

Work Planned Next Quarter

Testing next quarter will continue for other binders. In addition, testing of mastics will be started.

Subtask E1b-2: Feasibility of Determining Rheological and Fracture Properties of Thin Films of Asphalt Binders and Mastics using Nano-indentation (Year 2 start)

Work Done This Quarter

The research team completed the following steps:

- Drafted a literature review on existing nanoindentation technology in various material science and bioengineering applications.
- Identified different possible instruments and equipment and evaluated pros and cons of each.
- Performed early evaluation of binder responses using one of the technologies available to the research team.

Significant Results

Nanoindenters have only recently been used for the evaluation of binders and mastics (Pichler et al. 2005). We will begin a systematic evaluation of rheological and fracture properties of thin films of asphalt binders and mastics using nanoindentation testing technology.

Literature Review and Identification of Equipment
Nanoindenters are instruments that measure load displacement of the surface of different materials (e.g., metals, ceramics, polymers, living tissue, etc., Li and Bhushan 2002; Lin et al. 2006; Beake 2006; Oyen & Ko 2007; Cook & Oyen 2007; Oyen 2007). The collected data are used to evaluate mechanical properties of materials including elastic, elastoplastic, creep, hardness, fracture, fatigue, and dynamic properties (Li and Bhushan 2002; Lin et al. 2006). These properties are obtained by fitting different models to the data. A typical data set is shown in figure E1b-2.1, where three common loading histories are illustrated: loading, holding, and unloading. These loading stages permit evaluating elastoplastic properties (loading stage), creep (holding stage), and elastic (unloading stage, Li & Bhushan 2002; Pichler et al. 2005).

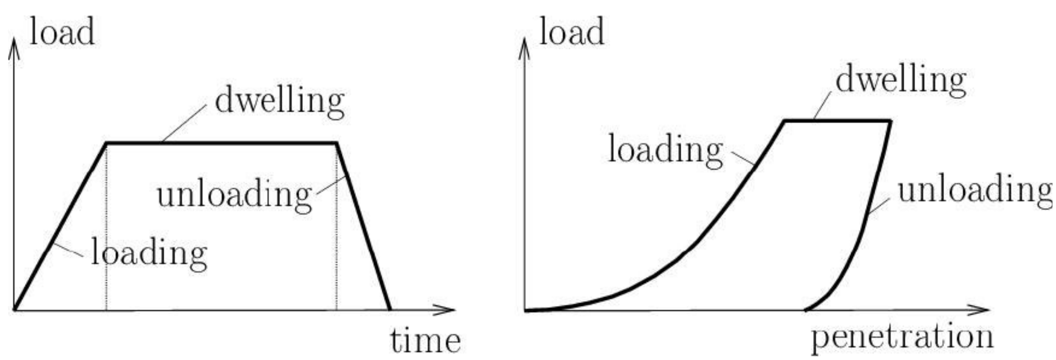


Figure E1b-2.1. Graphs. Typical nanoindentor test load-displacement response curve (source: Pichler et al. 2005).

The analysis of the curves yields the hardness H of the binder:

$$H = \frac{P}{A_c} = \frac{P}{\pi h_c^2 \tan^2(\theta)} \tag{1}$$

where P is the indenter normal force, A_c is the indenter projected horizontal area, h_c is the contact depth, and θ is the indenter half angle (Li and Bhushan 2002; Pichler et al. 2005). Young's modulus E is obtained from the initial part of the unloading part of the indentation curve $S=dP/dh_c$:

$$S = \beta \frac{2}{\sqrt{\pi}} \frac{E}{1-\nu^2} \sqrt{A_c} = \beta \frac{2}{\sqrt{\pi}} \frac{E}{1-\nu^2} \sqrt{\pi h_c^2 \tan^2(\theta)} \tag{2}$$

where β is a constant that depends on the geometry of the intender and ν is Poisson's ratio.

The viscosity η of the binder is obtained from fitting a three-parameter Kelvin-Voight model to the dwelling part of the nanoindentation curve (Pichler et al. 2005) or alternatively by fitting a log of time model to the constant rate of loading part of the curve (Beake 2006). That is, the nanoindentation data can then be used to calculate the elastic stiffness along the unloading part of the curve and the viscosity along the loading or dwelling parts of the curve (Li and Bhushan 2002; Pichler et al. 2005; Beake 2006). The results can then be compared with data from dynamic shear rheometer testing.

Nanoindenting hardware
Nanoindenters make very small indentions in a material (in the order of nanometers, Nanoindentation, 2008) to measure load (while applying displacement) or displacement (while applying loads). The most common type of nanoindenters is known as *soft* nanoindenters. These nanoindenters are load-controlled systems where changes in the displacement do not generate changes in the applied force. There are different types of technologies used for soft nanoindenters, including those shown in figure E1b-2:

- Electromagnetic actuator
- Electrostatic actuator
- Spring actuators (including atomic force microscope)

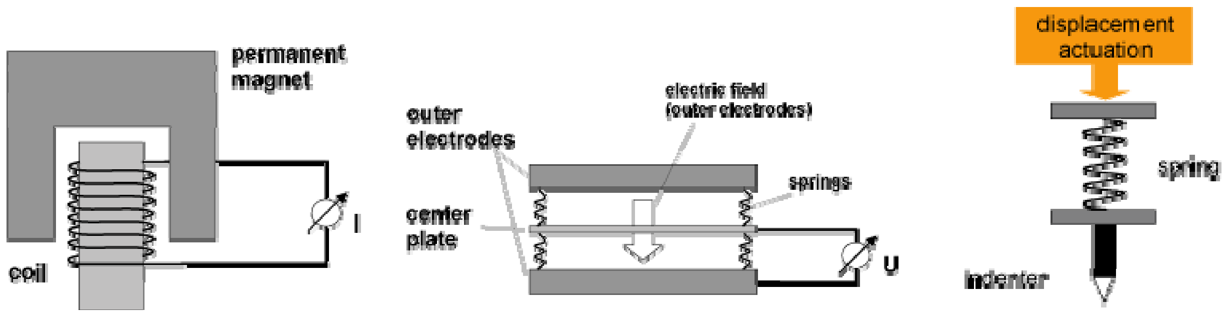
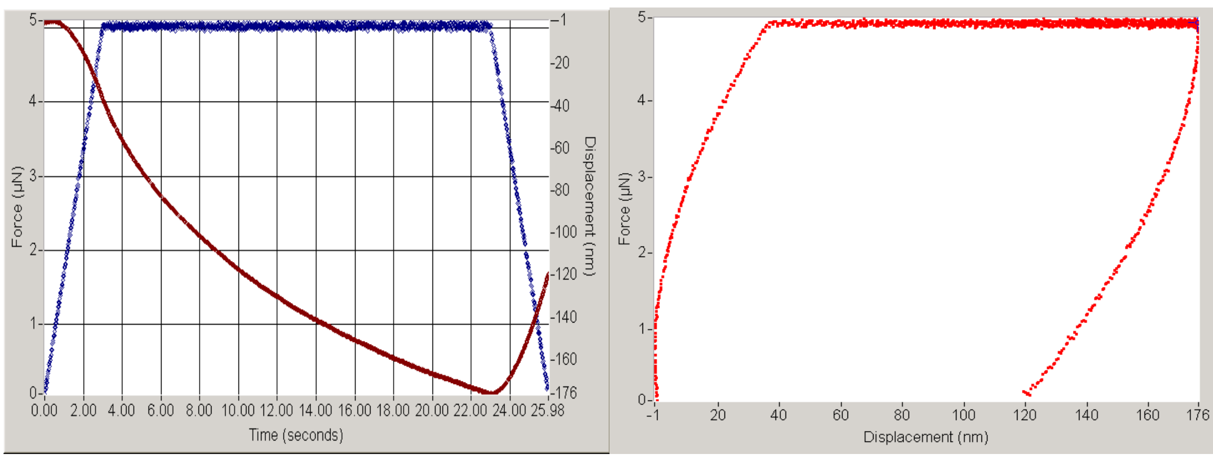


Figure E1b-2.2. Illustrations. Different technologies used in the development of soft nanoindenters: (a) electromagnetic actuator, (b) electrostatic actuator, and (c) spring actuators (source: Nanoindentation, 2008).

Commercially available indentation systems
The research team identified the following commercially-available system. Manufacturer Web site information is also included.

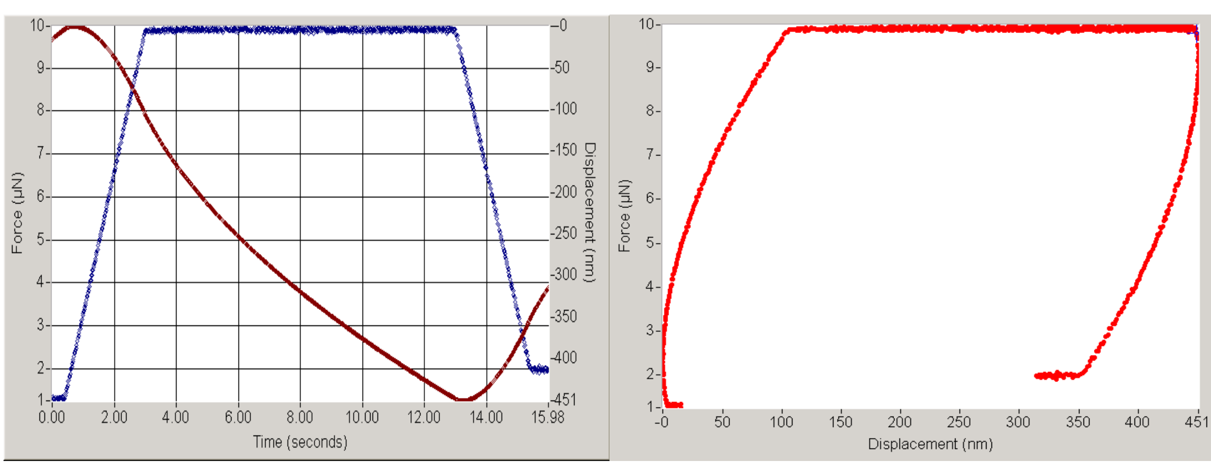
- CSIRO Ultra-Micro-Indentation System. http://www.csiro.au/
- Hysitron TriboScope. http://www.hysitron.com/
- MTS NanoIndenter. http://www.mtsnano.com/
- Micromaterials Nano Instruments. http://www.micromaterials.co.uk/
- CMS Nano Hardness Tester. http://www.csm-instruments.com/

Preliminary tests
The preliminary nanoindentation tests were run on B9Y+Limestone filler (PG 64-34 Elvaloy modified with limestone filler conditioned for 72 hours at 135 °C) using 500 μm by 500 μm flat indenter to maximum loads equal to 5 μN and 10 μN. Results are shown in figure E1b-2.3 and figure E1b-2.4. These values yield maximum stresses equal to 20 Pa and 40 Pa. The following loading sequence was used: constant loading rates of 6.67 Pa/s and 13.34 kPa for 3 seconds up to the maximum contact pressures, 20 seconds of constant load and then 3 seconds of unloading at rates equal to -6.67 Pa/s and -13.34 kPa. The results obtained are similar to the results reported by Pichler et al. 2005. However, the testing lab reported indenter-binder adhesion problems.



(a) (b)

Figure E1b-2.3. Graphs. Plots for 5 μN indentation results on B9Y+Limestone filler with a 500 μm flat punch probe. (a) Force and displacement versus time and (b) force versus displacement



(a) (b)

Figure E1b-2.4. Graphs. Plots for 10 μN indentation results on B9Y+Limestone filler with a 500 μN flat punch probe. (a) Force and displacement versus time and (b) force versus displacement

Significant Problems, Issues and Potential Impact on Progress

- The company that ran the test on binders had problems related to the stickiness between the binder and the nanoindenter. They solved this problem by adding a water film on the binder surface. However questions remain about how the water film interacts with the binder and nanoindenter and whether alternate solutions are possible.
- There is a question whether load/stress histories can be reproduced with dynamic shear rheometer testing. There are concerns with low stresses and rates, whether they are within the load cell and actuator resolutions. Preliminary tests have been run and results seem promising
- The research team needs to evaluate the minimum size for the indenter. An indenter that is too small will interact with the polymer molecules and there will be problems related to local heterogeneities. An indenter that is too large will face problem related to indenter size effect. Exploratory studies will most likely be used to solve this problem.

Work Planned Next Quarter

Next quarter, the research team will:

- Continue with the literature review and identification of equipment
- Explore the use of nanoindentation devices
- Begin exploratory tests on binder specimens
- Draft an analysis methodology

Cited References

Beake, B., 2006, Modelling indentation creep of polymers: a phenomenological approach. *J. Phys. D: Appl. Phys*. 39: 4478–4485.

Cook, R. F., and M. L. Oyen, 2007, Nanoindentation behavior and mechanical properties measurements of polymeric material. *Int. J. Mat. Res*., 98: 5-14.

Li, X., and B. Bhushan, 2002, A review of nanoindentation continuous stiffness measurement technique and its applications. *Materials Characterization*, 48: 11–36.

Lin, D. C., E. K. Dimitriadis, and F. Horkay, 2006, Advances in the mechanical characterization of soft materials by nanoindentation. *Recent Res. Devel. Biophys*. 5, 38 pages.

Nanoindentation, 2008, URL: http://www.nanoindentation.cornell.edu/home_main.htm. Accessed on June 10, 2008.

Oyen, M. L., 2006, Nanoindentation hardness of mineralized tissues. Short communication. *Journal of Biomechanics*, 39: 2699–2702.

Oyen, M. L., and C.-C. Ko, 2007, Examination of local variations in viscous, elastic, and plastic indentation responses in healing bone. *J. Mater Sci: Mater Med*., 18: 623–628.

Pichler, C., A. Jäger, R. Lackner, and J. Eberhardsteiner, 2005, "Identification of Material Properties from Nanoindentation to Bitumen and Cement Paste." 22nd DANUBIA-ADRIA Symposium on Experimental Methods in Solid Mechanics, September 28-October 1, 2005, Monticelli Terme, Parma, Italy.

Work element E1c: Warm and Cold Mixes

Subtask E1c-1: Warm Mixtures

Work Done This Quarter

1. Investigation of Effects of Warm Mix Additives on the Rheological Properties of Binders

During this quarter the research team started testing the binder properties according to the proposed Year Two Work Plan. Standard rheological properties such as G*, phase angle, and true grade of the binders used in this study are being measured. Based on information gathered at the TRB conference and Warm Mix Working Group, the team also ran extensive testing trying to measure normal force and correlate the normal force measurements with workability of warm mix asphalt (WMA) produced with a selected additive. So far the results are not encouraging and testing efforts are unsuccessful in obtaining meaningful repeatable results. Experiments included film thicknesses ranging from 1000 μm to 50 μm on neat and modified binders. Typical results are shown in the figures E1c-1.1 and E1c-1. 2.

2. Evaluation of the Effects of Warm Mix Additives on Workability and Stability of Mixes

Work began on evaluating the effect of WMA additives on mixture workability and stability. The effect of Advera on workability and stability has been evaluated using one fine graded mix design (N_{des} = 100). Table E1c-1.1 provides the factors varied thus far in the study.

Table E1c-1.1. Summary of independent variables for current warm mix evaluation work.

Summary of Independent Variables				
	Control		WMA Additives	
Variable	**Values**	**Levels**	**Values**	**Levels**
Compaction Temperature (C)*	90	3	90	2
	110			
	135		110	
Compaction Pressure (kPa)	300	2	300	2
	600		600	
Binder Grade	PG 64-22	2	PG 64-22	2
	PG 76-22		PG 76-22	
Additive Type	Control	1	Advera	1
Aggregate Type	Granite	1	Granite	1
NMAS (mm)	19.5	1	19.5	1
Gradation	Fine	1	Fine	1
	Two Replicates	**24**		**16**
	Total Mixes	**40**		

Future evaluations plan to add different aggregate types, nominal maximum aggregate size (NMAS), and a coarse gradation. Laboratory evaluation will also include Sasobit and a version of Evotherm. Evaluation parameters for workability include air voids, the Construction Densification Index (CDI), and the Construction Force Index (CFI). Mechanical stability is estimated using the Traffic Densification Index (TDI) and Traffic Force Index (TFI). Definitions of the densification and force indices can be found in Mahmoud and Bahia (2004).

3. Field Project Selection and Coordination

There have been two significant work areas in regards to field projects this quarter:

- University of Nevada-Reno: Researchers have identified and are sampling materials from three field projects
    - California
    - North Las Vegas
    - Utah
- University of Wisconsin-Madison: Researchers have identified hot mix asphalt (HMA) mixes that show temperature sensitivity in both laboratory and field compaction. Materials will be collected from these projects and samples reproduced with WMA additives to evaluate the effect on compaction temperature sensitivity.

Furthermore, the two universities collaborated to develop a detailed testing plan for field trial mixes.

Significant Results

1. Investigation of Effects of Warm Mix Additives on the Rheological Properties of Binders

A brief summary of the rheological properties measurements we are conducting is presented in table E1c-1.2:

Table E1c.2. A brief summary of rheological properties.

Binder	Source	Additive	Pass/Fail Temp. °C	PG Grade	G*/sin(δ) kPa
PG 64-22	Citgo	Neat	66.9	64	1.4171
PG 64-22	Citgo	Sasobit 2%	72.2	70	1.2715
PG 76-22	Citgo	Neat	77.5	76	1.1586
PG 76-22	Citgo	Sasobit 2%	80.6	76	1.4827

Figures E1c-1.1 through E1c-1.4 exemplify several attempts at measuring normal force using different instruments.

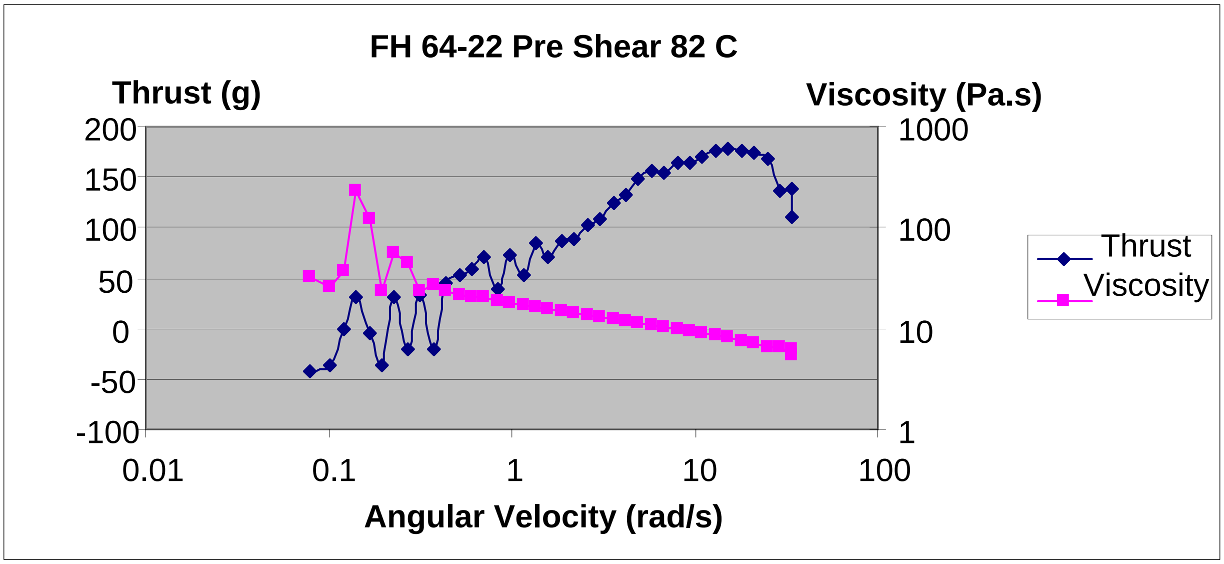


Figure E1c-1.1. Graph. Normal force measurement using the Bohlin dynamic shear rheometer (DSR); gap of 100 µm, run 1.

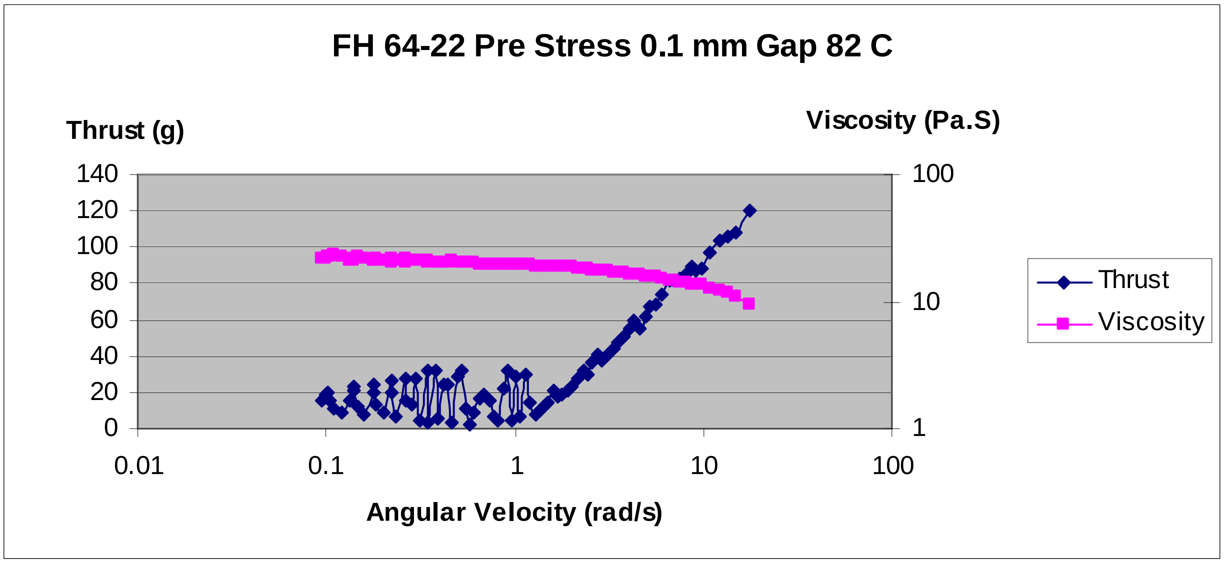


Figure E1c-1.2. Graph. Normal force measurement using the Bohlin DSR; gap of 100 µm, run2.

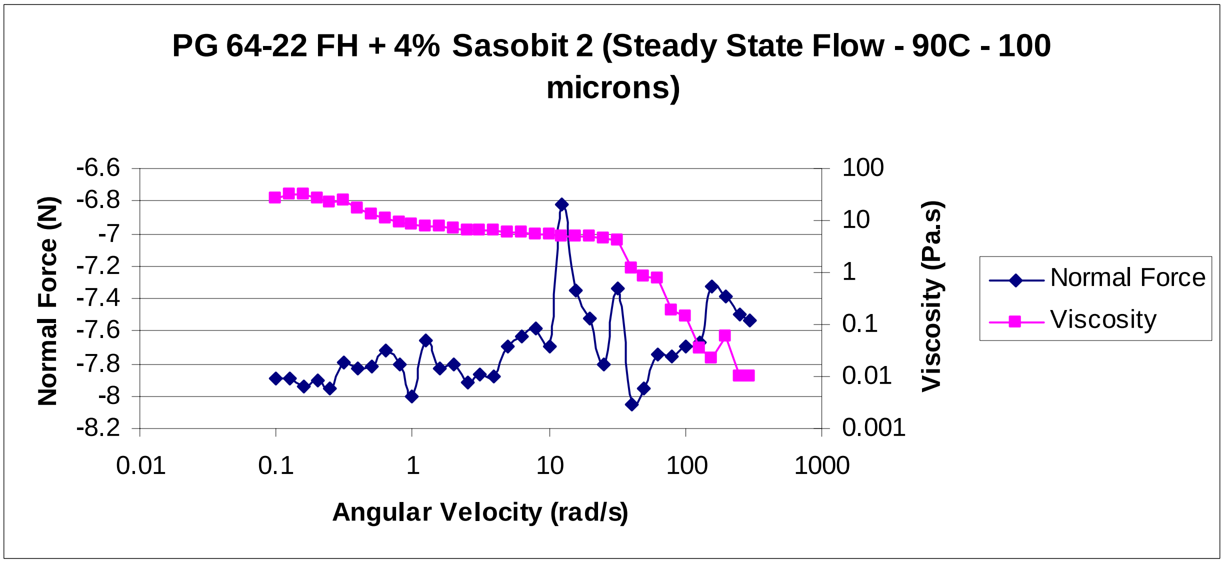


Figure E1c-1.3. Graph. Normal force measurement using the TA Instruments DSR; gap of 100 µm.

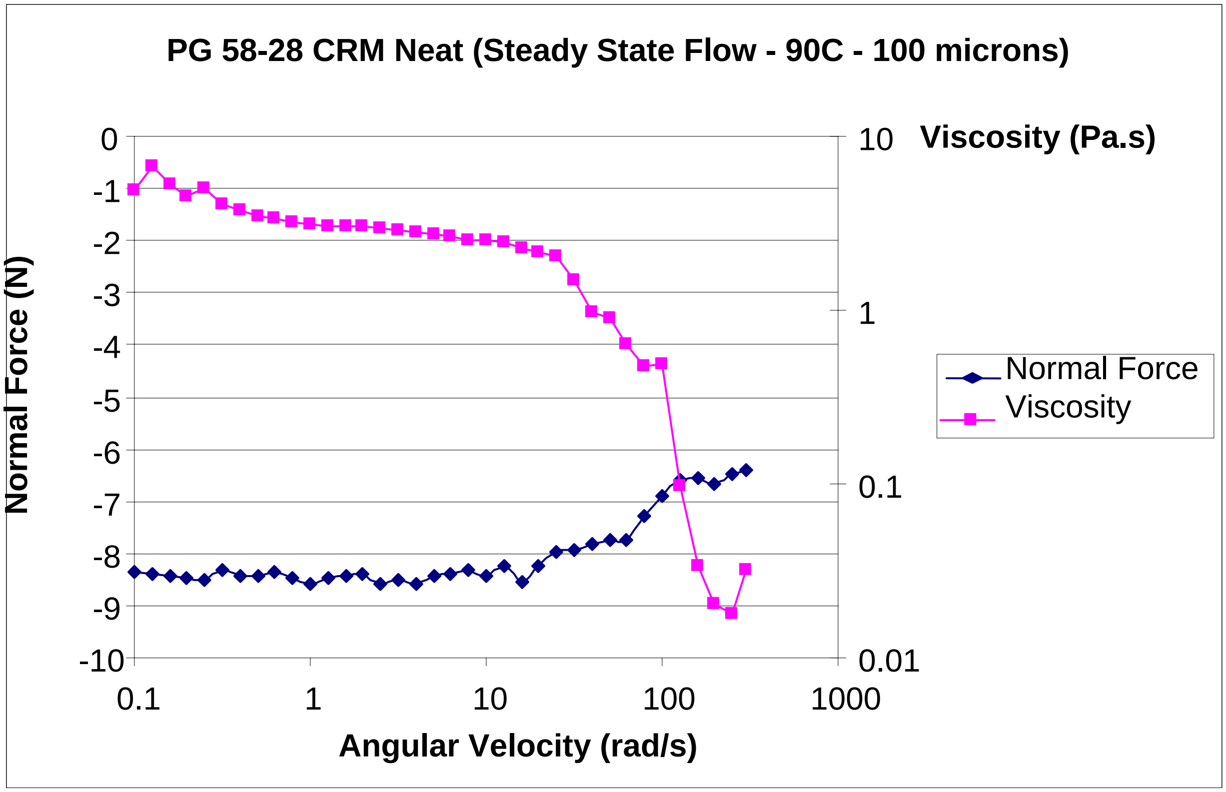


Figure E1c-1.4. Graph. Normal force measurement using the TA DSR; gap of 100 µm.

Similar results were obtained when a Paar-Physica DSR instrument was used.

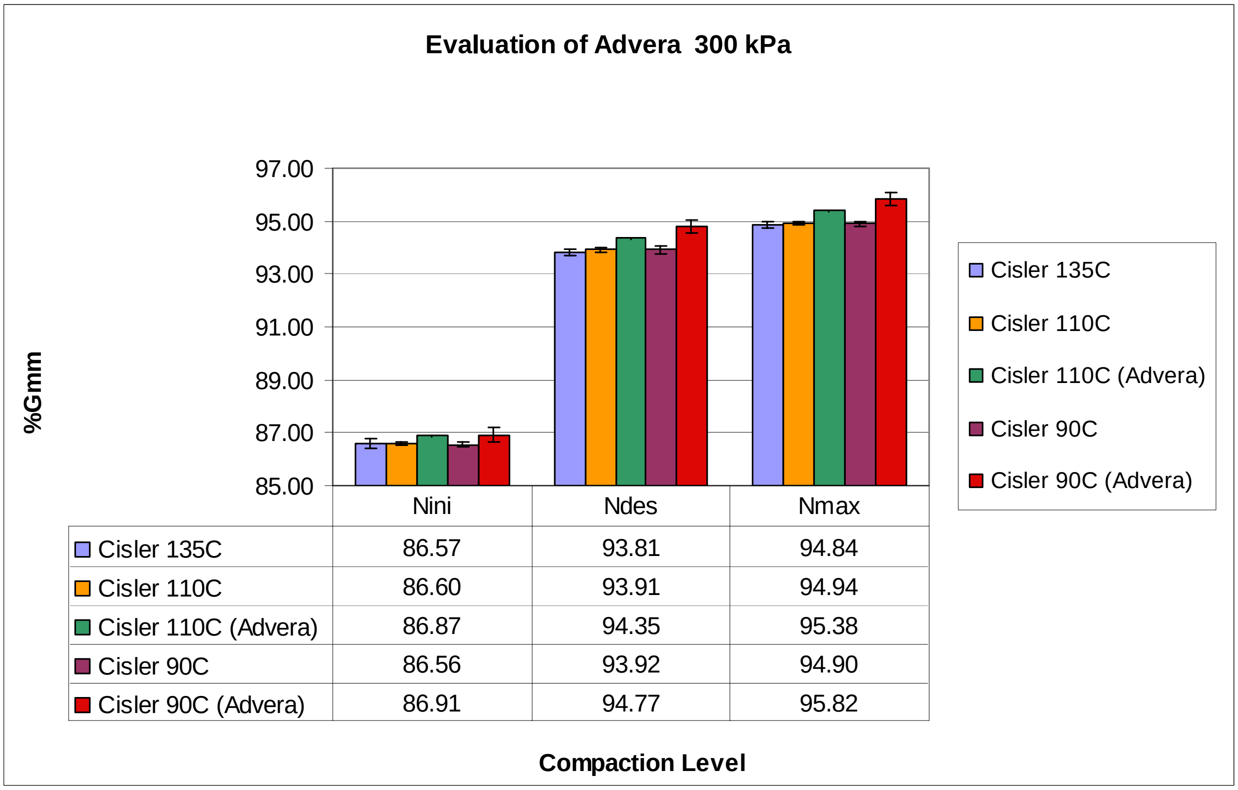
2. Evaluation of the Effects of Warm Mix Additives on Workability and Stability of Mixes

As of the end of the quarter, all of the mixes using the PG 64-22 binder were complete and data analyzed for the air voids and CDI. TDI and force index analysis will be available in the following few weeks. Table E1c-1.3 provides a summary of the differences in air voids between the HMA mixes and WMA mixes compacted using Advera.

Table E1c-1.3. Difference in air voids between HMA and WMA mixes.

Difference in Air Voids between HMA and WMA mixes			
		Percent Difference	
Mix	**Gyrations**	**600 kPa**	**300 kPa**
Cisler 110	8	0.13	0.27
	100	0.69	0.44
	160	0.73	0.45
Cisler 90	8	0.29	0.35
	100	0.38	0.85
	160	0.43	0.92

Figure E1c-1.5 and E1c-1.6 provide graphical comparisons of the results for 300 kPa and 600 kPa respectively.



	Nini	Ndes	Nmax
Cisler 135C	86.57	93.81	94.84
Cisler 110C	86.60	93.91	94.94
Cisler 110C (Advera)	86.87	94.35	95.38
Cisler 90C	86.56	93.92	94.90
Cisler 90C (Advera)	86.91	94.77	95.82

Figure E1c-1.1. Graph. Evaluation of Advera 300 kPa compaction pressure.

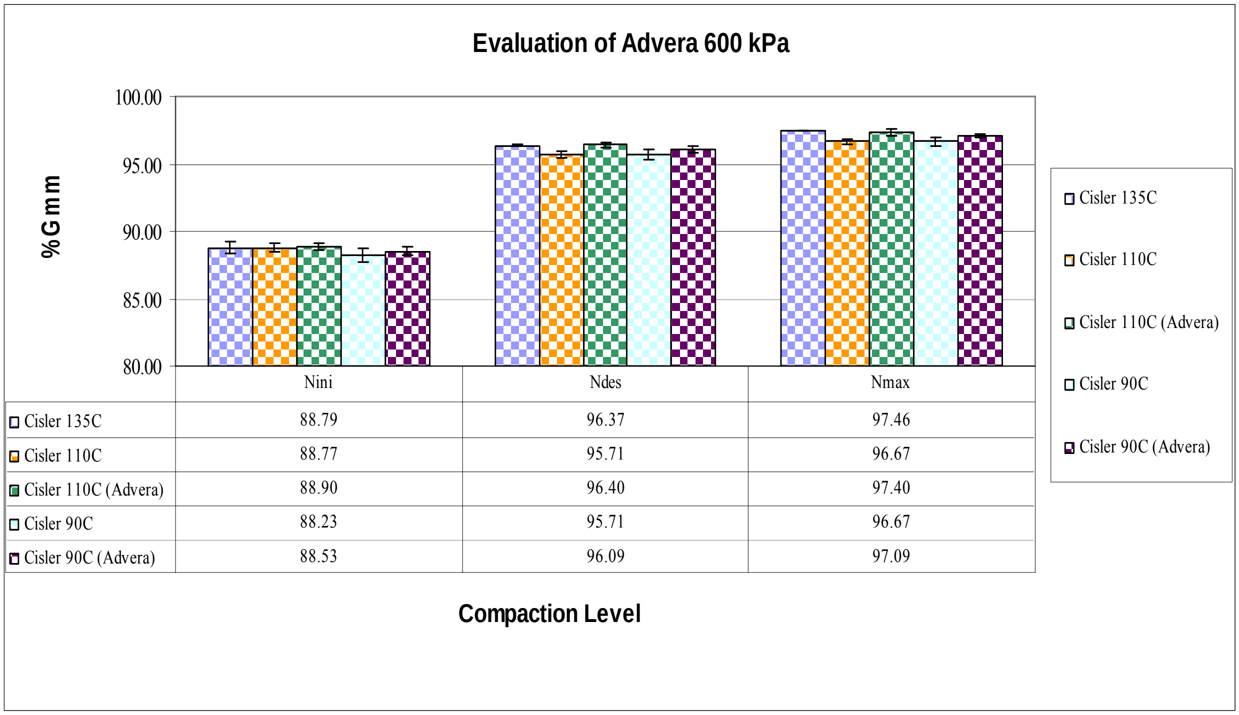


Figure E1c-1.6: Evaluation of Advera 600 kPa compaction pressure.

Enhanced workability due to the addition of Advera would be noted by an increase in air voids given table E1c-1.3, and the supporting figures show that for the 600 kPa compaction pressure and 300kPa compacted at 110 ºC the effect of Advera cannot clearly be discerned from experimental error for either temperature. However, for mixes compacted at 300 kPa and 90 ºC there is a significant increase in air voids at both N_{des} (0.85%) and N_{max} (0.92%). These results will be verified in subsequent text using the CDI.

The results of the air voids analysis were confirmed using the CDI. Table E1c-1.4 and figure E1c-1.7 show the results of the analysis. Table 4 is the difference in CDI between conventional HMA and WMA using Advera. Thus, increased workability would be given as a positive number.

Table E1c-1.4. Difference in air voids between HMA and WMA mixes.

Difference in Air Voids between HMA and WMA mixes		
Mix	**Pressure**	**CDI Difference**
Cisler 110	300 kPa	111.85
	600 kPa	2.60
Cisler 90	300 kPa	109.85
	600 kPa	31.75

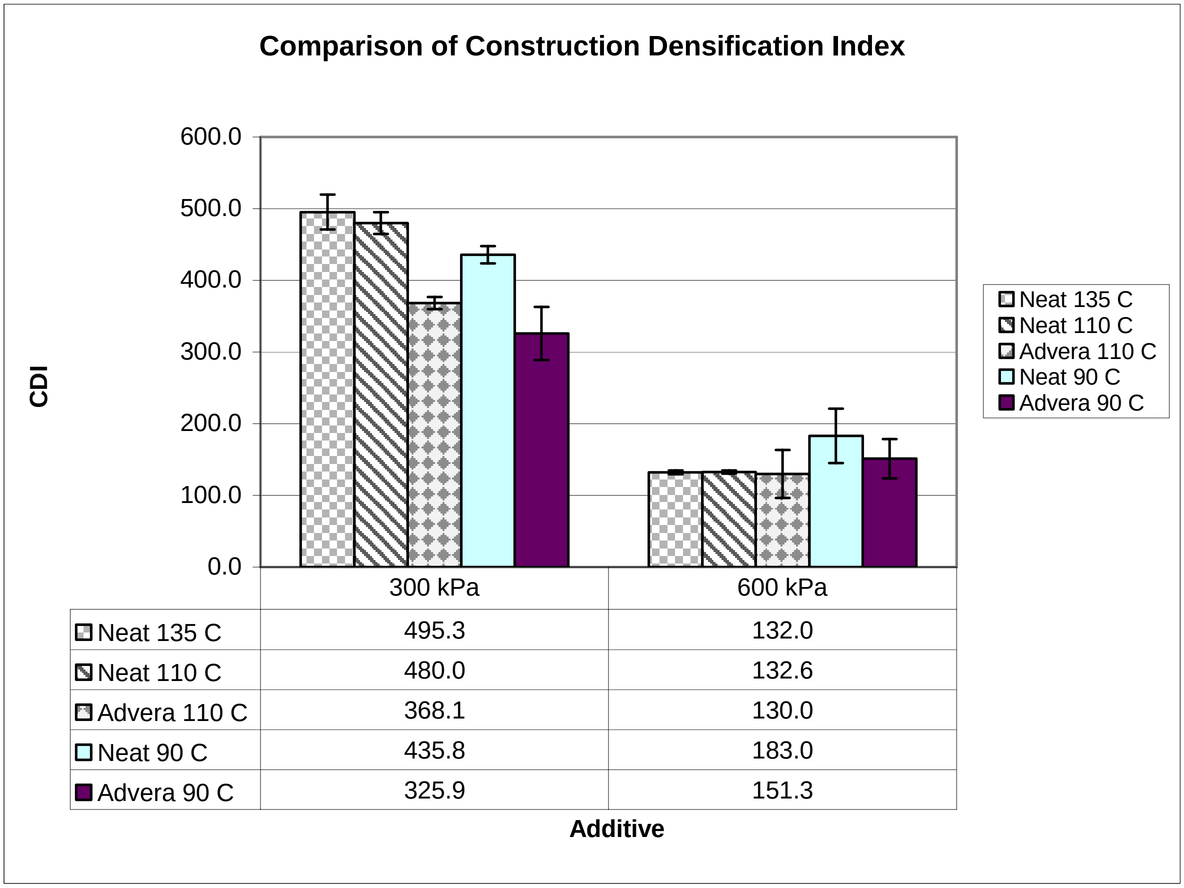


Figure E1c-1.7. Graph. Comparison of Construction Densification Index (CDI) for HMA and WMA using Advera at 300 kPa and 600 kPa compaction pressures

Table E1c-1.4 and figure E1c-1.7 support the data presented in the air voids analysis. At the 600 kPa compaction pressures the decrease in CDI due to the addition of Advera is indiscernible from the error of the measurement. For the 300 kPa compactions, the addition of Advera results in a significant decrease in CDI, hence increased workability for both 110 ºC and 90 ºC compaction temperatures. Another observation is that the mix design used is insensitive to decreases in compaction temperature as noted by the small variations in air voids a CDI for the HMA mixes. Future work should focus on compaction of harsher mixes to more clearly demonstrate the impact of Advera on mixture workability.

Significant Problems, Issues and Potential Impact on Progress

1. Investigation of Effects of Warm Mix Additives on the Rheological Properties of Binders

The most significant problem encountered during this quarter is the difficulty of obtaining good normal force readings using thin film rheology. This may be due to the difficulty of conducting normal force measurements in general on a parallel plate system. The parallel plate geometry is particularly sensitive when attempting normal force measurements. Any imperfection in plate smoothness, roundness, concentricity, or alignment would lead to inconsistent and unrepeatable normal force measurements when using this geometry.

The research team has identified a mathematical way of calculating the normal force by using data obtained from typical oscillation measurements. This method uses the following identity which is known to be true for viscoelastic liquids (Macosko 1994):

$$\eta'(\omega)_{\omega\to 0} = \eta(\dot{\gamma})_{\gamma\to 0} \text{ and } \frac{G'(\omega)}{\omega^2}_{\omega\to 0} = \frac{N_1(\dot{\gamma})}{2\dot{\gamma}^2}_{\gamma\to 0}$$

where η is viscosity, ω is angular velocity, γ is strain, $\dot{\gamma}$ is strain rate, G' is elastic modulus, and N is normal force.

The team does not expect this setback to have a significant impact on the overall progress of this work element.

2. Evaluation of the Effects of Warm Mix Additives on Workability and Stability of Mixes

No significant setbacks have occurred to date. The feasibility of using the force and densification indices to quantify the effects of warm mix additives will be clarified based on analysis of the data from compaction of a wider range of mix designs. No significant delays have been realized in the identification and materials collection from field trials.

Work Planned Next Quarter

1. Investigation of Effects of Warm Mix Additives on the Rheological Properties of Binders

Next quarter the team will continue testing following the proposed experimental matrix. The thin film rheology measurements will be replaced with oscillation measurements and the respective normal force will be calculated using the abovementioned identity.

2. Evaluation of the Effects of Warm Mix Additives on Workability and Stability of Mixes

Next quarter a wider range of mix designs will be evaluated using the framework described above. The research team also plans to incorporate Sasobit and Evotherm into the evaluation of warm mix additives. The Warm Mix Technical Working Group will be consulted as to which version of Evotherm should be used. Activities will continue with regard to collection of materials from field trials and identification of mix designs for laboratory evaluation.

Cited References

Macosko, C. W., 1994, *Rheology: principles, measurements, and applications*. VCH: New York, p xviii, 550 p.

Mahmoud, A. F., and H. Bahia, 2004, *Using the Gyratory Compactor to Measure Mechanical Stability of Asphalt Mixtures*. Report WHRP 05-02, Wisconsin Highway Research Program.

Subtask E1c-2: Improvement of Emulsion Characterization and Mixture Design for Cold Bitumen Applications

Work Done This Quarter

Efforts this quarter have been focused on three separate tasks:

- Literature Review
    - Literature Search: A full literature search has been conducted on the following topics:
        - Emulsion specifications
        - Construction properties of emulsions (i.e., viscosity, breaking and setting, and development of adhesion and cohesion)
        - Residue recovery procedures and emulsion breaking and setting
        - Design methods and performance tests for chip seals, slurry seals, fog seals, and microsurfacing
    - The literature review report is currently in draft format.
- Project Advisory Group. In cooperation with SemMaterials, members for the Project Advisory Group were selected. Invitations were sent to suppliers, contractors, state agencies, consultants, and academia. Twelve individuals were invited; thus far 11 have accepted. A kickoff conference call was held on Friday, June 13.
- Development of candidate test methods for characterization of emulsions. Test methods have been identified for measurement of adhesion, cohesion, strain tolerance, and resistance to deformation. The tests are applicable to both emulsions during setting as well as residual binders. Initial data have also been gathered for evaluating the feasibility of using intermediate temperature dynamic shear rheometer (DSR) measurements to predict low temperature behavior as measured by the bending beam rheometer (BBR). Tests are promising for conventional binders and will be evaluated for emulsion residue.

The research team has also participated in one face-to-face meeting and two conference calls of the Emulsion Task Force, a sub-group of the Pavement Preservation ETG. The team will continue to work closely with this group to provide updates of activities and coordinate with other projects such as the Federal Lands Study: Best Practices for the use of Polymer Modifiers in Asphalt Emulsions and NCHRP 14-17: Manual for Emulsion-Based Chip Seals for Pavement Preservation.

Significant Results

Project Advisory Group

The Project Advisory Conference Call held June 13 included participation by 63% of the group members. Discussion generated during the meeting confirmed that the research approach presented in the Year 2 Work Plan was appropriate. The group also identified high priority construction and in-service emulsion properties that initial research should focus on. The minutes for the meeting will be posted on the ARC website pending review by the Project Advisory Group members.

Residue Recovery

The Project Advisory Group identified the selection of an appropriate residue recovery method as imperative to the success of the research. The draft literature review report prepared this quarter summarizing different residue recovery methods provided enough background data for selection of an evaporative recovery method. The method is currently a draft ASTM standard and involves residue recovery by putting a thin film of the emulsion in a forced draft oven at 25 ºC for 24 hours then conditioning at 60 ºC for an additional 24 hours.

The recovery method must be able to provide residue from latex and polymer modified emulsions that is representative of the residue in the field. A work plan has been developed to verify the draft ASTM standard. The summary of factors in the evaluation experiment is provided in table E1c-2.1:

Table E1c-2.1. Independent variables for evaluation of draft ASTM recovery procedure.

Variable	Values	Levels
Emulsion Charge	Cationic	1
Emulsion Rate of Setting	Rapid	2
Modification	None	4
	Polymer Modifed	
	High Float	
	Latex Modified	
	Combinations	**8**
	Replicates	2
	Total Tests	**16**

The emulsion will be sampled at 2, 6, and 24 hours at each curing temperature to evaluate the development of stiffness and strain tolerance over time. The final residue will also be compared to the base binder. Evaluation tests selected include strain sweep (25 ºC) and multiple stress creep recovery (MSCR) test (25 ºC and 60 ºC). The study is underway and expected to be completed by the end of the next quarter.

Coordination with Emulsion Task Force of the Pavement Preservation ETG

Research team members have coordinated with the emulsion task force in the following areas:

- Participation in subcommittees
  - Emulsion Testing & Residue Recovery Methods – Andrew Hanz
  - Residue Tests – Hussain Bahia

- Aggregates, Mix Design, and Performance Tests – Peter Sebaaly
- Approved Supplier Certification – Elie Hajj

- Coordination with Federal Lands Study: A memo was sent to Dr. Gayle King, principal investigator of the project, in response to questions about his proposed emulsion testing protocol. The memo included the following topics:
  - Recommendations for low temperature characterization of emulsions: Initial correlation between BBR stiffness (S(60)) and creep rate (m-value) at -12 ºC with G* and phase angle tested at 10 Hz and 10 ºC.
  - Temperature and frequency recommendations for development of master curves for residues.
  - Stress level selection for MSCR: Recommended testing at 10,000 Pa and 32,000 Pa to characterize behavior far into the nonlinear range of behavior. Initial tests at UW-Madison have shown that only 10,000 Pa is feasible for MSCR testing.
  - Recommendations for use of a strain sweep to identify high float emulsions.
  - A conference call is scheduled for early July to finalize details of the memo and discuss coordination of testing and data analysis responsibilities.

Significant Problems, Issues and Potential Impact on Progress

Submission of the literature review report has been delayed due to extensive review and revision of the draft report. More staffing will be available next quarter, it is expected that a full literature review report will be available in the fall.

Repeatability in testing was an issue that has been recently addressed by using new test protocols for the strain sweep and MSCR testing. Progress may be impacted because data previously collected will have to be repeated using these new protocols. It is expected that the testing can be completed within two months.

Work Planned Next Quarter

The following activities are planned for next quarter:

- Literature review: Revise and update draft report to include specifications, practice, and performance testing for emulsions and surface treatments.
- Project Advisory Group: Hold first face to face meeting of the advisory group at the Asphalt Emulsion Manufacturers Association conference on September 25.
- Residue Recovery Evaluation: Complete evaluation and submit a paper to the Transportation Research Board with results.
- Continue coordination with the Emulsion Task Force.

CATEGORY E2: DESIGN GUIDANCE

Work element E2a: Comparison of Modification Techniques (UWM Year 2 start)

Work Done This Quarter

This work element remains on hold. The only work performed this quarter was a conference call with a selected group of experts that took place on June 10, 2008. Based on the feedback from the group, the experimental plan was revised and adjusted to reflect recommendations of the group. The revised testing plan was submitted to the ATOR on June 17. The revised testing matrix is shown in table E2a.1.

Table E2a.1. Revised Experimental Matrix

Binders (modified by suppliers)	SBS Modified	no modification (base binder)	Testing Matrix (In addition to PG grading and PG+ testing)	MSCR
		low level of modification (one PG grade bump over base)		G* and sinδ
		high level of modification (2-3 PG grades bump over base)		Frequency Sweep Master curve
	Elvaloy Modified	no modification (base binder)		SENB/BBR
		low level of modification (one PG grade bump over base)		Fatigue (BYET)
		high level of modification (2-3 PG grades bump over base)		viscosity and phase angle (@ mixing and compaction temp)
	Acid (PPA) Modified	no modification (base binder)	Storage stability and storage separation @ High Temperature	0 hours
		low level of modification (one PG grade bump over base)		24 hours
		high level of modification (2-3 PG grades bump over base)		72 hours
	EVA	no modification (base binder)	Adhesion Dry/wet Cohesion Dry/wet	DSR – Tackiness with 2 aggregates DSR- Tackiness with metal plate (full adhesion)
		low level of modification (one PG grade bump over base)		
		high level of modification (2-3 PG grades bump over base)		
	Binary Modification (Polymer +PPA)	no modification (base binder)		
		low level of modification (one PG grade bump over base)		
		high level of modification (2-3 PG grades bump over base)		

Key: **SBS** styrene-butadiene-styrene. **PPA** polyphosphoric acid. **EVA** ???. **PG** performance grade. **MSCR** multiple stress creep recovery. **SENB** Single-Edge Notched Bending . **BBR** bending beam rheometer. **BYET** Binder Yield Energy Test. **DSR** dynamic shear rheometer.

Notes on revised plan
This work element will use materials provided by different manufacturers. Each manufacturer will be asked to provide three binders (unmodified, low level of modification, and high level of modification) as proposed in table E2a.1. The binders will be chosen and supplied by the respective manufacturers of the modified binders. The task will include four different modifiers (Elvaloy, SBS, EVA and acid PPA modifier). This will bring the total of different binders to 12 (4 unmodified, 4 with a low level of modification and 4 binders with a high level of modification). In addition, suppliers will be asked to provide a set of binders modified with a binary system (polymer and acid). The exact percentages of the modifier to be used and the exact modifier type will be selected by the manufacturers. The suggested targets for the provided binders are:

- Unmodified (base) binder PG58-XX
- Low level of modification PG64-XX
- High level of modification PG76-XX

Both modified and unmodified binders will be subjected to a battery of tests (shown in table E2a.1) in order to evaluate the performance and damage resistance properties of these materials. This will allow the research team to gain a better understanding of how different modifiers affect the performance of asphalt binders both in the lab and in service.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Begin work on revised work plan when Year 2 plan is approved.

Work element E2b: Design System for HMA Containing a High Percentage of RAP Material (UNR)

Work Done This Quarter

Aggregates were extracted from the 12.5 mm NMAS Nevada-andesite Superpave mix after long-term oven aging using the reflux, centrifuge, and ignition oven. The following physical properties of the extracted and original aggregates have been measured:

- Gradation, LA abrasion, soundness, absorption, specific gravity, fine aggregate angularity (FAA), coarse aggregate angularity (CAA), fractured faces, sand equivalent, and durability index.

Additionally the impact of reflux and centrifuge on the properties of the recovered binder from the Nevada –andesite mix has been evaluated.

The development of the bending beam rheometer (BBR) procedure for testing RAP mortars was completed. Due to the limitation of the BBR loading capacity, the geometry for the BBR specimen was modified by reducing the specimen thickness to 10.0 mm. This new geometry allowed easier molding of the specimen and resulted in more deflection of the specimen under load. The amount of virgin binder required for preparing the recycled asphalt pavement (RAP) mortars was also varied between 10% and 15% by weight of the RAP. It was found that acceptable deflection can be measured with either percentage, but it is easier to produce the mortar beams at 15% virgin binder.

The sensitivity of the stiffness S(60) and creep rate m(60) of the mortar properties to the properties of the binder in the RAP was evaluated using artificial RAP produced by aging a virgin binder in the pressure aging vessel (PAV) for 40 hours at 110 ºC. The aged binder was mixed with recovered RAP aggregates at the same percentage as the binder in the natural RAP. The artificial RAP was then mixed with 10% and 15% virgin binder and tested for S(60) and m(60). The data is currently being analyzed to determine the sensitivity of the procedure to the aged binder properties and to determine if the 15% mortar procedure is an effective method.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

A third source from South Dakota is added to the original two aggregate sources.

Preparation of the BBR specimens for RAP mortar has caused major delays. A mechanical molding technique is required.

Work Planned Next Quarter

An analysis is underway to evaluate the impact of the extraction method on the physical properties of the aggregates by comparing the measured properties of the Nevada-andesite aggregates before and after extraction.

Conduct the same experiment for the other two aggregate sources.

Work on evaluating the sensitivity of BBR procedure to properties of aged binders in the RAP will continue and a topical report on the success of the procedure will be completed. The back calculation of the PG of the binders in RAP from testing of the mortar RAP will be competed next quarter. Measurements of fracture properties of the RAP mortars will start next quarter.

Work element E2c: Critically Designed HMA Mixtures (UNR)

Work Done This Quarter

The 3D-Move software is used to evaluate the stress conditions under dynamic loads within the HMA layer. The following 3D-Move runs were completed for the Lockwood (andesite) + PG64-22 mix using the mixture specific dynamic modulus.

- Pavement structures:
  - 4" HMA over 6" base
  - 6" HMA over 8" base
  - 8" HMA over 10" base
- Geometries:
  - Level road
- Speeds:
  - 60 mph without braking
  - 40 mph without braking
  - 20 mph without braking
- Tire-Pavement Pressure Distribution
  - Uniform
- HMA layer temperature
  - 40^{o}C
  - 50^{o}C
  - 60^{o}C
  - 70^{o}C

Analyzed the data and identified the following:

- Time of loading at the middle of the HMA
- Magnitude of the confining and deviator stresses throughout the HMA layer

Completed the mix design for the Lockwood aggregate source with PG52-22 binder and measured its dynamic modulus master curve and damping ratio.

Significant Results

The octahedral stresses were found to be effective in converting the stress tensor in HMA pavements under moving dynamic loads to deviator and confining pressures to be applied in a repeated load triaxial test. The octahedral normal and shear stress are defined as follow:

Octahedral normal stress: $\sigma_{oct} = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3) = \frac{1}{3}\mathrm{I}_1$ (1)

Octahedral shear stress:
$$\tau_{oct}^{\ 2} = \frac{1}{9}\left[(\sigma_{xx} - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_{zz})^2 + (\sigma_{zz} - \sigma_{xx})^2\right] + \frac{2}{3}\tau_{\mathrm{xy}}^{\ 2} + \tau_{\mathrm{yz}}^{\ 2} + \tau_{\mathrm{xz}}^{\ 2}$$
$$= \frac{1}{9}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right] \quad (2)$$

The deviator stress to be applied in the lab under the triaxial setup is calculated from the octahedral shear stress using equation 3. Then the confining pressure is calculated from the octahedral normal stress and the computed deviator stress.

$$\sigma_d = \frac{3}{\sqrt{2}}\tau_{oct} \quad (3)$$

$$\sigma_3 = \sigma_{oct} - \frac{\sigma_d}{3} \quad (4)$$

Figures E2c.1 and E2c.2 show, respectively, the octahedral normal and shear stresses history at 40°C in the middle of a 4-inch HMA layer under a moving single tire at 40 mph. Figures E2c.3 and E2c.4 show the calculated deviator and confining stresses from the octahedral stresses. The time of loading is determined from the calculated deviator stress history.

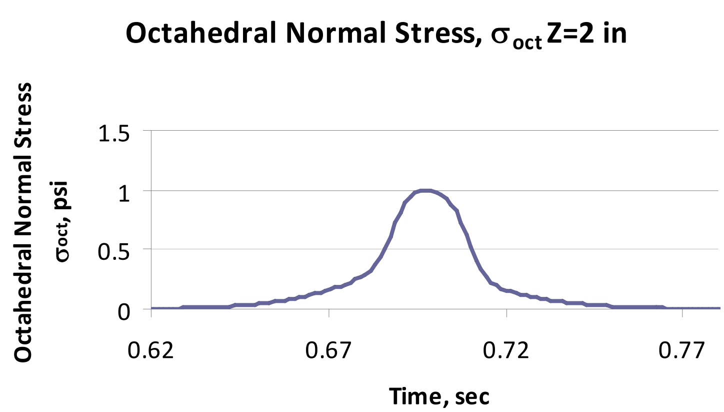


Figure E2c.1. Graph. Octahedral normal stress history under a moving single tire at 40 mph and 40°C.

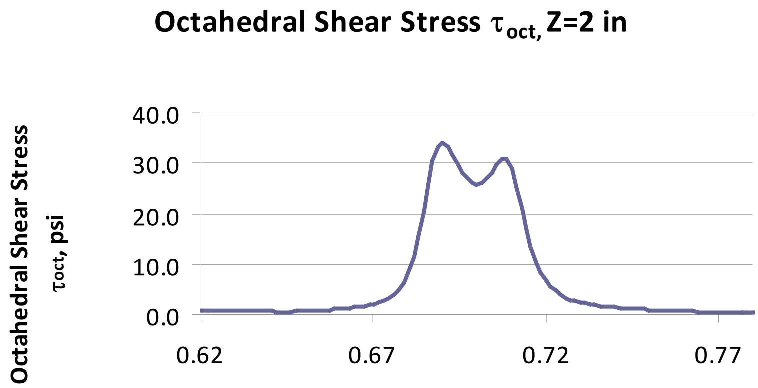


Figure E2c.2. Graph. Octahedral shear stress history under a moving single tire at 40 mph and 40°C.

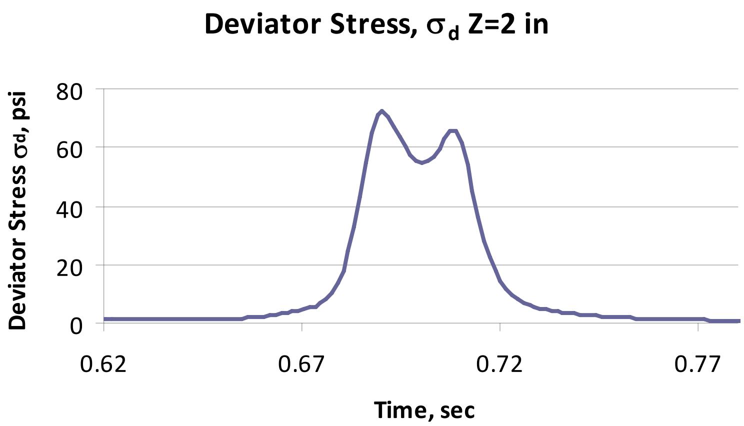


Figure E2c.3. Graph. Deviator stress history under a moving single tire at 40 mph and 40°C.

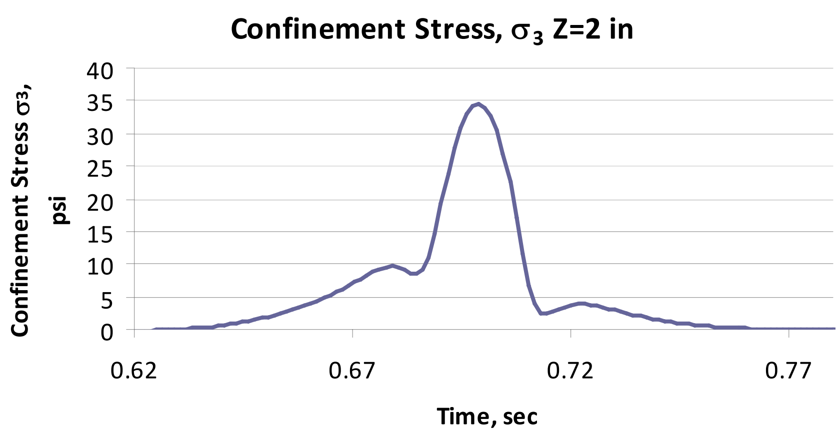


Figure E2c.4. Graph. Confining stress history under a moving single tire at 40 mph and 40°C.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The calculations of the 3D-Move model will continue to cover all the loading conditions that were described in the experimental plan for this work element.

Complete the mix design for the Lockwood aggregate source with PG58-22 binder and measure its dynamic modulus master curve and damping ratio.

Work element E2d: Thermal Cracking Resistant Mixes for Intermountain States (UNR & UWM)

Work Done This Quarter

This work element is a joint project led by University of Nevada-Reno and supported by University of Wisconsin-Madison. The UNR team continued the long-term oven aging process for the following binders as described in the experimental plan for this work element:

- Neat PG64-22
- Polymer modified PG64-28 (using the same PG64-22 crude source) that meets the specs of UT, NV, and CA.

The team started testing the aged binders for rheological properties. Aged binders are shipped to UWM for conducting the tests according to the plan.

Work continued on analyzing the pavement temperature profile data from the LTPP and Westrack pavement sections and the TSRST experiment plan on investigating the impact of specimen size and shape.

Efforts at UW this quarter include parts of Subtask E2d-2: "Identify the Causes of the Thermal Cracking" and Subtask E2d-3: "Identify an Evaluation and Testing System." These are described below.

A new device is being built which will be used to conduct multiple types of testing:

- Binder thermal dilatometric measurements
- Mixture thermal linear expansion and contraction
- Mixture Thermal Stress Restrained Specimen Test (TSRST)

This all-in-one testing device, shown in its current state in figure E2d.2, will replace testing equipment used in the past with the anticipated benefits of being more reliable, making testing operation easier, and providing more accurate test results.

Similarly, the modification of the Bending Beam Rheometer (BBR) loading frame to allow for conducting the Single-Edge Notched Bending (SENB) testing is underway. A literature review was conducted to determine prior experience with the SENB and the potential for success in using the BBR to conduct the test. The new loading frame will make it possible to evaluate fracture properties of asphalt binders, mastics and possibly mixtures at low temperatures. The manufacturing of the frame is in its final stages.

Following work done in the previous quarter, further attempts to conduct improved measurements of mixture length changes during thermal cycling testing were conducted.

Significant Results

Figure E2d.1 shows the results for the measured mass loss and gain of the PG64-22 asphalt binder when aged at different temperatures and periods in the forced convection (horizontal airflow) ovens.

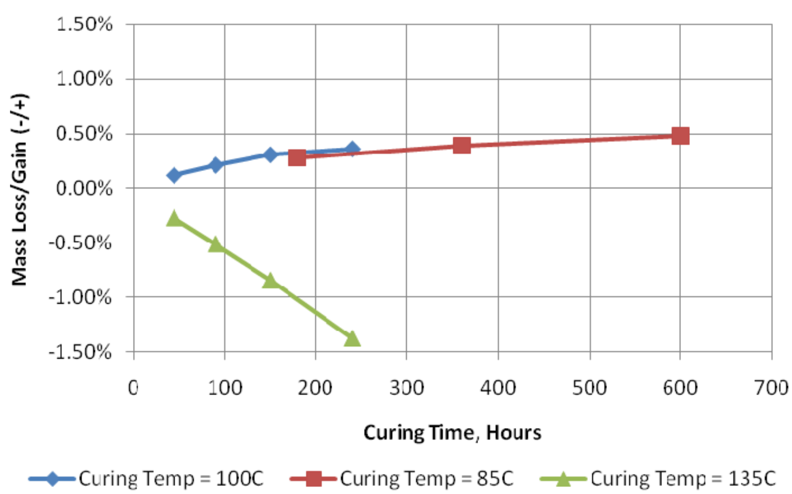


Figure E2d.1. Graph. PG64-22 Mass loss/gain at various curing temperatures and times.

The preparation stage of the new glass transition temperature measuring and TSRST device was carried out. The design of the machine was finalized and manufacturing components were ordered. Some tests of single components were run to simulate tests on binder samples. A new calibration of the dilatometric cells has been performed.

Figure E2d.2. Photograph. The all-in-one testing device in its current state.

The single components of the modified BBR load frame have been obtained and the assembly stage has been started (figure E2d.3). The motor and the screw lead (figure E2d.4) are being calibrated.

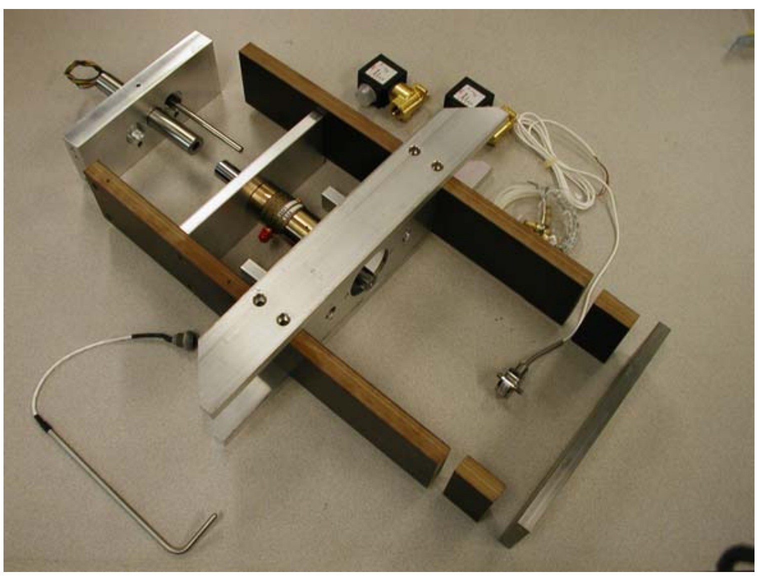


Figure E2d.3. Photograph. Components of the new bending beam rheometer load frame.

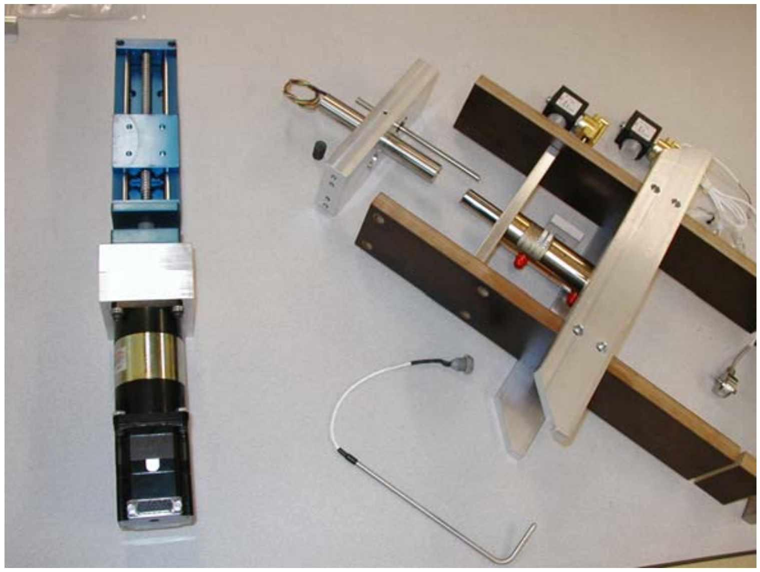


Figure E2d.4. Photograph. Motor and screw lead of the new bending beam rheometer loading frame.

Significant Problems, Issues and Potential Impact on Progress

The building of the new piece of equipment encountered a significant delay on the manufacturing side.

The simulations of glass transition tests on binder samples showed some problems with the automatic reading of the capillary height. This suggested the need to substitute the pressure sensors with new designs. Attempts to run the test manually have also faced problems, indicating the necessity to further investigate individual components. However, since this was performed using existing equipment, the research team has postponed testing until completion of the new testing device.

The linear variable displacement transducers and the load cells for the new BBR frame were delivered later than expected and the assembly process has been delayed as well by the manufacturer.

Work Planned Next Quarter

The UNR team will continue the aging process of binders, measuring the properties of the aged binders, continue the analysis of the temperature profile data from the LTPP and Westrack sections. Also at UNR, they will continue the TSRST investigation on the impact of specimen size and shape and start the investigation on the impact of cooling rate.

The UWM team will undertake detailed investigations of the dilatometric cells again while waiting for the new all-in-one testing equipment to be completed. New glass transition tests on binder samples will be run with manual and automatic readings in order to check the correct functioning of the system.

For the SENB testing, once the new frame is ready, the configuration of the machine will be set up and communication will be enabled between the computer interface and the control unit of the existing BBR.

Work element E2e: Design Guidance for Fatigue and Rut Resistance Mixtures (AAT)

<u>Work Done This Quarter</u>

No effort was expended this Quarter on this work element pending approval of the Year 2 Work Plan.

<u>Significant Results</u>

Improvements have been identified for the following models developed in NCHRP Project 9-25:

(1) Hirsch Model for dynamic modulus,
(2) Resistivity Model for rutting resistance,
(3) Continuum Damage Fatigue Model
(4) Permeability Model

Preliminary experimental plans have been developed to address the needed model improvements.

<u>Significant Problems, Issues and Potential Impact on Progress</u>

None.

<u>Work Planned Next Quarter</u>

With the Year 2 Work Plan approved and no comments received on the preliminary experimental designs, final experimental designs will be prepared using the specific materials selected by the Asphalt Research Consortium.

Engineered Materials Year 2	Year 2 (4/2008-3/2009)												Team
	4	5	6	7	8	9	10	11	12	1	2	3	
(1) High Performance Asphalt Materials													
E1a: Analytical and Micro-mechanics Models for Mechanical behavior of mixtures													TAMU
E1a-1: Analytical Micromechanical Models of Binder Properties										P	JP	P	
E1a-2: Analytical Micromechanical Models of Modified Mastic Systems										P	JP	P	
E1a-3: Analytical Models of Mechanical Properties of Asphalt Mixtures			P	P	JP					P	JP	P	
E1a-4: Analytical Model of Asphalt Mixture Response and Damage										P	JP	P	
E1b: Binder Damage Resistance Characterization													UWM
E1b-1: Rutting of Asphalt Binders													
E1b-1-1: Literature review													
E1b1-2: Select Materials & Develop Work Plan		DP, P					P						
E1b1-3: Conduct Testing							P						
E1b1-4: Analysis & Interpretation						JP			P			JP	
E1b1-5: Standard Testing Procedure and Recommendation for Specifications													
E1b-2: Feasibility of Determining rheological and fracture properties of thin films of asphalt binders and mastics using nano-indentation													UWM
E1b-2i. Literature Review and Identification of Equipment													
E1b-2ii. Exploratory Use of Nanoindentation Devices							M&A					JP	
E1b-2iii. Conduct of Exploratory Tests on Binder Specimens										P		P	
E1b-2iv. Compare the Binders Responses with DSR													
E1b-2v. Develop & Design Testing Setup													
E2a: Comparison of Modification Techniques													UWM
E2a-1: Literature Review Report							P					P	
E2a-2: Develop a new system for classification of additives													
E2a-3: Conduct testing and propose models									DP			P	
E2a-4: Write an asphalt modification manual													
E2a-5: Develop database for effect of additives													
E2c: Critically Designed HMA Mixtures													UNR
E2c-1: Identify the Critical Conditions				JP						D		F	
E2c-2: Conduct Mixtures Evaluations													
E2c-3: Develop a Simple Test													
E2c-4: Develop Standard Test Procedure													
E2c-5: Evaluate the Impact of Mix Characteristics													
E2d: Thermal Cracking Resistant Mixes for Intermountain States													UWM/UNR
E2d-1: Identify Field Sections							D		F				
E2d-2: Identify the Causes of the Thermal Cracking													
E2d-3: Identify an Evaluation and Testing System													
E2d-4: Modeling and Validation of the Developed System													
E2d-5: Develop a Standard													
E2e: Design Guidance for Fatigue and Rut Resistance Mixtures													AAT
E2e-1: Identify Model Improvements													
E2e-2: Design and Execute Laboratory Testing Program					JP					P			
E2e-3: Perform Engineering and Statistical Analysis to Refine Models													
E2e-4: Validate Refined Models													
E2e-5: Prepare Design Guidance													
(2) Green Asphalt Materials													
E2b: Design System for HMA Containing a High Percentage of RAP Material													UNR
E2b-1: Develop a System to Evaluate the Properties of RAP Materials													
E2b-1.b: Develop a System to Evaluate the Properties of the RAP Binder		P		JP						P			
E2b-2: Compatibility of RAP and Virgin Binders													
E2b-3: Develop a Mix Design Procedure													
E2b-4: Impact of RAP Materials on Performance of Mixtures													
E2b-5: Field Trials													
E1c: Warm and Cold Mixes													UWM
E1c-1: Warm Mixes													
E1c-1i: Effects of Warm Mix Additives on Rheological Properties of Binders													
E1c-1ii. Effects of Warm Mix Additives on Mixture Workability and Stability				JP	P				D		DP	F	
E1c-1iii. Mixture Performance Testing													
E1c-1iv. Develop Revised Mix Design Procedures													
E1c-1v. Field Evaluation of Mix Design Procedures and Performance Recommendations													
E1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications													
E1c-2i: Review of Literature and Standards				JP,P		D			F				
E1c-2ii: Creation of Advisory Group													
E1c-2ii: Identify Tests and Develop Experimental Plan												P, DP	
E1c-2iv. Develop Material Library and Collect Materials.													
E1c-2v. Conduct Testing Plan													

Deliverable codes	Deliverable Description
D: Draft Report	Report delivered to FHWA for 3 week review period.
F: Final Report	Final report delivered in compliance with FHWA publication standards
M&A: Model and algorithm	Mathematical model and sample code
SW: Software	Executable software, code and user manual
JP: Journal paper	Paper submitted to conference or journal
P: Presentation	Presentation for symposium, conference or other
DP: Decision Point	Time to make a decision on two parallel paths as to which is most promising to follow througjh

Work planned
Work completed
Parallel topic

Engineered Materials Year 2 - 5	Year 2 (4/08-3/09)				Year 3 (4/09-3/10)				Year 4 (04/10-03/11)				Year 5 (04/11-03/12)				Team
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
(1) High Performance Asphalt Materials																	
E1a: Analytical and Micro-mechanics Models for Mechanical behavior of mixtures																	TAMU
E1a-1: Analytical Micromechanical Models of Binder Properties				P, JP	JP	P	P	JP	M&A	D	F,SW						
E1a-2: Analytical Micromechanical Models of Modified Mastic Systems				P, JP	JP	P	P		M&A	JP	D	F,SW					
E1a-3: Analytical Models of Mechanical Properties of Asphalt Mixtures	P	P,JP		P, JP	JP	P	P	M&A		D	SW,JP	F					
E1a-4: Analytical Model of Asphalt Mixture Response and Damage				P, JP	JP	P	P		M&A	D	F,JP	SW					
E1b: Binder Damage Resistance Characterization																	UWM
E1b-1: Rutting of Asphalt Binders																	
E1b-1-1: Literature review																	
E1b1-2: Select Materials & Develop Work Plan	DP, P		P														
E1b1-3: Conduct Testing			P			JP	D	F									
E1b1-4: Analysis & Interpretation		JP	P	JP	P			M&A			JP						
E1b1-5: Standard Testing Procedure and Recommendation for Specifications										P		DP	P	D	JP	F	
E1b-2: Feasibility of Determining rheological and fracture properties of thin films of asphalt binders and mastics using nano-indentation																	
E1b-2i. Literature Review and Identification of Equipment							D	F									
E1b-2ii. Exploratory Use of Nanoindentation Devices		M&A		JP	M&A,SW	JP											
E1b-2iii. Conduct of Exploratory Tests on Binder Specimens			P	P						JP		P					
E1b-2iv. Compare the Binders Responses with DSR														JP			
E1b-2v. Develop & Design Testing Setup															D	P,F	
E2a: Comparison of Modification Techniques																	UWM
E2a-1: Literature Review Report		P		P		P	D	F									
E2a-2: Develop a new system for classification of additives						P											
E2a-3: Conduct testing and propose models			DP	P			JP	P			JP						
E2a-4: Write an asphalt modification manual						P			P			P			D	P,F	
E2a-5: Develop database for effect of additives						P			P			P			D	P,F	
E2c: Critically Designed HMA Mixtures																	UNR
E2c-1: Identify the Critical Conditions		JP		D, F													
E2c-2: Conduct Mixtures Evaluations									D, F	JP							
E2c-3: Develop a Simple Test													D, F	JP			
E2c-4: Develop Standard Test Procedure													D, F				
E2c-5: Evaluate the Impact of Mix Characteristics																D, F	
E2d: Thermal Cracking Resistant Mixes for Intermountain States																	UWM/UNR
E2d-1: Identify Field Sections			D, F														
E2d-2: Identify the Causes of the Thermal Cracking									D, F	JP							
E2d-3: Identify an Evaluation and Testing System												D, F	JP				
E2d-4: Modeling and Validation of the Developed System																D, F	
E2d-5: Develop a Standard																D, F	
E2e: Design Guidance for Fatigue and Rut Resistance Mixtures																	AAT
E2e-1: Identify Model Improvements																	
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E2e-3: Perform Engineering and Statistical Analysis to Refine Models						JP		P				D,F					
E2e-4: Validate Refined Models										JP		P					
E2e-5: Prepare Design Guidance															M&A	D,F	
(2) Green Asphalt Materials																	
E2b: Design System for HMA Containing a High Percentage of RAP Material																	UNR
E2b-1: Develop a System to Evaluate the Properties of RAP Materials		JP		P	D, F	JP											
E2b-1.b: Develop a System to Evaluate the Properties of the RAP Binder	P			JP	P			GP									
E2b-2: Compatibility of RAP and Virgin Binders					D, F	JP											
E2b-3: Develop a Mix Design Procedure									D, F	JP							
E2b-4: Impact of RAP Materials on Performance of Mixtures										JP						D, F	
E2b-5: Field Trials																D, F	
E1c: Warm and Cold Mixes																	
E1c-1: Warm Mixes																	
E1c-1i: Effects of Warm Mix Additives on Rheological Properties of Binders.																	UWM
E1c-1ii. Effects of Warm Mix Additives on Mixture Workability and Stability		JP,P	D	F,DP													UWM
E1c-1iii. Mixture Performance Testing						JP		P, DP									UW/UNR
E1c-1iv. Develop Revised Mix Design Procedures										JP	P						UW/UNR
E1c-1v. Field Evaluation of Mix Design Procedures and Performance Recommendations														JP	D	P,F	UW/UNR
E1c-2: Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications																	UWM
E1c-2i: Review of Literature and Standards		JP, D	F														
E1c-2ii: Creation of Advisory Group																	
E1c-2ii: Identify Tests and Develop Experimental Plan				P, DP				P, DP									
E1c-2iv. Develop Material Library and Collect Materials.																	
E1c-2v. Conduct Testing Plan						JP											
E1c-2vi. Develop Performance Selection Guidelines										JP	D	P, F					
E1c-2vii. Validate Guidelines														JP	P		
E1c-2viii. Develop CMA Mix Design Procedure												P					
E1c-2ix. Develop CMA Performance Guidelines														JP	D	F	

Deliverable codes
D: Draft Report
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Mathematical model and sample code
Executable software, code and user manual
Paper submitted to conference or journal
Presentation for symposium, conference or other
Time to make a decision on two parallel paths as to which is most promising to follow througjh

Work planned
Work completed
Parallel topic

PROGRAM AREA: VEHICLE-PAVEMENT INTERACTION

CATEGORY VP1: WORKSHOP

Work element VP1a: Workshop on Super-Single Tires

The Workshop on Wide-Base Tires was held at FHWA TFHRC on October 25-26, 2007. FHWA has prepared draft minutes of the Workshop. All attendees have been reimbursed for their travel expenses.

The Workshop minutes are posted on the ARC website. The minutes can be found at the following link: http://www.arc.unr.edu/Workshops.html

This work element is complete.

CATEGORY VP2: DESIGN GUIDANCE

Work element VP2a: Mixture Design to Enhance Safety and Reduce Noise of HMA (UWM)

Work Done This Quarter

In this quarter, the research team's focus was on the following tasks: reviewing literature, evaluating different testing methodologies, collecting asphalt mixtures, and testing surface textures for selected mixtures. Also, the team made significant progress in designing, building, calibrating and testing an acoustical impedance tube. Furthermore, the team contacted the Federal Highway Administration to participate on the Circular Texture Meter (CTMeter) and Dynamic Friction Tester (DFTester) equipment loan program that allows practitioners and researchers to utilize portable solutions to measuring pavement friction. FHWA's DFTester and CTMeter will arrive at UW-Madison in October 2008.

Significant Results

A number of different mixtures were tested to characterize the skid resistance and acoustic properties. In this quarter, the focus was on dense mixtures with different air void content and different aggregate sources. A limited number of open hot mix asphalt (HMA) specimens were tested as well. Obvious questions regarding the finishing of surfaces still need to be addressed (see the *Significant Problems* section of this report). The gyratory compactor and roller compactor, used in cylindrical and slab specimens, and the roller compactors used in the field could yield very different mixtures surfaces that will control the skid resistance and acoustic properties of the specimens. Furthermore, the team needs to establish a procedure to simulate the traffic effect on the pavement surface.

Skid resistance properties
The surface texture of specimens was measured using the sand patch method. The sand patch test can clearly differentiate between the dense and porous HMA specimens, as shown in table VP2a.1 and table VP2a.2. However, the obtained measurements depend on sand grain size used in the test and its relationship to the specimen surface texture. To further evaluate the sand patch test results, the team will use the CTMeter from the FHWA loan program. These results will be combined with the DFTester to evaluate the specimen surface friction.

Table VP2a.1. Porous HMA sand patch results.

				TOP		BOTTOM			
Binder Type	**AC**	**Air Voids**	**Aggregate**	**D1 mm**	**D2 mm**	**D3 mm**	**D4 mm**	**AVG mm**	**MTD mm**
PG 76-22 1.5% Elvaloy 0.17% PPA	6.5%	21.4%	Fine	68	68	97	90	80.8	2.929
PG 76-22 1.5% Elvaloy 0.17% PPA	3.5%	21.4%	Fine + RAS	71	73	82	83	77.3	3.200
PG 76-22 1.5% Elvaloy 0.17% PPA	3.0%	21.2%	Coarse + RAS	74	68	57	67	67	4.319
PG 76-22 1.5% Elvaloy 0.17% PPA	3.5%	NA	Coarse + RAS	53	54	58	65	58	5.777
PG 76-22 1.5% Elvaloy 0.17% PPA	5.5%	22.7%	Coarse	53	54	92	88	72	3.710

Key: **AC** asphalt content. **Dx** indicates diameter measurement. **MTD** mean texture depth. **PPA** polyphosphoric acid. **RAS** recycled asphalt shingles.

Table VP2a.2. Dense mixture sand patch results.

Binder Type	**AC**	**Air Voids**	**Aggregate**	**D1 mm**	**D2 mm**	**AVG mm**	**MTD mm**
58-40 SBS Flint Hills	OPT	4%	G	>210	>210	>210	<0.087
58-40 SBS Flint Hills	BUMP	4%	G	187	210	198.5	0.097
58-28 Plain Seneca	OPT	4%	G	173	175	174.0	0.126
58-28 Plain Seneca	BUMP	4%	G	180	182	181.0	0.117
58-28 Plain Seneca	OPT	4%	LS	>210	>210	>210	<0.087
58-28 Plain Seneca	BUMP	4%	LS	202	205	203.5	0.092
58-28 Plain Seneca	OPT	7%	G	188	195	191.5	0.104
58-28 Plain Seneca	BUMP	7%	G	156	172	164.0	0.142
58-28 Plain Seneca	OPT	7%	LS	116	134	125.0	0.244
58-28 Plain Seneca	BUMP	7%	LS	142	139	140.5	0.193
64-28 Plain Seneca	OPT	4%	G	200	207	203.5	0.092
64-28 SBS Seneca	OPT	4%	G	>210	>210	>210	<0.087
64-22 Plain Seneca	OPT	4%	G	169	176	172.5	0.128

Key: **AC** asphalt content. **Dx** indicates diameter measurement. **MTD** mean texture depth. **SBS** styrene butadiene styrene. **OPT** optimal asphalt content. **BUMP** "bumped" asphalt content. **G** granite. **LS** limestone.

Acoustic properties
To evaluate the acoustic absorption characteristics of asphalt mixture, the research team designed, built and calibrated an impedance tube using ASTM C384-0 “Standard Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method” using a

plastic tube, two microphones and a Digital Frequency Analysis System (DFAS). However, instead of using a cylindrical specimen inside the impedance tube (as indicated by the ASTM standard), the research team is placing the impedance tube on the flat surface of a mix specimen. This modification that was first proposed by Crocker et al. (2004) should allow using the impedance tube on slab HMA specimens and also deploying the instrument in the field to evaluate the acoustic characteristics of roads.

Figure VP2a.1 presents sketches of the impedance tubes and examples of preliminary results. The team found that some of the acoustic absorption results are not very consistent (e.g., relevant differences in the acoustic absorption of different specimens). The research team is working on resolving these measurement problems.

Significant Problems, Issues and Potential Impact on Progress

One of the issues the research team is concerned about is the best method to simulate surface conditions after traffic action in the evaluation of the acoustic and skid resistance. It is known that traffic can change surface properties of pavements. To address this concern, the research team is considering modifying the "sweep test" (ASTM D7000) to simulate "traffic polishing effect" of lab prepared specimens. Alternatively, the research team is considering using a simple abrasive rotating disk to remove loose surface particles and binder films. These proposed methodologies will be further evaluated using the loaned FWHA instruments.

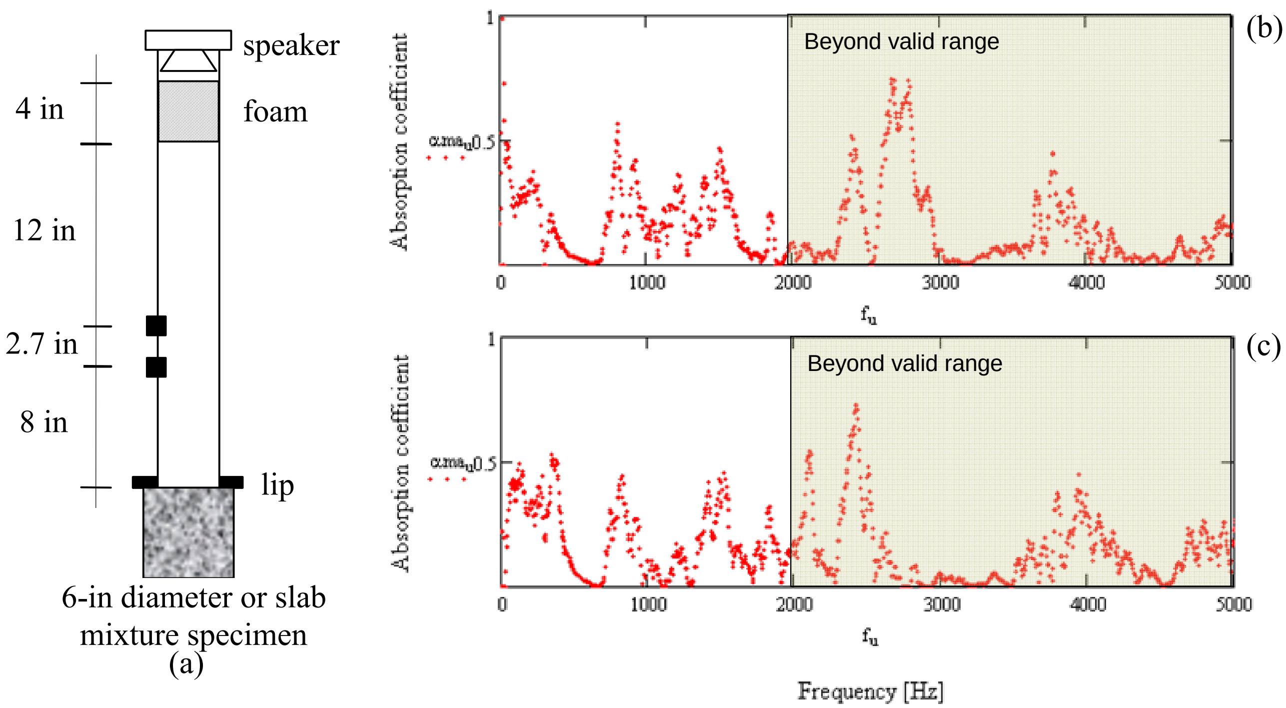

Figure VP2a.1. Illustration and graphs. (a) Impedance tube for the evaluation of sound absorption. Typical results: (b) slab dense sample 58-28 Plain Seneca BUMP 7% air void and (c) cylindrical sample: porous HMA specimen 5.5 % asphalt content.

Work Planned Next Quarter

During Q3 2008, the research team will:

- Evaluate the use of the sweep test or alternative techniques to simulate polishing by traffic
- Finalize the laboratory testing protocol
- Evaluate the effect of aggregate gradation on macro texture and noise
- Run parametric studies as described in the Year 2 Work Plan

Cited References

Crocker, M. J., Hanson, D. Li, Z., Karjatkar, R., and Vissamraju, K. S. (2004). "Measurement of Acoustical and Mechanical Properties of Porous Road Surfaces and Tire and Road Noise". *Transportation Research Record*. 1891: 16-22.

CATEGORY VP3: MODELING

Work element VP3a: Pavement Response Model to Dynamic Loads (UNR Year 2 start)

Work Done This Quarter

Started working on the 3D-Move model to make it a menu-driven software. Working on developing a subroutine to calculate the dynamic modulus (E*) and the elastic and viscous modulus (E' and E") from the input of the E* test results.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Continue working on the 3D-Move model to make it a menu-driven software.

Vehicle-Pavement Interaction

	Year 2 (4/2008-3/2009)												Team
	4	5	6	7	8	9	10	11	12	1	2	3	
(1) Workshop													
VP1a: Workshop on Super-Single Tires													UNR
(2) Design Guidance													
VP2a: Mixture Design to Enhance Safety and Reduce Noise of HMA													UWM
VP2a-1: Evaluate common physical and mechanical properties of asphalt mixtures with enhanced frictional skid characteristics												DP	
VP2a-2: Evaluate pavement macro- and micro-textures and their relation to tire and pavement noise-generation mechanisms												DP	
VP2a-3: Develop a laboratory testing protocol for the rapid evaluation of the macroand micro-texture of pavements					M&A							P	
VP2a-4: Run parametric studies on tire-pavement noise and skid response							JP						
VP2a-5: Establish collaboration with established national laboratories specialized in transportation noise measurements. Gather expertise on measurements and analysis													
VP2a-6: Model and correlate acoustic response of tested tire-pavement systems													
VP2a-7: Proposed optimal guideline for design to include noise reduction, durability, safety and costs													
(3) Pavement Response Model Based on Dynamic Analyses													
VP3a: Pavement Response Model to Dynamic Loads													UNR
VP3a-1: Dynamic Loads										JP			
VP3a-2: Stress Distribution at the Tire-Pavement Interface													
VP3a-3: Pavement Response Model													
VP3a-4: Overall Model													

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DP: Decision Point	Time to make a decision on two parallel paths as to which is most promising to follow througjh

Work planned
Work completed
Parallel topic

Vehicle-Pavement Interaction	Year 2 (4/08-3/09)				Year 3 (4/09-3/10)				Year 4 (04/10-03/11)				Year 5 (04/11-03/12)				Team
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
(1) Workshop																	
VP1a: Workshop on Super-Single Tires																	UNR
(2) Design Guidance																	
VP2a: Mixture Design to Enhance Safety and Reduce Noise of HMA																	UWM
VP2a-1: Evaluate common physical and mechanical properties of asphalt mixtures with enhanced frictional skid characteristics				DP													
VP2a-2: Evaluate pavement macro- and micro-textures and their relation to tire and pavement noise-generation mechanisms				DP													
VP2a-3: Develop a laboratory testing protocol for the rapid evaluation of the macroand micro-texture of pavements		M&A		P													
VP2a-4: Run parametric studies on tire-pavement noise and skid response			JP			JP	D	P, F									
VP2a-5: Establish collaboration with established national laboratories specialized in transportation noise measurements. Gather expertise on measurements and analysis																	
VP2a-6: Model and correlate acoustic response of tested tire-pavement systems										JP	D	F					
VP2a-7: Proposed optimal guideline for design to include noise reduction, durability, safety and costs											D	P, F					
(3) Pavement Response Model Based on Dynamic Analyses																	
VP3a: Pavement Response Model to Dynamic Loads																	UNR
VP3a-1: Dynamic Loads			JP						D, F	JP							
VP3a- 2: Stress Distribution at the Tire-Pavement Interface									D, F	JP							
VP3a-3: Pavement Response Model					SW - b version								SW, JP				
VP3a-4: Overall Model													D	F			

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Work planned
Work completed
Parallel topic

PROGRAM AREA: VALIDATION

CATEGORY V1: FIELD VALIDATION

Work element V1a: Use and Monitoring of Warm Mix Asphalt Sections (Year 1 start)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The first annual monitoring of the Yellowstone warm mix sections is scheduled for early September 2008.

Work element V1b: Construction and Monitoring of additional Comparative Pavement Validation sites (Year 1 start)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Contact state DOT representatives provided by Eric Weaver for possible new construction sites at LTPP sections that are slated to go out of service.

CATEGORY V2: ACCELERATED PAVEMENT TESTING

Work element V2a: Scale Model Load Simulation on Small Test Track (Later start)

This work element is included to indicate that this may be a possibility for accelerated pavement testing for ARC research because it is a facility in the TAMU system.

Work element V2b: Construction of Validation Sections at the Pecos Research & Testing Center (Later start)

This work element is included to indicate that this may be a possibility for accelerated pavement testing for ARC research because it is a facility in the TAMU system.

CATEGORY V3: R&D VALIDATION

Work element V3a: Continual Assessment of Specifications (UWM)

Work Done This Quarter

Work last quarter included further evaluation of the binder creep and recovery testing results to determine if there is a need to change the testing geometry and/or the number of cycles to capture the potential of tertiary flow. A review of the latest recommendation by FHWA for the multiple stress creep recovery (MSCR) test was conducted to evaluate the need to include a higher stress level and more loading cycles. The effect of testing temperature on the results was also evaluated. Two journal papers were completed this quarter. One was submitted and accepted for publication at an international conference in Qatar (Bahia et al. 2008), and the other will be submitted to the Association of Asphalt Paving Technologists or to the Transportation Research Board. The papers summarize the results of binder testing to study effect of stress, geometry, testing temperature, and loading time.

Work also included review of data collected for the Binder Yield Energy Test (BYET), which is intended to be used for binder fatigue characterization. The review is focused on selecting the temperature, aging, rate, and number of replicates needed for the standard test protocol. The issue of considering the pavement structure in the limits was addressed. There are some significant challenges in using the BYET data and frequency sweep data to simulate effects of pavement structure for estimating binder fatigue life. These challenges are related to non-linear behavior of some modified binders and the possibility of visco-plasticity at the testing temperatures. A detailed analysis of this problem, review of literature, and discussion with experts in the analytical modeling has started to address this problem. Testing at lower temperatures in Task F2e is being used in this analysis.

A meeting with experts from the Polytechnic University of Barcelona who have conducted extensive work on fatigue was held in Madison in May to discuss their research on evaluating the mechanical behavior of binders post peak of the stress in the monotonic testing and to explore opportunities of collaboration to leverage resources. The meeting resulted in a few action items involving sharing data and re-analysis of BYET data to look at post peak behavior of modified binders.

Significant Results

As explained in work element E1b-1, there appears to be clear indication that using the parallel plate geometry and 1.0 mm gap could lead to errors. Reducing the gap to less than 300 μm could solve the problem and give more reliable measurements. The effect of temperature on permanent strain of binders is found to follow a simple logarithmic function. The binders tested so far gives very similar trends and a possible universal temperature adjustment factor can be calculated. Such an adjustment factor could be used in accounting for accumulated permanent deformation at varying climatic conditions in binder specifications.

The use of the BYET to estimate binder resistance to fatigue under varying traffic and pavement structural capacity is under development. While a framework has been established, there are some challenges faced in the numerical modeling of the response of some modified binders. These challenges could be related to the effect of visco-plasticity and/or modeling of rheological master curves of some complex binders.

The concept of using the post-peak response in the BYET results of binders in evaluating binders' resistance to fatigue is underway. Modified binders appear to offer special capacity to resist load after maximum stress is reached. This behavior could have significant impact on ranking binders and relating their properties to performance.

Significant Problems, Issues and Potential Impact on Progress

None at this time.

Work Planned Next Quarter

Work will continue of the repeated creep procedure and the BYET test modeling and derivation of a binder fatigue parameter. It is expected that two general reports on each of these topics will be competed next quarter.

Work will also start on the binder fracture test results and the analysis of a parameter to be used as part of the binder specification for low temperature cracking.

Cited References

Bahia, H., Delgadillo, A. Motamed, and D. Christensen, "Performance of Modified Asphalt Binder and Mixtures under Increased Truck Loading Limits," Accepted at the Fourth International Gulf Conference on Roads, Qatar, November 2008.

Work element V3b: Validation of the MEPDG Asphalt Materials Models Using New MEPDG Sites and Selected LTPP Sites. (UNR, UWM)

Subtask V3b-1: Design and Build Sections (UNR Start Year 1, Year 2, and Year 3)

Work Done This Quarter

The UNR team conducted an MEPDG design for the RTC of Washoe County, Nevada for a new flexible pavement to be placed at Sparks Boulevard in Sparks, Nevada. The thickness design was validated after evaluating the mechanical properties of the HMA mix to be placed on the job. Field mixtures from behind the paver were collected in cooperation with Washoe RTC and Granite Construction.

The UNR team also worked with the South Dakota DOT and identified two new projects that will be evaluated and designed using the MEPDG design method in 2009/2010.

Significant Results

A MEPDG design report was submitted for Washoe RTC for the Sparks Boulevard project in Sparks Nevada. The Washoe RTC project was constructed and completed by August 1st.

Significant Problems, Issues and Potential Impact on Progress

Only three agencies have committed to the construction of MEPDG sites: the Washoe RTC in northern Nevada in 2008, the South Dakota DOT in 2009/2010, and the Wisconsin DOT in 2009. The researchers are facing significant hesitation from the DOTs to use the MEPDG to design and construct HMA pavements. The level of this work element may have to be reduced.

Work Planned Next Quarter

Discussions will continue with the states to select field sections for the MEPDG validations sites. Complete the MEPDG design and construct the Washoe RTC project.

Subtask V3b-2: Additional Testing (Start Year 2, Year 3, and Year 4)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

No work planned.

Subtask V3b-3: Select LTPP Sections (Start Year 1 thru Year 5)

Work Done This Quarter

In the previous quarter, the team identified asphalt binders from Specific Paving Study (SPS)-9 with field performance of fatigue cracking for the validation of preliminary findings at UW-Madison. In this quarter the team placed an order to the Long-Term Pavement Performance Program (LTPP) Materials Reference Library (MRL) and got approved by the Federal Highway Administration. The MRL shipped the asphalt binders to the University of Wisconsin at Madison. Currently, samples are being tested for validation tasks.

In this quarter the team has also identified more asphalt binders for the study of block cracking. These binders were used for the construction sections, ranging from SPS-1 through SPS-9. It is noted that most of the asphalt binders obtained from fatigue cracking study in SPS-9 have not exhibited block cracking in the field yet and can not be used for a block cracking study. The performance of these binders was also retrieved from the LTPP database. The binders identified for block cracking are listed in table V3b-3.1. The binders for the block cracking study will be ordered from MRL for laboratory testing.

Significant Results

The team ordered and received asphalt binders from LTPP MRL for the fatigue cracking study. The team also identified asphalt binders with field performance of block cracking in the LTPP sections.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The team will test the asphalt binders for the fatigue cracking study. The team will order and sample asphalt binders for block cracking.

Table V3b-3.1 Asphalt binders for block cracking study.

Shrp_ID	Sample Type	Sampled_Date	GridCoord	Agency
10600	AC LOWER BINDER 67-22 W/O POLYMER	05/12/98	E6-05-01	AL
10600	PG 76-22 UPPER BINDER MIX	05/14/98	E6-05-01	AL
40500	AC-20 BINDER		E3-05-02	AZ
40500	AC-40 BINDER		E3-05-02	AZ
60500	AC FOR RUBBERIZED MIX		E3-06-01	CA
60600	AR-4000 BINDER	08/11/92	E5-02-01	CA
80500	AC-20 BINDER		E2-04-03	CO
170600	AC BINDER		E5-01-01	IL
180600	BINDER (OPENED)		E4-04-02	IN
190100	BC-17 , PLANT BINDER	11/11/92	E2-04-03	IA
190600	LIQUID ASPHALT BINDER		E3-01-02	IA
230500	AC BINDER	06/20/95	E6-04-02	ME
280500	BINDER		E2-04-03	MS
290500	OIL FOR VIRGIN IC	08/27/98	E6-04-01	MO
290500	OIL FOR RECYCLE IB MIX	09/02/98	E6-04-01	MO
290600	AC BINDER		E5-03-02	MO
300500	85/100 , AC		E3-01-02	MT
300800	A/C		E3-05-02	MT
340500	AC-10 FOR RECYCLED, BINDER		E4-02-02	NJ
340500	AC-20 FOR VIRGIN MIX, BINDER		E4-02-02	NJ
350500	AC CEMENT FOR RAP	09/07/96	E6-01-02	NM
360800	BINDER	08/16/94	B1-02-03	NY
390100	AC-20 BINDER	07/01/94	E3-06-01	OH
400600	AC-20 BINDER		E5-01-01	OK
480500	AC 10 W/3% LATEX	10/16/91	E3-01-01	TX
480500	AC 5 RAP SURFACE BINDER		E3-02-01	TX
480500	AC-10 ASPHALT W/ 3% LATEX, BINDER	10/16/91	E4-02-02	TX
480800	AC-20 BINDER	07/17/96	E2-04-03	TX
490800	PG 58-34 BINDER	10/17/97	E3-06-01	UT
530800	AR 4000 ASHPHALT BINDER	10/26/95	E6-02-02	WA
550903	AR PG 58-72		E2-03-03	WI
810500	150/200 AC BINDER	10/03/90	E2-04-03	AB
810500	200/300 ASPHALT BINDER	10/10/90	E2-04-03	AB

Subtask V3b-4: Testing of Extracted Binders from LTPP Sections (Start Year 1)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

The 20 percent cost share to perform testing on LTPP samples to augment the LTPP database has not been identified. If a cost share is not obtained, this work will not be completed.

Work Planned Next Quarter

No work planned.

Subtask V3b-5: Review and Revisions of Materials Models (Start Year 2, Year 3, Year 4, and Year 5)

This subtask has not begun. The Year 2 Work Plan was not approved until mid-August 2008.

Subtask V3b-6: Evaluate the Impact of Moisture and Aging (Start Year 3, Year 4, and Year 5)

Validation	Year 2 (4/2008-3/2009)												Team
	4	5	6	7	8	9	10	11	12	1	2	3	
(1) Field Validation													
V1a: Use and Monitoring of Warm Mix Asphalt Sections													WRI
V1b: Construction and Monitoring of additional Comparative Pavement Validation sites													WRI
(2) Accelerated Pavement Testing													
V2a: Accelerated Pavement Testing including Scale Model Load Simulation on small test track													WRI
V2b: Construction of validation sections at the Pecos Research & Testing Center													WRI
(3) R&D Validation													
V3a: Continual Assessment of Specification													UWM
V3a-1: Evaluation of the PG-Plus practices and the motivations for selecting the "plus" tests.						P		D	F				
V3a-2: Detailed analysis of all PG-Plus tests being proposed or in use today, documentation of benefits and costs of these tests, and comparison with new tests									P				
V3a-3: Development of protocols for new binder tests and database for properties measured													
V3a-4: Development of specification criteria for new tests based on field evaluation of construction and performance													
V3a-5: Interviews and surveys for soliciting feedback on binder tests and specifications												JP	
V3b: Validation of the MEPDG Asphalt Materials Models and Early Verification of Technologies Developed by ARC using new MEPDG Sites and Selected LTPP sites													UNR/UWM/ WRI
V3b-1: Design and Build Sections													
V3b-2: Additional Testing													
V3b-3: Select LTPP Sites to Validate New Binder Testing Procedures				JP						P			
V3b-4: Testing of Extracted Binders from LTPP Sections													
V3b-5: Review and Revisions of Materials Models													
V3b-6: Evaluate the Impact of Moisture and Aging													

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Work planned
Work completed
Parallel topic

Validation	Year 2 (4/08-3/09)				Year 3 (4/09-3/10)				Year 4 (04/10-03/11)				Year 5 (04/11-03/12)				Team
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
(1) Field Validation																	
V1a: Use and Monitoring of Warm Mix Asphalt Sections																	WRI
V1b: Construction and Monitoring of additional Comparative Pavement Validation sites																	WRI
(2) Accelerated Pavement Testing																	
V2a: Accelerated Pavement Testing including Scale Model Load Simulation on small test track																	WRI
V2b: Construction of validation sections at the Pecos Research & Testing Center																	WRI
(3) R&D Validation																	
V3a: Continual Assessment of Specification																	UWM
V3a-1: Evaluation of the PG-Plus practices and the motivations for selecting the "plus" tests.		P	D,F														
V3a-2: Detailed analysis of all PG-Plus tests being proposed or in use today, documentation of benefits and costs of these tests, and comparison with new tests			P														
V3a-3: Development of protocols for new binder tests and database for properties measured					P		JP			P							
V3a-4: Development of specification criteria for new tests based on field evaluation of construction and performance								JP	P			JP	P		JP		
V3a-5: Interviews and surveys for soliciting feedback on binder tests and specifications				JP	P			JP	P		JP		P		D	F	
V3b: Validation of the MEPDG Asphalt Materials Models and Early Verification of Technologies Developed by ARC using new MEPDG Sites and Selected LTPP sites																	UNR/UWM
V3b-1: Design and Build Sections									D, F								
V3b-2: Additional Testing													D, F				
V3b-3: Select LTPP Sites to Validate New Binder Testing Procedures		JP			P					JP		P			D	F	
V3b-4: Testing of Extracted Binders from LTPP Sections																	
V3b-5: Review and Revisions of Materials Models																D, F	
V3b-6: Evaluate the Impact of Moisture and Aging																D, F	

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Work planned
Work completed
Parallel topic

PROGRAM AREA: TECHNOLOGY DEVELOPMENT

Work element TD1: Prioritize and Select Products for Early Development (Year 1)

Work Done This Quarter

None. This work element was completed last Quarter.

Significant Results

Six early technology development projects have been identified and all have received favorable ratings from the ETGs.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

No work planned.

Work element TD2: Develop Early Products (Year 2)

Work Done This Quarter

Initial work was completed this Quarter on the Simplified Continuum Damage Fatigue project. An improved method for analysis of continuum damage fatigue data was developed. Two new and very useful concepts were included in the improved method. The first is the concept of reduced loading cycles. Reduced loading cycles can be used as a much simpler alternative to the continuum damage parameter, *S*, in developing damage functions for HMA mixtures. The second concept introduced in the improved analysis approach is that of effective strain, which is the applied strain minus the endurance limit. Using effective strain allows for better collapse of damage curves generated at different temperatures and strain levels compared to the traditional approach. A journal paper describing the improved, simplified continuum damage analysis was prepared and submitted to the Association of Asphalt Paving Technologists.

Significant Results

An improved method was developed for analysis of continuum damage fatigue data. A journal paper describing the method was prepared.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Detailed work plans for the development of the other selected projects will be started.

Work element TD3: Identify Products for Mid-Term and Long-Term Development (Year 2, 3, and 4)

Work Done This Quarter

No activity this quarter.

Significant Results

None

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Consortium partners will begin identifying potential Mid-Term and Long-Term products from the completed research.

Work Element TD4: Develop Mid-Term and Long-Term Products (Years 3, 4, and 5)

This activity is planned for later in the project.

PROGRAM AREA: TECHNOLOGY TRANSFER

CATEGORY TT1: OUTREACH AND DATABASES

Work element TT1a: Development and Maintenance of Consortium Website (Duration: Year 1 through Year 5)

Work Done This Quarter

The ARC website was maintained and updated. Newsletter uploaded to the ARC website.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Continue maintaining and updating the ARC website.

Work element TT1b: Communications (Duration: Year 1 through Year 5)

Work Done This Quarter

The second ARC Newsletter published by May 2008.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Publish the third ARC Newsletter.

Work element TT1c: Prepare Presentations and Publications

Work Done This Quarter

ARC members attended the RILEM meeting in Chicago in June and made extensive presentations at the subsequent Fundamental Properties and Advanced Models ETG meeting.

In addition, the following presentation and paper were delivered during the quarter:

Paper presented at EATA conference, Lyon, France, April 14th – 15th and published in International Journal of Road Materials and Pavement Design:
Bhasin, A., D. N. Little, R. Bommavaram, and K. L. Vasconcelos, "A Framework to Quantify the Effect of Healing in Bituminous Materials Using Material Properties", *Road Materials and Pavement Design*, 2008, pp. 219-242.

Paper accepted for publication in the ASCE journal of materials:
Bhasin, A., V. C. Branco, E. Masad, and D. N. Little, "A Critical Review of Energy Methods to Characterize Fatigue Cracking of Asphalt Materials", *Journal of Testing and Materials*, American Society of Civil Engineers (Accepted for publication).

Work Planned Next Quarter

ARC members will attend and present updates on some of the ongoing research at the Binder and Mix & Construction ETG meetings in Reno, NV in September being hosted by ARC member Dr. Peter Sebaaly and his team at the University of Nevada Reno.

Three papers are planned for submission for publication in the next quarter. They are as follows:

Dr. Christensen will prepare a Journal Paper titled, "Analysis of HMA Fatigue Data Using The Concepts of Reduced Cycles and Endurance Limit," and submit it to the Association of Asphalt Paving Technologists.

Paper submitted to for consideration for TRB 2009:
Bhasin, A., R. Bommavaram, and D. N. Little, "Use of Dynamic Shear Rheometer to Determine the Healing Properties of Asphalt Binders", submitted for consideration for TRB 2009.

Paper submitted for RILEM publication:
Branco, V.C., E. Masad, A. Bhasin, and D. Little (2008). Nonlinear Viscoelastic and Damage Characterization of Fine Asphalt Mixtures Using Dynamic Mechanical Analysis (DMA). *Journal of Materials and Structures*, RILEM Publication.

Work element TT1d: Development of Materials Database (Duration: Year 2 through Year 5)

Work Done This Quarter

The Entity relationships Diagrams (ERD) for MDF-1, MDF-2, and MDF-3 blocks were developed. The Entity Relationship Diagrams are a major data modeling tool and will help organize the database into entities and define the relationships between the entities. This process enables the production of a better database structure so that the data can be stored and retrieved in a most efficient manner.

Significant Results

Figure TT1d.1 shows an example of the developed ERD.

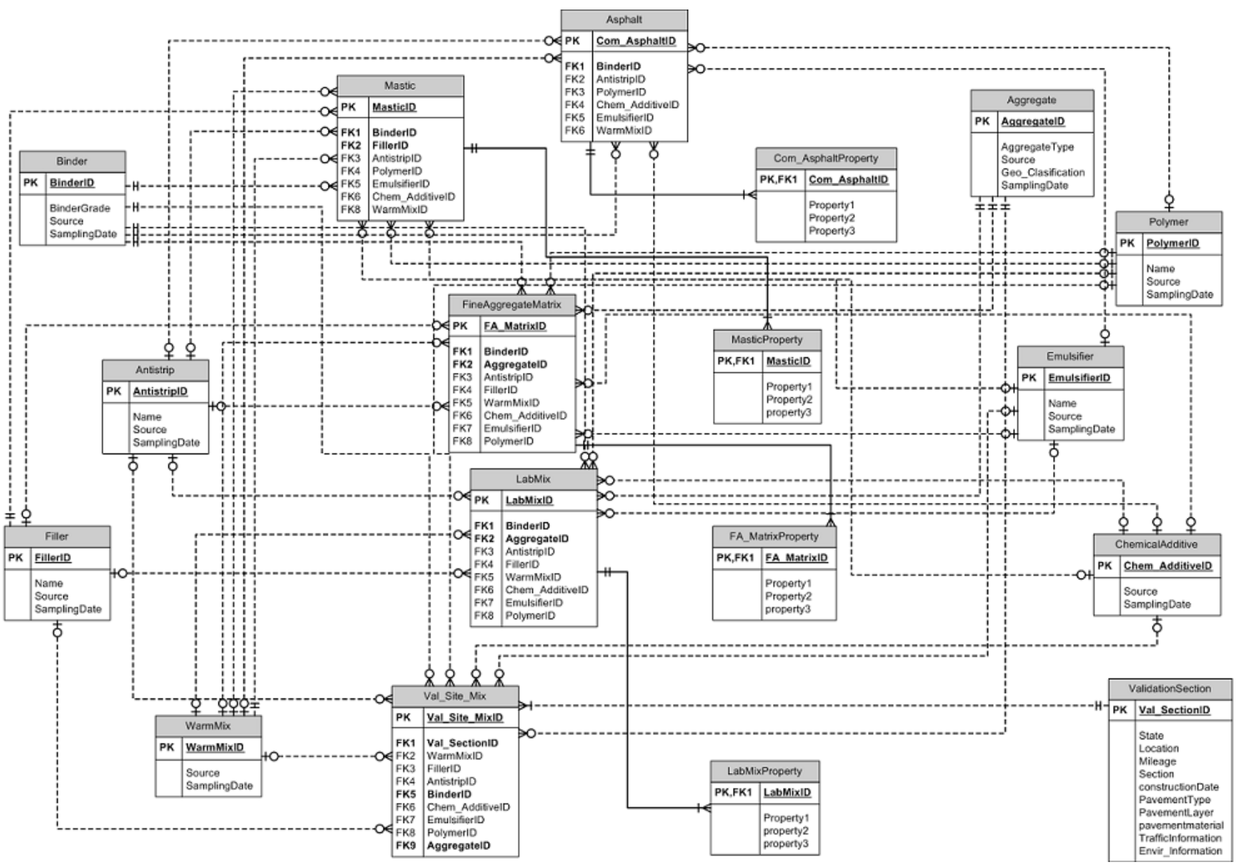

Figure TT1d.1. Diagram. Entity relationships diagram.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Create the tables in Microsoft Access according to the developed ERDs.

Work element TT1e: Development of Research Database (Duration: Year 2 through Year 5)

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Prepare a framework for the research database.

Work Element TT1f: Workshops and Training

Progress This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

No activities are planned for the next quarter.

Technology Transfer Year 2	Year 2 (4/2008-3/2009)												Team
	4	5	6	7	8	9	10	11	12	1	2	3	
(1) Outreach and Databases													
TT1a: Development and Maintenance of Consortium Website													UNR
TT1b: Communications													UNR
TT1c: Prepare presentations and publications													UNR
TT1d: Development of Materials Database													UNR
TT1d-1: Identify the overall Features of the Web Application													
TT1d-2: Identify Materials Properties to Include in the Materials Database													
TT1d-3: Define the Structure of the Database													
TT1d-4: Create and Populate the Database													
TT1e: Development of Research Database													UNR
TT1e-1: Identify the Information to Include in the Research Database													
TT1e-2: Define the Structure of the Database													
TT1e-3: Create and Populate the Database													
TT1f: Workshops and Training													UNR

Deliverable codes	Deliverable Description
D: Draft Report	Report delivered to FHWA for 3 week review period.
F: Final Report	Final report delivered in compliance with FHWA publication standards
M&A: Model and algorithm	Mathematical model and sample code
SW: Software	Executable software, code and user manual
JP: Journal paper	Paper submitted to conference or journal
P: Presentation	Presentation for symposium, conference or other
DP: Decision Point	Time to make a decision on two parallel paths as to which is most promising to follow througjh

Work planned
Work completed
Parallel topic

Technology Transfer Year 2 - 5	Year 2 (4/08-3/09)				Year 3 (4/09-3/10)				Year 4 (04/10-03/11)				Year 5 (04/11-03/12)				Team
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
(1) Outreach and Databases																	
TT1a: Development and Maintenance of Consortium Website																	UNR
TT1b: Communications																	UNR
TT1c: Prepare presentations and publications																	ALL
TT1d: Development of Materials Database																	UNR
TT1d-1: Identify the overall Features of the Web Application																	
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TT1f: Workshops and Training																	UNR

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Work planned
Work completed
Parallel topic