Asphalt Research Consortium

Quarterly Technical Progress Report
January 1 – March 31, 2008

April 2008

Prepared for
Federal Highway Administration
Contract No. DTFH61-07-H-00009

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INTRODUCTION

This document is the Quarterly Report for the period of January 1 to March 31, 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.

Past Quarterly Reports in some cases contained lengthy discussions of the work accomplishments, data, and analysis for the various Work Elements and Subtasks. However, in response to a request from the FHWA Agreement Officer's Technical Representatives (AOTR's) Dr. Jack Youtcheff and Mr. Eric Weaver, this Quarterly Report is being presented in more of a summary form. 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 1 and Year 2 Work Plans in order to obtain background information on specific areas of research.

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

Several Asphalt Research Consortium (ARC) members attended the 87th Annual Meeting of the Transportation Research Board in Washington, D.C. during the week of January 13, 2008. Several ARC members serve as committee members on various TRB committees and participated in committee meeting and other activities such as chairing session. Following the TRB meeting, a project review for the ARC research and the WRI Fundamental Properties of Asphalts and Modified Asphalts III research was presented to invited reviewers. The ARC members presented a selection of research topics to the reviewers.

At the end of January 2008, the ARC submitted a detailed Annual Work Plan for Year 2 to FHWA for review. Also at the end of January 2008, the ARC submitted a Quarterly Report for the period October 1 to December 31, 2007.

During the week of February 25, 2008, ARC members presented some of the results of the research to date and details of the proposed research for Year 2 to the Binder, Mix and Construction, and Fundamental Properties and Advanced Models Expert Task Group meetings in Tampa, Florida.

ARC members also attended the RAP Expert Task Group meeting in San Diego, California on March 5 & 6, 2008 that was hosted by CalTrans. Dr. Peter Sebaaly of the University of Nevada Reno presented on overview of the planned RAP research in the ARC and discussed important issues with CalTrans staff and others.

WORK PLANNED FOR NEXT QUARTER

Dr. Dallas Little of Texas A&M University attended the European Asphalt Technology Association meeting in Lyon, France in April 2008 and presented a paper on quantifying the effects of healing. This paper has been published in the journal Road Materials and Pavement Design. The complete reference is listed in the Technology Transfer section of this report under Work Element TT1c.

Several ARC members plan to attend the annual Association of Asphalt Paving Technologists (AAPT) meeting in Philadelphia, Pennsylvania during the week of April 28, 2008. ARC members will also attend the Sixth RILEM International Conference on Cracking in Pavements in Chicago, Illinois, on June 16 – 18, 2008. ARC members will then attend the next meeting of the Fundamental Properties and Advanced Models Expert Task Group meeting to be held following the conference on June 19 & 20, 2008.

PROGRAM AREA: MOISTURE DAMAGE

CATEGORY M1: ADHESION

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

Work Done This Quarter

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

1. Evaluation of displacement history in the modified pullout system response
2. Review of ASTM Standards to identify alternative setup for the pulling strength testing
3. Parametric study of the system sensitivity for the evaluation of adhesion and cohesion of different mineral aggregate and neat and modified binder systems
4. Evaluation of the methodology to characterize adhesive and cohesive failures

The following set of parameters was tested:

- Three different surfaces: granite, limestone, and clean glass
- Three different binders: neat FH PG 64-22 binder, PG 70-22 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

These set of test combinations were run and analyzed (over 150 tests). The summary of the results follow.

Significant Results

1. The evaluation of pullout tension and displacement history in the modified PATTI system was completed. The pullout tension allows the evaluation of the pressure rate and the maximum pressure at failure. Results show that the binder type and binding temperatures (despite their different stiffness) do not control the applied pressure rate but do control the maximum measured pullout pressure.

   The displacement history measurements required several iterations because fast pullout rates resulted in brittle failures with very small deformations (as shown in figure M1a.1). Several different displacement transducers were tested until an optimal configuration that included changes in the data acquisition dynamic range was found. This configuration seems to have solved the problem. The value of the displacement measurements and its practicality is not known yet. More work is needed to find out if the displacement measured can be used successfully to evaluate the tackiness. Also, the optimum pressure rate that could result in reliable displacement is yet to de defined.

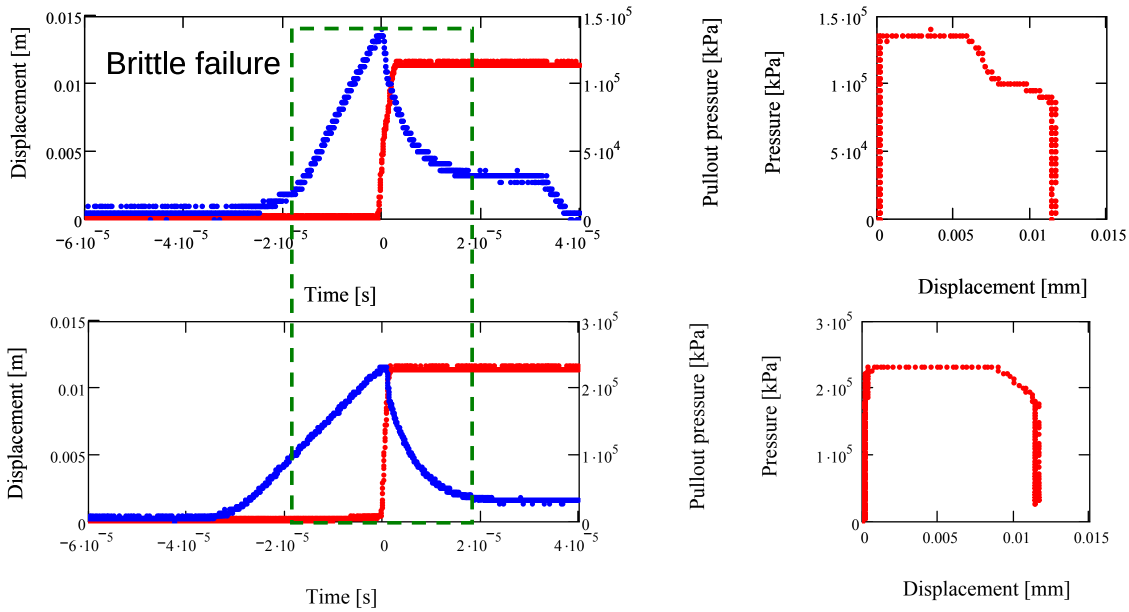


Figure M1a.1. Graphs. Displacement and pullout tension history in limestone-neat binder testing.

2. Because of the challenges in measuring displacements reliably with the modified PATTI, an effort was put into the review and evaluation of alternative testing methodologies for which standard equipment is already available. The review yielded a number of different set ASTM standards and alternatives from equipment manufacturers (including different rate of loading, alignment, portability and cost). The search included polymer and roofing industry testing. Table M1a.1 summarizes these results.

3. An extensive parametric study for the evaluation pullout response of specimen prepared with different mineral aggregates, neat and modified binders, binding temperatures, and loading rates was performed. Results have clearly shown the effect of binder type, binding temperature, and even aggregate type on the maximum pullout tension. Figure M1a.2 shows a summary of the results. One important issue that needs further investigation is the effect of mineral type on cohesive failures.

4. During pullout testing, the research team aimed at evaluating methodologies to characterize adhesive and cohesive failures. Every single failed surface was documented with photographs for further analysis and characterization. Most of the completed unconditioned tests show glassy, cohesive failures (it is expected that water damage would yield a greater percentage of adhesive failures). However, some tests on limestone aggregate showed internal failures at the rock surface. This is a clear indication of the low quality of the aggregate selected for the testing. The research team will look for alternatives for limestone aggregates.

Table M1a.1. Evaluation of testing methodologies.

ASTM Standards	Instrument	Comments
D 1623-03: Standard Test Method for Tensile and Tensile Adhesion Properties of Cellular Plastic (Also ASTM D1621 standard applies)	TestResources (1-800-430-6536, www.testresources.com) $11,500 plus grips (they will send a quote)	This instrument does exactly what we need: it measures and records pullout forces and displacements. Rates: 1 to 20 mm/min. Deformation range: ~ 15 cm. We would need to modify the grips and geometry to test our aggregate binder systems. The instrument is not portable and quite costly.
D 4541-02: Standard Test Method for Pull-Off Strength of Coating Using portable Adhesion Testers	a) PosiTest Pull-Off Adhesion Tester (www.defelko.com) $1,950 plus $95 for the recording software	This tester measures the peak pull-out strength. It controls pressure rates. The instrument is portable and it does not required external pressure source. The setup allows for the self alignment of the pull-out stub.
	b) PATTI Tester (SEMicro Corp. - www.semicro.org) $3295.00 for the Quantun Digital	The PATTI instrument measures the peak pull-out strength. It is referred to as a self-alignment adhesion tester. It controls pressure rates. The instrument is portable; however, it does require an external pressure source.
D 228-06: Standard Test Methods for Sampling, Testing, and Analysis of Asphalt Roll Roofing, Cap Sheets, and Shingles Used in Roofing and Waterproofing		This standard does not apply to our needs. It describes testing related to determination of moisture, pliability, mass loss and behavior on heating, tear strength, and fastener pull-through resistance.
D 5100-95a: Standard Test Methods for Adhesion of Mineral Aggregate to Hot Bitumen	None available	(This standard does not apply directly to our pull-out problem, however it could be used, with proper conditioned, as a very simple surrogate test. It would not yield deformation information.) This standard determines the adhesion of aggregate to a coat of bitumen by turning a saturated, bitumen-coated felt with aggregate upside down and measuring the lost aggregate mass.
D 1970-01: Standard Specification for Self-Adhering Polymer Modified Bituminous Sheet Materials Used as Steep Roofing Underlayment for Ice Dam Protection	Constant rate extension type tester	This standard evaluates the properties of self-adhering bituminous materials. Rate of laminate separation 25 mm/min.
D 3019-94: Standard Specification for Lap Cements used with Asphalt Roll Roofing, non Fibered, Asbestos Fibered, and Non Asbestos Fibered		Non applicable to our problem.

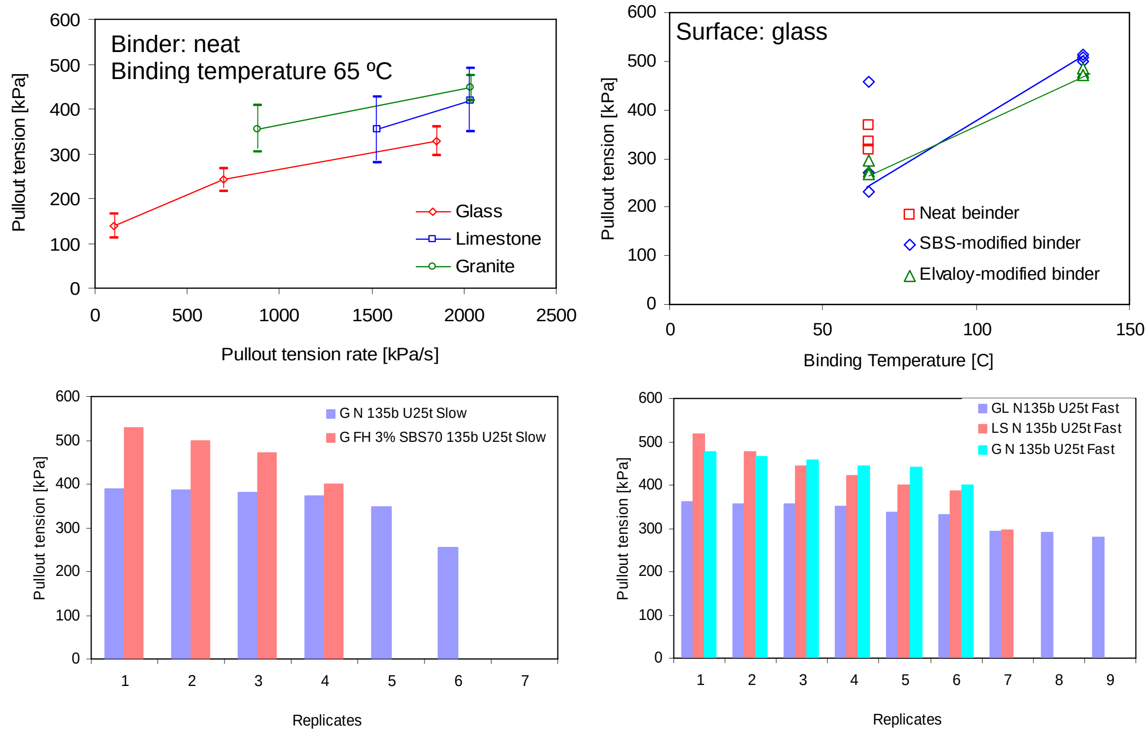


Figure M1a.2. Graphs. Summary of typical results on maximum pullout tension.

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. Definitions of better data acquisition dynamic ranges seem to have finally solved this problem by focusing in the small deformation rather than in the overall deformation of the pullout specimen. The team does not expect further delays due to this problem.

Work Planned Next Quarter

In Q2 2008, the UW-Madison research team will complete the validation of the modified PATTI test methodology and will further evaluate the results by comparing binder-aggregate system behavior with results using the DSR testing methodology. Additional tests will be performed using different mastics and under conditioning environments.

The analysis methodology proposed is a statistical evaluation of the tested parameters. PATTI test results have shown problems with repeatability, evaluation of the energy dissipated, and failure type (adhesion vs. cohesion). Once these issues are addressed, moisture damage studies will be performed to evaluate material behavior with the proposed new methodology. A manuscript will be written summarizing the results obtained in Year 1.

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>

Preliminary tests to evaluate the reactivity of different asphalt binders to hydrated lime were conducted during this quarter. Different types of asphalt binder solution and filler particles were mixed in a calorimetric cell. Initial experience indicates that some refinement to the test technique is required to ensure complete wetting of the filler particles by the binder.

<u>Significant Results</u>

None.

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

None.

<u>Work Planned Next Quarter</u>

Work related to the use of a micro-calorimeter will be resumed in later quarters of year 2. This work will be on the evaluation of: (i) the effect of active fillers and liquid anti strip agents on the total energy of adhesion between asphalt binders and aggregates, (ii) differences in the reactivity of different asphalt binders to hydrated lime, and (iii) the possible use of this technique to detect presence of clay contamination that may be present in the filler material used in the production of asphalt mixtures.

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

<u>Work Done This Quarter</u>

The work plan for this subtask is to be developed at the start of Year 2 beginning April 1, 2008.

<u>Significant Results</u>

None.

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

None.

Work Planned Next Quarter

Develop work plan for review.

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

Work Done This Quarter

Specimens for different types of minerals that are present in typical aggregates were obtained. These minerals are being individually characterized for their surface properties using the Universal Sorption Device (USD) and the flow calorimeter. Tests with minerals quartz, microcline, and calcite are nearing completion. Information on the performance characteristic of individual minerals will be combined with the known performance characteristics and composition of different aggregates. The composition of different aggregates will be made available from work element M3a.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The planned activity for the next quarter is to continue determining the surface properties of different pure minerals using the USD and a flow calorimeter.

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

Work Done This Quarter

The experimental and analytical procedure to evaluate the performance of moisture conditioned FAM specimens is very similar to the procedure used for unconditioned or dry specimens. Therefore, the work being developed and reported in Task F2b also applies to this work element.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Work in the next quarter will continue for Task F2b. The most important difference between this work element and Task F2b is that the moisture conditioning procedure used for the DMA specimens. The moisture conditioning procedure will be developed in the later quarters of this work area.

Furthermore, in work element M2b there is ongoing work related to the measurement of diffusion rates of water through DMA specimens using gravimetric methods. Results from these measurements will establish a datum for water concentration versus time under natural conditions (without the aid of any accelerating technique). This information will serve as a useful reference to quantify the time scaling effect of accelerated moisture conditioning techniques such as vacuum saturation or submergence at elevated temperatures. For example, it will be possible to determine the amount of time a DMA specimen needs to be submerged in water at 50°C (at any other elevated temperature or under vacuum) in order for the specimen to have the same moisture concentration profile as a specimen submerged in water at room temperature for a specified duration. This relationship will allow accelerated conditioning of DMA specimens to different levels of moisture prior to testing.

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 this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

No work planned.

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

Work Done This Quarter

The work plan for this subtask is to be developed at the start of Year 2 beginning April 1, 2008.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Develop work plan for review.

Work Element M2b: Impact of Moisture Diffusion in Asphalt Mixtures

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

Work Done This Quarter

DMA specimens with three different types of asphalt binders and aggregates were immersed in water. These specimens are continually being monitored since the last quarter.

An environmental chamber to condition the FTIR specimens to measure diffusivity of water through thin films of asphalt binder was also fabricated. In addition to the FTIR measurements, phase changes on the surface of the binder film on FTIR windows were also imaged using an AFM before and after moisture conditioning.

Significant Results

Gravimetric water absorption data obtained thus far indicates that there are two distinct phases of moisture transport within the bulk of the DMA specimens. In the first phase, moisture diffusion is primarily through the bulk of the binder and as a result the rate of moisture absorption was dependent only on the type of binder and not the type of aggregate. In the second phase, moisture absorption was dependent on the type of binder as well as aggregates. Researchers recognize the exceedingly time consuming nature of this test method despite its simplicity. Therefore, the plan for the use of this test is to: (i) generate a set of data for cross verification of results from other models and methods, and (ii) serve as a reference set of values for the accelerated moisture conditioning techniques that will be used in work element M1c.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The planned activity for the next quarter is to continue the experiments related to gravimetric measurement and FTIR, using different asphalt binders. ARC researchers will also coordinate with FHWA to compare results on diffusivity of water determined using electronic impedance spectrometry for similar binders prepared using similar techniques.

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

Pilot tests are planned for measurement of combined diffusion of water through the interface as well as bulk binder using the FTIR. However, these tests will be conducted subject to availability of reasonable amounts of data for subtask M2b-1. This is because the results from subtask M2b-1 will have to be used in combination with the results from subtask M2b-2 to obtain meaningful information on the kinetics of debonding at the binder-aggregate interface.

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

Work Done This Quarter

Table M2c.1 illustrates the testing matrix proposed for this work element. During this quarter the research team started the testing following the test matrix.

Table M2c.1. Stress sweep and tack test experimental matrix.

Neat Binders	PG 58-28	Mineral Fillers	Limestone
	PG 64-22		Sandstone
Modifiers	D1101 Kraton SBS		Ottawa Sand
	D1184 Kraton SBS	Conditioning Media	Distilled water
	Elvaloy AM		NaCl (aq)
	Elvaloy 4170		$CaCl_2$ (aq)
	PPA 115 (or 105)	Conditioning Time	24 hours
Testing Temperature	19°C		No Time
	25°C	Conditioning Temperature	60°C
Aggregate Disks	Limestone		
	Granite		
	Sandstone		

The DSR tack test was performed on neat, SBS, Elvaloy, and PPA modified binders, with different concentrations of polymer modifier (3% and 5% for LSBS, 2% for Elvaloy). Testing more than one concentration of the same polymer modifier enabled the team to detect if the testing method is sensitive enough not only to discriminate between different modifiers, but also to be able to detect different levels of modification. The results obtained so far prove that the test is sensitive enough to differentiate between different modifiers and different levels of modification.

The team also tested a subset of the neat and modified binders using limestone rock disks for the stress sweep test in the DSR. Tests were performed on both unconditioned and water-conditioned samples. The initial testing temperature for the stress sweep test was 25°C. This proved to be inadequate for the testing geometry used (25 mm parallel plate). The rheometer reaches its maximum torque before the sample can be driven to failure. As a result, the testing temperature was raised to 46°C in order to achieve failure of the sample at lower torque values and in order to correlate the results with previously published findings (Bahia 2007).

A meeting with the research teams of Texas A&M and UW-Madison was held in Madison to discuss collaborative work and coordinate the activities for the moisture damage area. The teams discussed collaboration in writing a response to critical review presented at the Modeling ETG. The teams will start sharing materials and results to correlate surface energy and DSR tackiness/stress sweep testing and to start developing material models and defining response variables needed.

<u>Significant Results</u>

Table M2c.2 shows the initial results of the tack test for an asphalt binder modified with selected additives. The results indicate that the tack test is able to differentiate between different modifiers as well as between different levels of modification with the same modifier.

Table M2c.2. The tack test discriminates between different modifiers and levels of modification (All results are for the dry condition at 25ºC).

Sample	Replicate (N·s)			Average (N·s)	Standard Deviation (N·s)	C.V. %
	1	2	3			
FH 64-22 neat	254.90	282.23	303.50	280.21	24.36	8.69
FH 64-22 PPA 1%	380.56	437.55	480.88	433.00	50.32	11.62
FH 64-22 2% Sasobit	306.46	252.21	330.22	296.30	39.98	13.49
FH 64-22 4% Sasobit	331.78	327.06	327.12	328.66	2.71	0.82
FH 70-22 3% LSBS	668.85	695.99	771.62	712.15	53.26	7.48
FH 76-22 5% LSBS	1095.13	1170.98	1189.70	1151.94	50.08	4.35
CP 64-28 4% RSBS	313.42	356.62	332.42	334.15	21.65	6.48
CP 64-28 2% Elvaloy	670.61	547.21	558.28	592.03	68.27	11.53

The initial set of results for the stress sweep (adhesion test) performed at 46°C provides very good differentiation between conditioned and unconditioned samples without reaching the testing limits of the rheometer. More results are needed to conduct a comprehensive analysis and define findings. The tack test results and the stress sweep results will be correlated to the surface energy measurements collected by Texas A&M.

Based on comments from the Modeling ETG, the research team is considering including the cone-plate geometry in the stress sweep test. This new approach will be evaluated next quarter and a decision on the need to change the geometry will be made.

Significant Problems, Issues and Potential Impact on Progress

The main issue regarding the stress sweep test was the testing temperature. Raising the test temperature solved the issue. Another solution that needs to be investigated is using the 8 mm parallel plate geometry instead of the 25 mm parallel plate. The practicality of cutting 8 mm rock disks will be investigated and reported on during the next quarter. This issue should not significantly impact the progress of this work element.

No significant issues were encountered for the tack test.

Work Planned Next Quarter

For the next quarter the team plans on investigating the practicality of using a cone-plate geometry and also obtaining and testing 8 mm parallel plate rock disks. The team will also continue testing based on the matrix previously proposed. Work on correlating measured responses with surface energy and development of models for adhesion/cohesion will continue.

For the tack test, testing will continue on unconditioned materials following the previously presented testing protocol in the Year 2 Work Plan, and testing will begin on materials that have been conditioned. Comparison to the PATTI results will also be conducted.

Cited References

Bahia, H., and C. Dong-Woo, 2007, Effects of Aggregate Surface and Water on Rheology of Asphalt Films. *Transportation Research Record 1998*.

CATEGORY M3: AGGREGATE SURFACE

Work Element M3a: Aggregate Surface Characterization (TAMU)

Work Done This Quarter

Aggregates from the SHRP reference library (RA, RC, RD, RK and RL) are being analyzed for their mineralogy using an electron microprobe technique. This is because these aggregates are currently being used by several researchers during the method development stage. The performance characteristic of these aggregates is also well known and mineralogical characterization from this task can aid in the selection of core aggregates. Electron microprobing will also be conducted on core aggregates immediately following the finalization of these materials.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

It is planned to complete the surface characterization of selected SHRP aggregates. Surface characterization of core aggregates will commence immediately upon finalization and receipt of representative samples.

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

A model for the binder/mastic-aggregate interface was created with idealized geometry. A parametric analysis for the various inputs used in this model is underway. It is important to recognize that this model is significantly different from finite element moisture damage models that have been developed previously by other researchers. The most significant difference is that the current model focuses on the interfacial damage or stripping that occurs at the binder/mastic-interface along with deterioration in the mechanical properties of the mastic, whereas the model from previous studies by other researchers focus on the deterioration in the mechanical properties of the mastic. While neither model is a comprehensive representation of moisture damage in asphalt mixtures, each model addresses a different yet equally important mechanism of moisture damage. Both models require diffusivity of water through asphalt binder as an input. In addition the current model also requires the rate of interfacial damage as an input. The rate of interfacial damage is related to the surface free energy of materials based on fundamental laws of physics. Measurement of both of these properties is being rigorously evaluated in work element M2b. Furthermore, the current model also requires the mechanical traction-separation behavior of binder/mastic-aggregate interface failure (not bulk) in dry and wet conditions as an input. A test method to obtain this material property input is being rigorously evaluated in work element F1a-4. Concurrently as part of this work element, a computational analysis of the change in the traction-separation behavior as a function of moisture content at the interface is in progress.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The plan for next quarter is to complete the parametric analysis on the influence of moisture diffusion, thermodynamic potential, and absolute rate of reaction on the rate of moisture damage at the asphalt-aggregate interface.

CATEGORY M5: MOISTURE DAMAGE PREDICTION SYSTEM

This area is planned to start later in the project.

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)

<u>Work Done This Quarter</u>

The literature review conducted this quarter focused on the documentation of the relationship between practical (or measured) and ideal (thermodynamic or based on surface free energy) work of fracture. This review was based on the work of other researchers with materials other than asphalt binder on this topic for the last three decades.

<u>Significant Results</u>

Based on the literature review on the difference between practical work of fracture to the ideal work of fracture it was determined that, for elasto-plastic materials the relatively high magnitude of energy dissipated due to irreversible processes such as plastic deformation is one of the primary reasons for this difference. However, evidence in the literature also indicates that there exists a relationship between the energy dissipated due to plastic deformation and the work of fracture due to surface free energy. The presence of this relationship has been implicitly verified for asphalt materials in the past. This implicit verification lies in the fact that ARC as well as other researchers have found consistent agreement between predictions based on models that rely on surface free energy (ideal work of fracture) and expected performance, despite the large difference in magnitudes of ideal and practical work of fracture. In fact, the work element of F1a was specifically designed by ARC researchers to formally determine this relationship for asphalt materials as described in the year 1 and year 2 work plans. The aforementioned findings were documented in the form of a white paper.

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

None.

<u>Work Planned Next Quarter</u>

The literature review will be continued to address the aforementioned issue as well as other topics of relevance to this task such as experimental and analytical methods to determine the work of cohesion or adhesion using mechanical tests, sources of differences between thermodynamic work of adhesion or cohesion and mechanical work of adhesion or cohesion, methods to account for these differences, and on the acid-base scale to determine the surface free energy components of asphalt binders and aggregates.

Subtask F1a-2: Develop Experiment Design (TAMU)

<u>Work Done This Quarter</u>

The development of a detailed experiment design is subject to finalization of feasible test configuration that can provide the required inputs with reasonable precision and accuracy. This is being addressed in task F1a-4.

<u>Significant Results</u>

None.

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

None.

<u>Work Planned Next Quarter</u>

A detailed experiment design will be developed following the completion of some preliminary tests being conducted in F1a-4.

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

<u>Work Done This Quarter</u>

No activity this quarter.

<u>Significant Results</u>

None.

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

None.

<u>Work Planned Next Quarter</u>

Most work elements in the ARC research are in a method development stage and utilize limited materials with known properties. It is envisaged that surface energy measurements under this task will be continually measured for: (i) core asphalt binders (after these are finalized and procured), and (ii) additional asphalt binders that are included in other work elements that require surface energy measurement as a material property input.

Subtask F1a-4: Mechanical Work of Adhesion and Cohesion

Work Done This Quarter

The two main objectives of this task are, i) to establish the relationship between practical work of adhesion or cohesion with ideal work of adhesion or cohesion, respectively and ii) to generate basic inputs such as the traction-separation behavior between binder/mastic-aggregate interface for inputs in the modeling effort. Preliminary tests on thin films subjected to transverse tension were conducted in this quarter. Tests have been conducted with films 50 micron to 0.5 micron in thickness. The tests were conducted with films prepared over a metal substrate instead of an aggregate. This is because a metal is a high energy surface similar to aggregates and it can be used to prepare control surfaces with a very high degree of uniformity. The use of aggregate substrates will be added at a later stage. The preliminary tests are being used to establish the precision and accuracy of this test method.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Tests will be continued on dry specimens in the direct transverse tension mode. A few tests will also be conducted after moisture conditioning the specimens for different durations of time. Fixtures for a T-peel geometry will also be fabricated and used for the tension tests.

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

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 F1b: Viscoelastic Properties (Year 1 start)

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

Work Done This Quarter

Fine aggregate matrix (FAM) specimens using different materials were testing using the Dynamic Mechanical Analyzer (DMA). The results are currently being analyzed based on the approach described in the previous quarterly report to:

i. identify the limiting stress of 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.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

To complete analysis of the available test data on limited materials to determine the three parameters described above.

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

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Same as F1b-1.

Work Element F1c: Aging

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

Work Done This Quarter

Review of oxidative aging has continued during this quarter. Of particular interest have been previous models for calculating pavement temperatures as a function of time and depth. Also reviewed have been data and models for the fast rate (initial jump) region of binder oxidation kinetics. Both of these issues are important to calculating estimates of binder oxidation in pavements and thus calculating changes to binder rheology as a function of time and position in the pavement as a critical issue to modeling pavement performance.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Review of previous work will be an ongoing effort.

Subtask F1c-2: Develop Experimental Design (TAMU)

Work Done This Quarter

In this quarter, experimental design continued with consideration of the data required to enhance and further develop the aging models and the subsequent mixture fatigue resistance predictions. Factors to be added or enhanced to models used in previous projects include the primary factors that account for the shift between laboratory and field fatigue resistance. These include healing, anisotropy, and aging.

In addition, field sections utilized in previous projects were considered for further monitoring to build on the data collected to date.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The planned activity for the next quarter is to continue the experimental design, specifically estimating quantities of component SHRP MRL materials (3 binders and 1 aggregate), procuring materials, and commencing specimen fabrication for the extensive laboratory mixed – laboratory compacted experiment. This experiment will provide data for the theoretical development of the aging models and the subsequent mixture fatigue resistance predictions.

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

Work Done This Quarter

Significant progress has been made this quarter on improving our ability to model pavement temperature as a function of depth. The model calculations were compared to LTPP pavement temperature measurements as a function of time and depth over an entire year. Comparisons of the calculations to recent literature models show significant improvements.

The model that has been developed is a semi-infinite slab heat conduction model with a calculated time-dependent heat flux boundary condition at the pavement surface (based on available weather and solar radiation data) and a condition that at a sufficient depth into the pavement the heat flux is independent of depth. The detail and implementation of these boundary conditions is different from prior heat conduction models and is responsible for very significant improvements to the temperature predictions.

To elaborate on the boundary conditions, the surface heat flux condition is calculated using hourly solar radiation data (available from the National Solar Radiation Data Base) and hourly wind speed and air temperature (interpolated hourly values based on data available from the National Climatic Data Center). The condition that the heat flux well into the pavement depth be depth independent provides excellent results and avoids having to specify the temperature at a specific depth.

Pavement properties have been estimated using parameter estimation techniques that compare measured temperature to the model calculations. Parameters have been estimated for a number of LTPP pavement sites nationwide and include longwave emissivity, longwave absorption coefficient, albedo, thermal diffusivity, and convective heat transfer coefficient parameters. Sensitivity analyses of these parameters also have been conducted.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Work in the next quarter will focus on non-dimensionalizing the oxygen transport model of pavement binder oxidation (reported in detail last quarter) and conducting representative calculations. Work will also proceed on the issue of plans for validating the model with field measurements of binder oxidation and hardening.

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

Work Done This Quarter

This quarter 16 cores from the Arizona WRI field validation site were received.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

As the expanded mixture testing protocol for prismatic specimens cut from pavement cores is finalized (Work Element F2c), measurement of mixture properties and extracted binder properties (at the end of the protocol) 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. Emphasis of the literature review was to identify the various fracture and crack growth models that are used for asphalt materials. The motivation of this review was determine a mechanism to integrate the healing and crack growth model. Another emphasis of the literature review was to determine methods (experimental or analytical) to determine the two remaining unknowns in the healing model that was proposed earlier. These are the maximum healing zone and the bonding stress across the interface.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Researchers will continue the literature review in the area of healing with emphasis on areas other than bituminous materials.

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

Work Done This Quarter

The use of molecular modeling techniques was investigated to identify key material properties that govern the healing process in asphalt binders. Molecular modeling has two benefits; (i) it allows the researchers to determine intrinsic material properties that significantly affect the healing process thus enabling a more targeted selection of materials for further tests and experiments, and (ii) it allows the verification of the hypothesis for healing mechanism which is the basis of analytical modeling.

Significant Results

A brief summary of the progress from the two molecular modeling studies that were conducted this quarter are:

i. The rank order of measured surface free energy of three SHRP binders was found to be the same as the surface free energy determined using molecular modeling techniques. The latter was achieved using average NMR based molecular structure for the selected binders from previous SHRP studies. This helps validate the applicability of the molecular modeling approach to conduct parametric analysis and verify the mechanisms that are responsible for healing in asphalt binders.

ii. The effect of molecular morphology on the surface free energy and self diffusion characteristics of asphalt binders was evaluated based on a parametric study. Results from this parametric analysis were consistent with results obtained in a previous study (Kim et al, 1990) that indicated that molecules with longer chains and fewer branches will have better healing properties.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The findings from this initial molecular modeling study will be documented in a detailed report. The modeling efforts will be continued to include more number of asphalt binders or molecular morphology parameters. A procedure will be developed to identify asphalt binders that have the required molecular morphology for inclusion in a detailed experiment design.

Cited Reference:

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

The literature review conducted in task F1d-1 and the material properties measured in F1d-3 will be used to develop a detailed experiment design for this work element.

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 simple test method based on the use of a DSR was developed to determine the intrinsic healing function of the asphalt binder. This test method is currently being refined based on some of the inputs received during the ETG meetings. A literature review to identify other test methods is in progress.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Continue the development of the DSR as a simplistic test method to obtain intrinsic healing properties. It is important to recognize that the parameter extracted using the DSR in this approach is normalized (results from a two part specimen are normalized with the values from a single specimen) and is therefore largely independent of the mode of loading. We will also evaluate the feasibility of using an ultra high resolution CT or MRI to determine the change in density gradient across surfaces that heal over time in order to obtain and independently verify the intrinsic healing function.

Subtask F1d-5: Testing of Materials (TAMU)

Work Done This Quarter

Testing of different asphalt binders using the DSR was continued in this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

We plan to continue testing of different asphalt binders using the DSR to obtain the intrinsic healing function as well as measurement of surface energy for the selected materials.

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

Work Done This Quarter

Three binders were tested this quarter using one established method for evaluation of asphalt healing. Previous work performed at Texas Transportation Institute by Yong-Rak Kim, D.N. Little and R.L. Lytton (2002) used fine aggregate matrix (FAM) cylinders to investigate the effect of rest periods on the fatigue life of the material as tested in the DMA. At UW-Madison, the research has focused on the testing of asphalt binder alone, using the 8-mm parallel plate set-up in the DSR.

The three materials are all derived from one base binder, a PG 64-22 provided by Flint Hills Resources. The neat binder was blended with two separate polymers to create two modified binders, one with 3% L-SBS (Kraton 1101) and one with 2% Elvaloy (with 0.17% PPA added to help accelerate the reaction between the polymer and the asphalt). All materials (neat, SBS-modified and Elvaloy-modified binders) were RTFO- and PAV-aged, with the PAV material tested this quarter.

Similar to the procedures described in the ARC quarterly progress report for Q4 2007, time sweep testing in the DSR was used to evaluate the materials. However, replicate runs were used for the "control" time sweep without rest periods, which allowed average values to be used for the durations of the intervals corresponding to a 5% reduction in stiffness. These intervals were then used to locate the rest periods for healing evaluation. The same process was used to locate the single 50-minute rest period at 45% modulus reduction for the 1 RP tests.

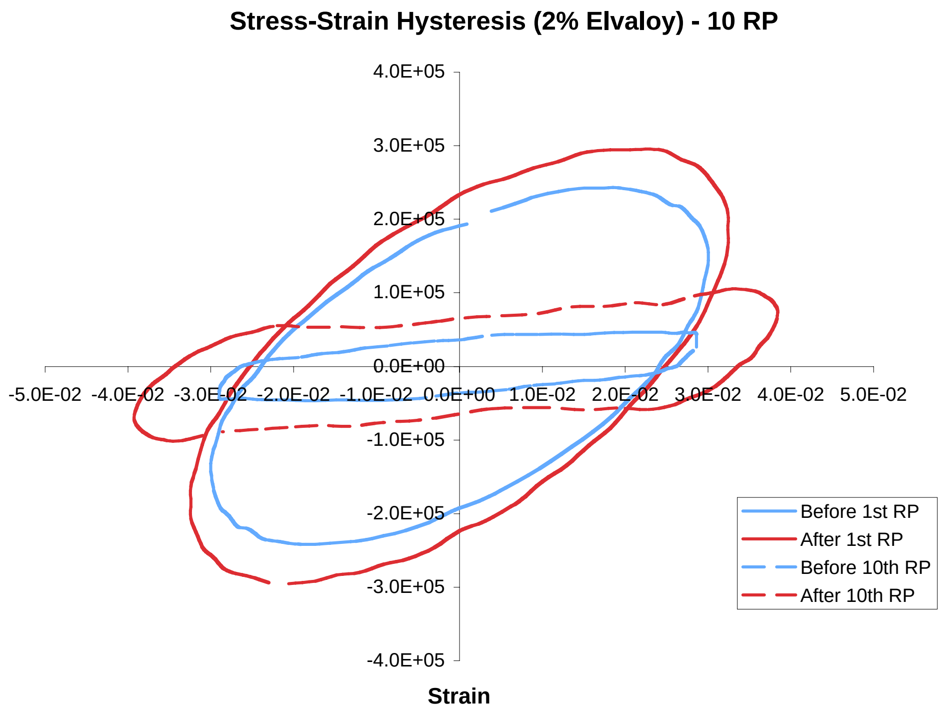
Significant Results

Table F1d-6.1 shows the preliminary results from evaluating the single binder as modified with two different modifiers. The table lists the change in dissipated energy (W_i) before and after rest periods when binders are tested in the DSR using cyclic loading at 10 Hz.

The Elvaloy-modified binder appears to show greater overall resistance to damage at this point, while the L-SBS shows greater ability to heal, shown primarily before and after a single 50-minute rest period. The dissipated energy plots for the Elvaloy-modified and the L-SBS modified binders are shown in figure F1d-6.1. However, more base binders need to be included in the experiment in order to draw any significant conclusions.

Table F1d-6.1. Evaluation of effect of rest periods on fatigue of a binder with two different modifiers. (RP = rest period, W_i = energy dissipated per cycle.)

FLINT HILLS 64-22		**Neat**		**3% SBS**		**2% Elvaloy**	
Test Conditions		**W_i [Pa]**	**% Increase**	**W_i [Pa]**	**% Increase**	**W_i [Pa]**	**% Increase**
10 RPs	Before 1st RP	23,093		13,659		17,596	
	After 1st RP	31,209	35.14%	19,843	45.27%	23,133	31.47%
	Before 10th RP	11,084		448		3,498	
	After 10th RP	12,553	13.25%	916	104.8%	8,817	152.0%
1 RP	Before RP	7,645		1,704		5,827	
	After RP	11,868	55.24%	33,789	1883%	19,156	228.7%



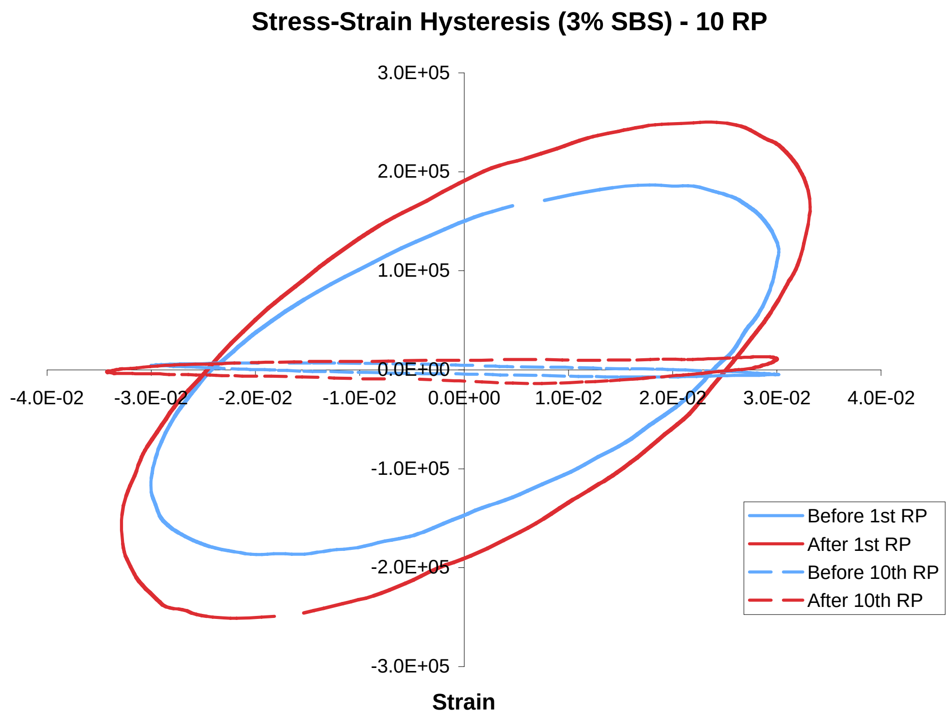


Figure F1d-6.1. Graphs. Dissipated energy before and after rest periods for Elvaloy modified binder (top) and L-SBS modified binder (bottom).

Significant Problems, Issues and Potential Impact on Progress

The time sweep test being employed has a history of poor repeatability, and the healing tests in this subtask are showing the same problem. A more repeatable method needs to be investigated, and the first direction would be to look at the sample preparation procedure to ensure good adhesion. Also, the use of mastic or the FAM cylinders mentioned above will be investigated.

Also, applying a repeated loading in the DSR that is not sinusoidal is proving to be difficult. For example, repeated loading on mixture specimens typically uses a haversine waveform with a 0.1 s load pulse followed by a 0.9 s rest period. The research team at UW-Madison is currently corresponding with TA Instruments to work towards a solution, but other manufacturers may need to be contacted in order to address this issue.

Work Planned Next Quarter

The focus next quarter will be on completing the following subtasks as proposed in the Year 2 Work Plan:

1. Develop protocols from literature on mixture healing and apply to asphalt binders
2. Evaluate testing protocols and develop an efficient testing procedure

For these tasks, three additional binders will be evaluated using the test method described previously. Also, depending on the repeatability of the results, mastic/FAM testing along with the use of additional procedures will be pursued.

Cited References

Kim, Yong-Rak, Dallas 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, Vol. 71, pp. 176-206.

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

Work Done This Quarter

The work plan for this subtask is to be developed at the start of Year 2 beginning April 1, 2008.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Develop work plan for review.

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

Work Done This Quarter

No activity this quarter.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

In the previous quarter we developed a framework to model the healing phenomenon with explicit relationships for the wetting and intrinsic healing function and a test method to determine parameters for the latter. In the next quarter we will focus on development of test and/or analytical methods to determine the two remaining unknowns for this model, the wetting length and bond stresses.

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

Work Done This Quarter

The team discovered that sample size has a great effect on the changes in rheological properties of PPA modified binders during storage at 135°C. In order to better understand this effect, the team decided to test several variables such as oven type (natural convection versus forced convection), position in the natural convection oven (temperature in this oven was found to vary by as much as 15°C with the position of the sample in the oven), sample size (small—20 g versus large—over 300g), and binder type (two neat binders from different sources were used: A5 and FH).

Binders were tested neat and modified with 1% PPA(105) by weight. Both modified and unmodified binders were subjected to up to 72 hours of storage at 135°C in either the natural or the forced convection oven. This allowed the team to gauge the temperature susceptibility of the PPA modified binder. It also brought to attention that sample size is very important when dealing with PPA modified binders.

Significant Results

The most significant finding of the work performed during this quarter is that sample size plays a big role in the changes in rheological properties of PPA modified binders in response to storage at high temperature for up to 72 hours. Differences in G*/sinδ measured after various storage times are shown for a small sample (figure F2a.1) compared to a large sample (figure F2a.2).

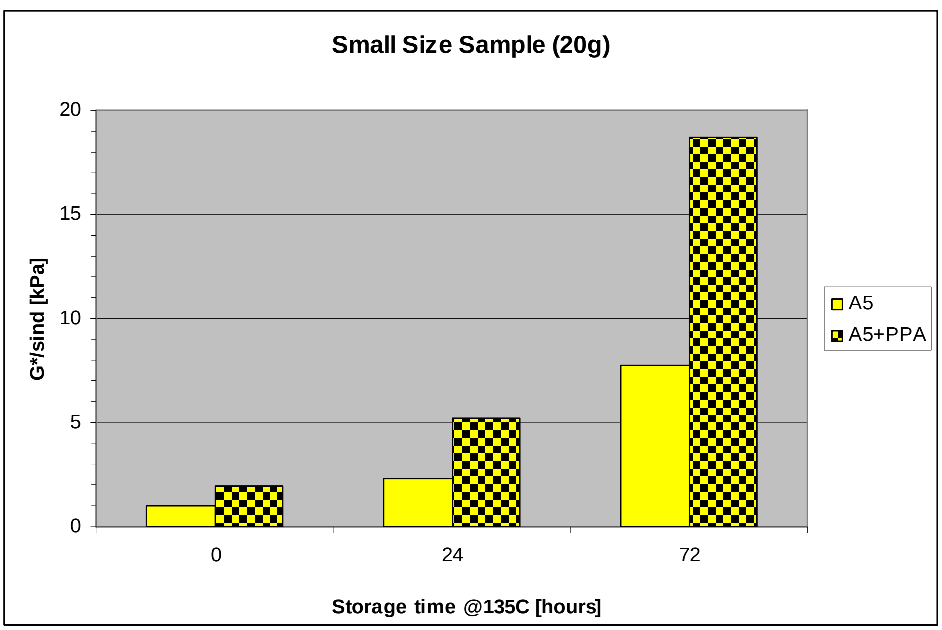


Figure F2a.1. Graph. Sample size effect on stiffness shown for a small sample.

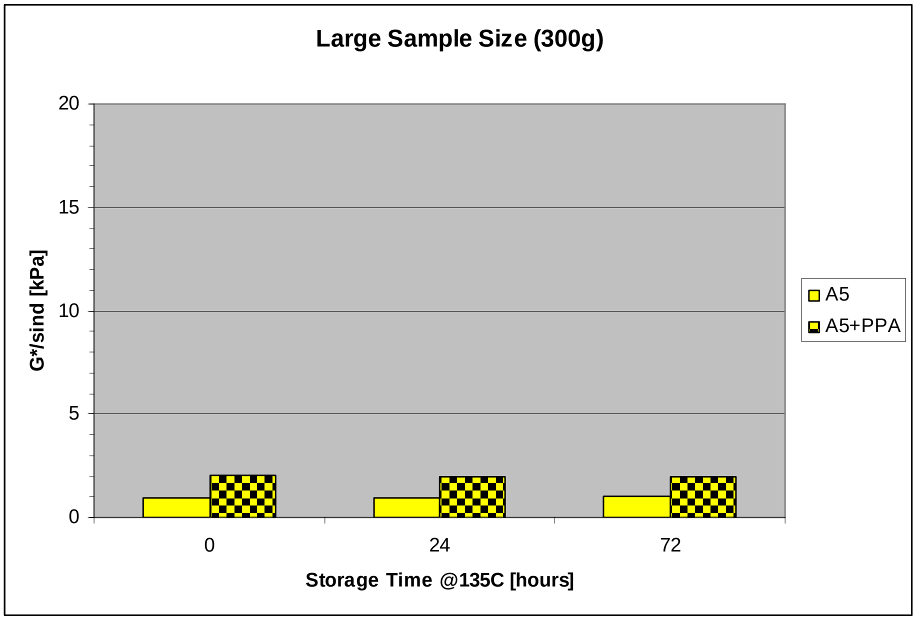


Figure F2a.2. Graph. Sample size effect on stiffness shown for a large sample.

As shown in figure F2a.1, storing the PPA modified binder in a small sized sample (20 g) in an oven at 135 °C results in a very significant increase in G* that amounts to more than 18 times the original neat binder and more than 8 times the initial G* of the PPA modified binder after 72 hours. It is noted, however, that in the case of the large sample, there is no noticeable storage time effect on the G* of either PPA modified or unmodified binder (figure F2a.2). In the case of the small sample size, it is clear that the PPA modified binder is far more susceptible to storage at high temperature than the unmodified binder.

The storage temperature effect can be observed by looking at the sample placement in the natural convection oven (the front of the oven is 15 °C lower than the middle and 10 °C lower than the back of the oven). This is illustrated in figure F2a.3.

It appears that the middle and back of the oven yield similar results. The front of the oven, which is cooler that the back or the middle, shows a slower initial increase in stiffness (24 hours) but after 72 hours of storage it ends up being significantly stiffer that the other two. This behavior could be explained by the "skin" formation that is observed for the samples placed in the back and middle of the oven, while no "skin" formation was observed for the sample in the front after 24 hours. It is noted that all PPA modified samples exhibited skin formation after 72 hours.

The oven used for the storage experiment has also an effect on the results. Figure F2a.4 clearly shows that the forced convection oven does not age the binder (the stiffness does not increase with storage time) as much as the natural convection oven. The team believes that this is related both to the way the two types of ovens control the temperature and to the position of the feedback thermocouple in the oven. The forced convection oven has a more uniform temperature distribution inside the chamber due to a quicker, better feedback loop. Regardless of the oven used, it is also clear that the PPA modified binders are very susceptible to storage at high temperature in small sample sizes.

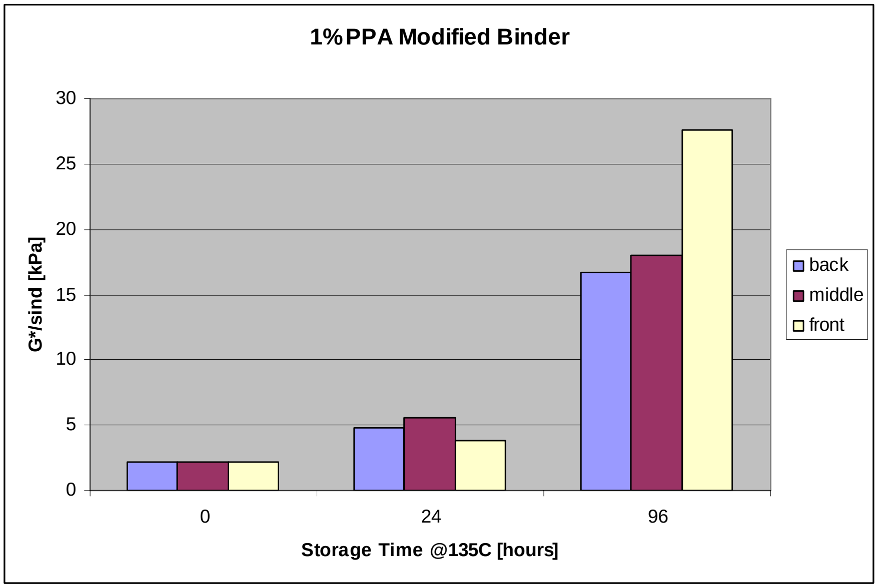


Figure F2a.3. Graph. Oven position effect on stiffness.

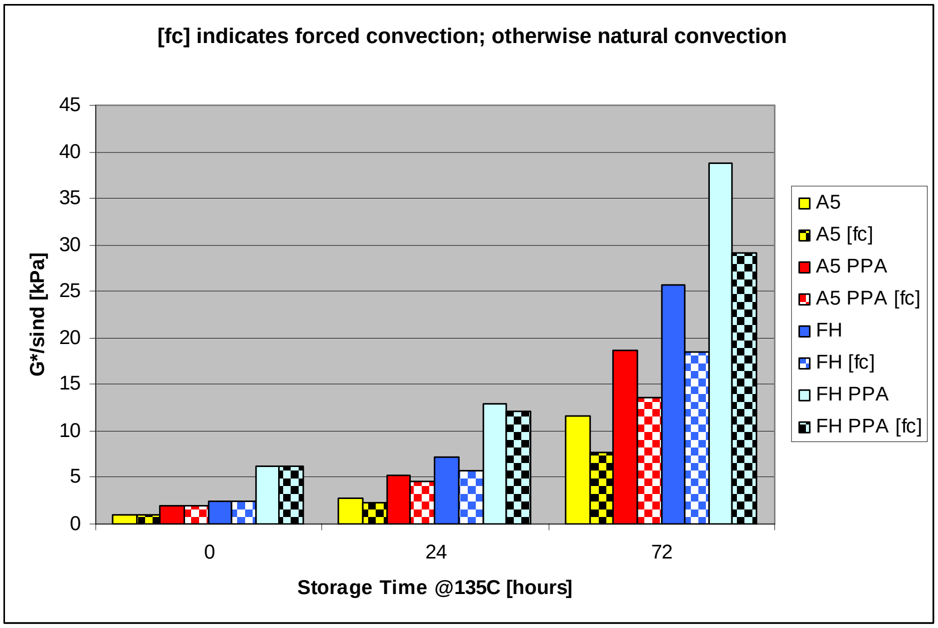


Figure F2a.4. Graph. Effect of oven type (forced versus natural convection) on stiffness.

Significant Problems, Issues and Potential Impact on Progress

The sample size used in this experiment has a significant effect on the results. Also, it appears that temperature variation in the oven can have significant role in defining the final change in properties. Following these findings, all of the consequent testing will be performed using large sample sizes and a forced convection oven for the long term storage experiments.

Work Planned Next Quarter

The team will follow the testing matrix proposed in the Year 2 Work Plan. All testing will be performed on large sample sizes.

Work Element F2b: Mastic Testing Protocol (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 will coordinate with Advanced Asphalt Technologies in the technology development area for the further development of the test method to determine properties of the FAM using the DMA.

Work Element F2c: Mixture Testing Protocol (TAMU)

Work Done This Quarter

In this quarter, the calibrated mechanistic with surface energy (CMSE) fatigue analysis approach utilized in previous TxDOT Projects 0-4468 Evaluate the Fatigue Resistance of Rut Resistant Mixes and 0-4688 Development of a Long Term Durability Specification for Modified Asphalt was updated to separate the different mechanisms of energy dissipation during fatigue cracking analogous to the DMA fatigue analysis of mastics. Dummy laboratory mixed – laboratory compacted (LMLC) specimens were tested, and data were analyzed with the older CMSE analysis techniques and the updated techniques that separate the effects of apparent stiffness and phase angle changes due to cracking and permanent deformation.

In addition to the CMSE approach, the output from the fatigue tests is also being analyzed using an approach similar to the one used for the FAM tested with the DMA (F2b-1 and F1b-1). The resulting parameter from this approach, that is the crack growth index, will also be explored for use as a measure of fatigue resistance. These two approaches differ slightly in the way fatigue life is quantified whereas the test requirements for both these approaches are similar.

In addition, development of a mixture testing protocol for prismatic specimens cut from pavement cores began. 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

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

In the next quarter, the expanded mixture testing protocol for prismatic specimens cut from pavement cores will be finalized using dummy specimens. Planned additions to the protocol include: (1) dynamic modulus testing and measurement of Poisson's ratio at multiple frequencies, (2) healing assessment during repeated direct tension testing, and (3) anisotropic evaluation.

Work Element F2d: Tomography and Microstructural Characterization (TAMU)

Work Done This Quarter

Fabrication of a micro-scale loading frame was completed. This loading frame will be used to conduct fatigue, relaxation and healing tests on thin films of asphalt binders on thin elastic glass substrates. Preliminary tests were conducted using this loading frame. There are some adjustments that need to be made to the loading frame trigger the formation of fatigue cracks in the thin film. The change in morphology and mechanical characteristics of the asphalt binder film due to fatigue cracking, relaxation, and healing will be monitored using an AFM.

It is important to emphasize that the use of an AFM in this subtask is not to understand the origin and nature of different morphological characteristics in asphalt binders (that is addressed in other work elements), but to determine the mechanical and viscoelastic properties of different phases and the relationship of these properties to damage. In this connection, a detailed literature review to measure the elastic modulus and phase angle of different phases in a soft material (such as asphalt binder) using an AFM is underway.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The plan for the next quarter is to complete the detailed literature review on the measurement of the elastic properties and phase angle using the AFM. Some more preliminary tests will also be conducted using the thin film cyclic loading device.

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

Work Done This Quarter

In this quarter, the UW research team continued to work on the fatigue characterization of asphalt binders based on viscoelastic continuum damage mechanics. In addition, the team attempted to develop a draft specification on fatigue of asphalt binders, based on the FHWA ALF binders.

Significant Results

Previously the team found that the monotonic test, or binder yield energy test (BYET), has great potential to characterize and predict the fatigue behaviors of asphalt binders. The yield energy from BYET correlated well with the field performance. Efforts were attempted to link the material properties from BYET to those from fatigue tests, either from time sweep (constant strain or constant stress) or stress sweep tests.

In this quarter, the properties from BYET were used to simulate the fatigue behaviors of asphalt binder in time sweep test, based on the viscoelastic continuum damage mechanics (VECD) (Kutay 2007). The simulation consists of these steps: (1) obtain the regression coefficients of the C (material integrity) and S (damage intensity) curve from BYET; (2) calculate C in the time sweep domain; (3) calculate S in the time sweep domain; and (4) calculate the complex modulus in the time sweep domain. In addition, a closed-form solution developed by Kim et al., was used to predict the fatigue life of asphalt binder in the time sweep test, as shown in equation F2e.1 (Lee 2000). The fatigue life of binder from simulation and the closed-form solution were compared to the measured fatigue life (50% reduction of complex modulus).

$$N_f = \frac{fS^p}{p(0.5C_{11}C_{12})^\alpha}(G^*\varepsilon_0)^{-2\alpha} \qquad \text{(F2e.1)}$$

Where f = frequency,
G^* = complex modulus,
$P = 1+(1-C_{12})\alpha$,
C_{11}, C_{12} = regression coefficients of C and S curve, and
α = a constant related to the slope of relaxation modulus.

As shown in figure F2e.1, there is a close agreement of fatigue life between simulation and closed-form solution. However, some discrepancies exist between the predicted and measured fatigue life (figure F2e.1) and fatigue behaviors (figure F2e.2). It is believed that plasticity plays a significant role and viscoelastoplasticity continuum damage mechanics should be used.

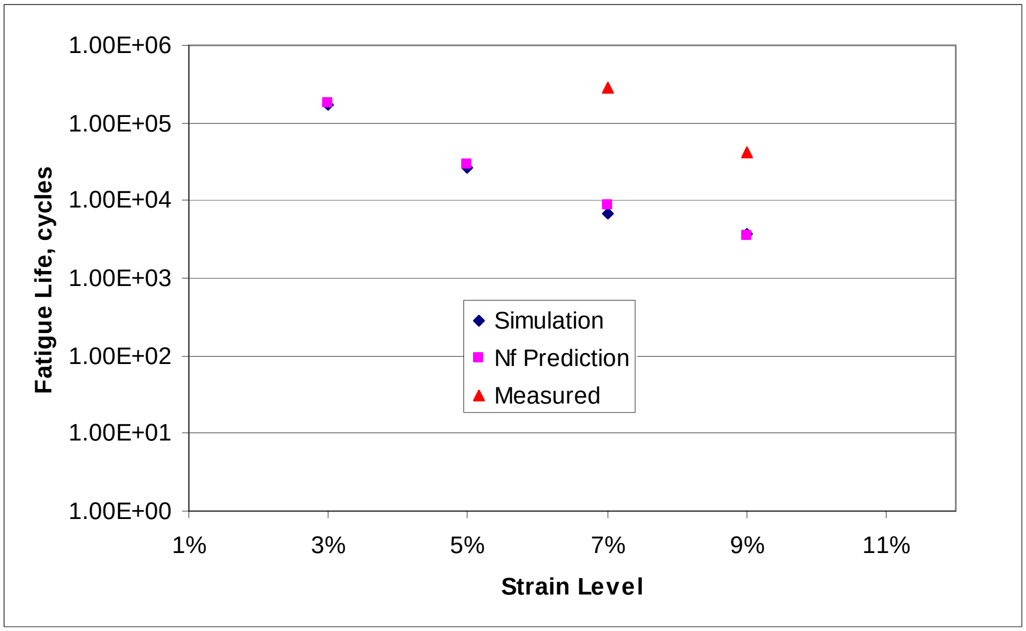


Figure F2e.1. Graph. Measured vs. predicted fatigue life of asphalt binder.

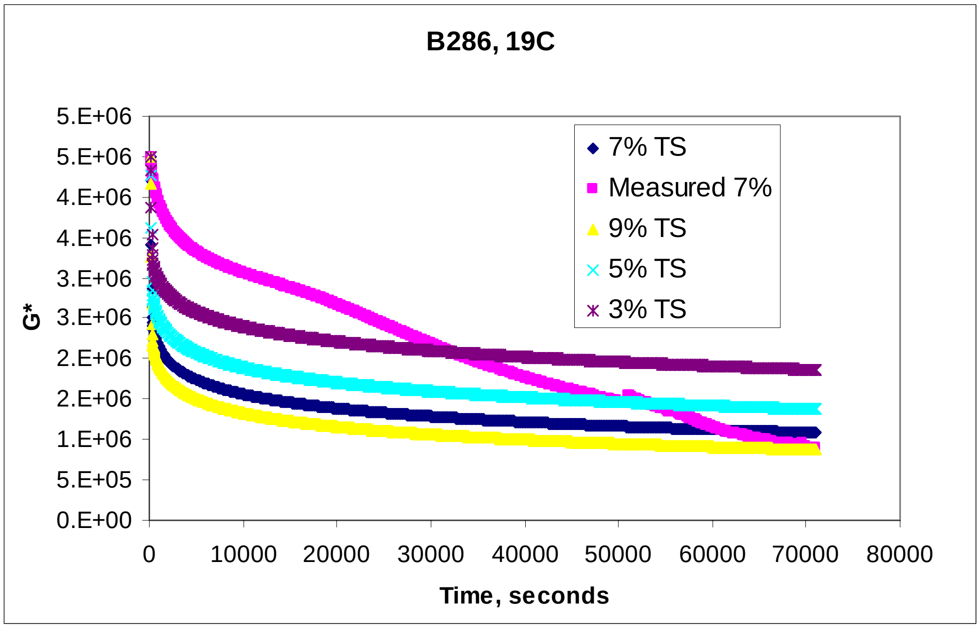


Figure F2e.2. Graph. Measured vs. simulated complex modulus.

By representing the terms *C* and *S* with *M* (for material integrity) and *D* (for damage intensity), *M(D)* plots were generated to compare the results from BYET with those from stress sweep testing. Initially, it was apparent that the values of *D* calculated for the stress sweep data were significantly smaller that those calculated for the monotonic shear test. By shifting the stress sweep *D* values by eight to ten orders of magnitude, the plots could be compared within the same general domain. Some binders have shown good comparisons between the two tests, as shown in figure F2e.3, while others, namely the polymer-modified binders, have not.

Also during this quarter, seven binders were evaluated for yield energy for comparison to the ALF binders that have already been tested. ALF binder testing occurred at 19°C, approximately 8 °C below the PG-specified intermediate temperature for various binders. Therefore, intermediate temperature minus 8 °C (IT-8) was used for the seven additional values in order to obtain similar stiffness conditions. The yield energy for the seven binders tested and the ALF binders previously tested is plotted in figure F2e.4. This preliminary investigation has shown that the BYET is able to distinguish between different materials at approximately the same stiffness level. Work will continue on this investigation in order to develop a database of values for various binders, with a focus on materials that are currently being monitored for field performance.

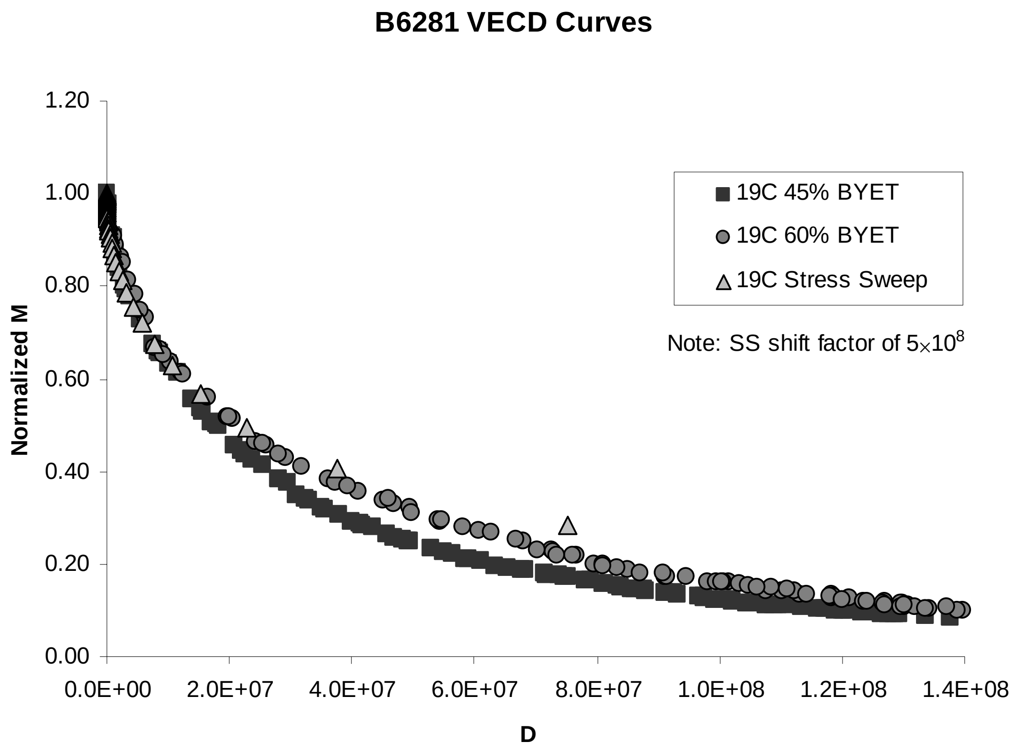


Figure F2e.3. Graph. Material integrity (M) and damage intensity (D) from BYET and stress sweep tests.

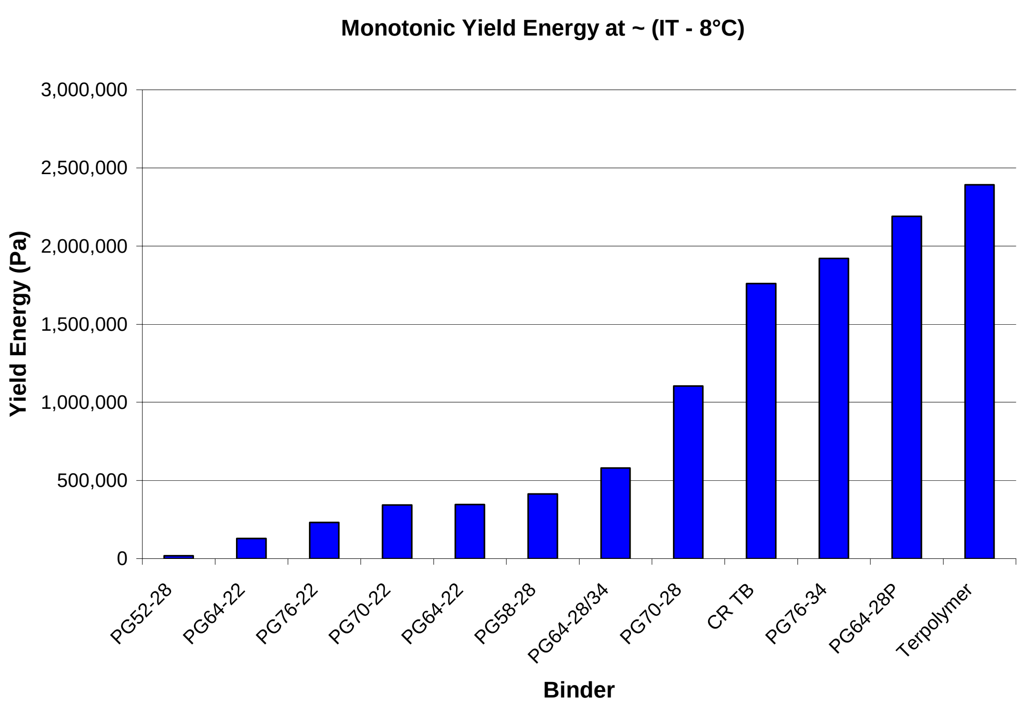


Figure F2e.4. Graph. Evaluation of binder yield energy.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The issue of phase angle during the time sweep test will be investigated, as it is believed that the change of phase angle plays a role in characterizing fatigue. Viscoelastoplasticity continuum damage mechanics will be investigated. The issue of uneven stress distribution in parallel-plate DSR will be investigated by using the cone-plate geometry to perform BYET. The stress response under constant shear loading will be compared to the data collected using parallel plate geometry to see if there is an effect of uneven stress distribution within the binder specimens.

Cited References

Kutay, M. E., N. Gibson, and J. Youtcheff, 2007, "Conventional and Viscoelastic Continuum Damage (VECD) based Fatigue Analysis of Polymer Modified Asphalt Pavements," paper accepted for publication and presentation at 2008 AAPT Meeting, Philadelphia, Pennsylvania.

Lee, H. J., J. S. Daniel, and Y. R. Kim, 2000, Continuum Damage Mechanics-Based Fatigue Model of Asphalt Concrete. *Journal of Materials in Civil Engineering*, Vol. 12, No. 2, May, 2000.

CATEGORY F3: MODELING

Work Element F3a: Asphalt Microstructural Model

Work Done This Quarter

The work plan for this subtask is to be developed at the start of Year 2 beginning April 1, 2008.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Develop work plan for review.

Work Element F3b: Micromechanics Model

Subtask F3b-1: Model Development

Work Done This Quarter

A summary of the activities conducted by the researchers at the University of Nebraska during this quarter are as follows:

- Continued the review of literature related to the micromechanics-based computational modeling techniques and the cohesive zone modeling approaches;
- Discussed with researchers at the lead university (Texas A&M University) in order to determine materials to be considered for the model development stage;
- Studied the representative volume elements (RVE) of asphalt mixtures to facilitate the computational modeling within the micromechanics concept; and
- Initiated testing programs to obtain key material properties for the micromechanics-based computational modeling.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The planned activities for the next quarter are

- Continue literature review;
- Complete testing facility set-up and experimental design;
- Perform laboratory tests to obtain key model parameters;
- Complete RVE study of asphalt microstructure without considering damage; and
- Present research outcomes and draft journal articles.

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

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 F3c: Development of Unified Continuum Model

Work Done This Quarter

The research group at NCSU has completed integrating various software components related to multi-scale lattice modeling procedure. The resulting seamless software package requires minimal intervention from the user and can virtually fabricate the microstructure at various scales as well as perform lattice modeling at these scales, eventually resulting in the macroscopic stress-strain relationships and micro-structural images of failed (virtual) specimens. In addition, as the first step towards developing an integrated model transitioning from continuum damage mechanics to fracture mechanics, the research group has initiated a detailed study of linking the VECD model to lattice micromechanical models.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The research group will continue to enhance the integrated lattice modeling software by increasing the efficiency by incorporating special algorithms. Research will also continue in the direction of developing qualitative and quantitative links between micromechanical and VECD models.

Work Element F3d: Calibration and Validation

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

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

A forward and inverse self-consistent micromechanics model of an asphalt-aggregate-air composite material was developed, programmed and applied to the analysis of the viscoelastic properties of mixtures. The results of the first analyses done with this method were presented at the ETG meeting in Tampa, Florida. The Inverse process takes as input the volumetric composition of the mixture and the measured frequency-dependent bulk and shear properties of a mixture and a binder and extracts from them the bulk and shear properties of the aggregate. The forward process takes as input the frequency-dependent bulk and shear properties of the aggregate and binder and produces the frequency-dependent properties of the mixture. It was demonstrated that the forward and inverse operations are in fact the inverse of each other. The aggregate properties thus inferred from the inverse analysis have been compared with the bulk and shear properties of unbound aggregate samples which were tested at high and low levels of bulk stress. The comparison showed that the inferred bulk and shear properties of the aggregate were considerably stiffer than were the measured stiffness of the mineral skeletons of the unbound aggregate samples. The inferred Young's modulus of the aggregate was about 1/3 of the stiffness of concrete and considerably stiffer than the mixture from which it was inferred. Thus far, the inverse analysis to determine the frequency-dependent aggregate properties appears to produce valid results. Frequency sweep tests of cores of the rock from which the aggregate was quarried are planned to further verify the validity of the inferred frequency-dependent properties of the aggregate. If this technique can be shown to give accurate results, it will be possible to catalog the properties of aggregate and use them in a computerized determination of the combinations of volumetrics, aggregates, and binders to produce the desired properties of mixtures.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Cores from the quarry from which a limestone aggregate were taken will be tested over a wide range of frequencies in the Petroleum Engineering laboratories at Texas A&M University to determine if the inverse-calculated frequency dependent properties of the rock are accurately determined. A second series of tests will be made in the Rapid Triaxial Test (RaTT) cell to determine the stress-dependent anisotropic properties of a mixture using different binders, different periods of aging and different temperatures. This series of tests will require more than the next quarter to complete but will be begun as soon as the first samples are molded. The important measurement that must be made accurately is that of the Poisson's Ratio which our analyses with the self-consistent micromechanics model have shown to be critical to the process of inverse analysis. We expect to use creep or relaxation tests to determine the time-dependent anisotropic properties of the mixture and use Laplace Transform to convert these properties into their frequency dependent forms. Unpublished work by Dr. Zach Grasley at Texas A&M has demonstrated that this method produces the most accurate measurement of the frequency-dependent Poisson's Ratio.

Work element E1b: Binder Damage Resistance Characterization (DRC)

Subtask E1b-1: Rutting of Asphalt Binders

Work Done This Quarter

The efforts in Q1 2008 were mainly preparatory in nature.

Data were collected for the cone-plate geometry and parallel plate geometry at various film thicknesses. It was shown that by reducing the film thickness in the parallel plate geometry to a value close to the average film thickness in the cone-plate, very similar creep results could be collected and the edge failure reported in the previous quarter could be totally eliminated.

It was also discovered that the creep-recovery behavior of binders at very high number of cycles is extremely sensitive to temperature equilibration and thermal history. It appears that non-linear behavior and tertiary flow of binders is affected by adhesion to the plate and, if this is not performed carefully, the variability of creep at high cycles could be very high. A summary of these effects and a brief report on the quality of creep data is being written.

A literature review on modeling and testing geometry was completed. This literature review was based on a search of existing data and published papers in this area, with a focus on studies that investigated the relationship between asphalt binder and mixture properties.

Nine asphalt binders were selected for evaluation. They are:

1. PG 76-XX SBS modified from Flint Hills PG 64-XX (76SBS-FH),
2. PG 76-XX Elvaloy modified from Flint Hills PG 64-XX (76EL-FH),
3. PG 70-XX SBS modified from Flint Hills PG 64-XX (70SBS-FH),
4. PG 70-XX Elvaloy modified from Flint Hills PG 64-XX (70EL-FH),
5. PG 64-XX Flint Hills neat (64UM-FH),
6. PG 64-XX Exxon Mobil unmodified (64UM-EM),
7. PG 64-XX SBS modified from Flint Hills PG 64-XX (64SBS-FH),
8. PG 58-XX neat SS (source to be determined) (58UM-SS), and
9. PG 58-XX SBS modified from SS PG 58-XX (58SBS-SS).

Three mineral fillers were selected. They are:

1. pulverized limestone,
2. granite, and
3. hydrated lime.

A preliminary work plan was developed. In this, the plans for further literature review, materials selection, and laboratory testing were detailed.

Significant Results

The evaluation of properties of asphalt mastic was added in the newly developed preliminary work plan. Since mineral filler is suspended in the asphalt binder in mastic, asphalt mastic can be considered the true binder in asphalt mixture. Therefore, it is hypothesized that the rheological properties of asphalt mastic may provide better correlation with the behavior of asphalt mixture than those of asphalt binder.

Significant Problems, Issues and Potential Impact on Progress

To date, no significant problems or issues have been encountered.

Work Planned Next Quarter

The review of literature will be expanded with an emphasis placed on searching international literature. Most recent development in evaluation methods for binder, mastic and mixture rutting will be documented. In addition, an attempt will be made to focus on worldwide publications in which relationships among binder, mastic and mixture behavior in rutting were studied.

The selection of materials and development of the work plan will continue. In addition, trial asphalt binder and mastic testing will begin.

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

This work element will move beyond the initial scoping tasks carried out during Year 1. Testing will begin in earnest starting in Year 2.

Significant Results

There were no significant advances during this quarter.

Significant Problems, Issues and Potential Impact on Progress

No problems encountered.

Work Planned Next Quarter

The following tasks are planned for the second quarter of 2008.

- The report on the literature review will be completed.
- Material selection and the experimental plan will be finalized.
- Nanoindentation tests on asphalt binders and mastics will begin.

Work element E1c: Warm and Cold Mixes

Subtask E1c-1: Warm Mixtures

Work Done This Quarter

After collecting warm mix additives for this project, the research team performed a quick study of the effect of mixing and compaction temperature on the workability of asphalt mixtures. The goal was to compare standard HMA practices and new low-energy practices with and without warm-mix additives.

The team started with the hypothesis that warm mix additives function by enabling the coating of aggregates at reduced mixing temperatures. Reduced compaction temperatures are then a side-effect of reduced mixing temperatures. Previous work done by Delgadillo, continued by Schmitt & Johnson, has shown that target densities are achievable at significantly lower temperatures. This was discovered for conventional HMA mixes in the absence of any warm mix additives. The experimental design used is shown in the table below:

Table E1c-1.1. Experimental design.

One aggregate blend	Cisler E-10, 19 mm
One neat asphalt binder	Citgo PG64-22
• Two additives	Advera Sasobit
• Two mixing/compaction temperatures o Only the control mix was mixed and compacted at high temperature	Control Mix @ 150 °C Compact @ 135 °C Experimental Mix @ 130 °C, Compact @ 110 °C
• One SGC pressure	300 kPa

In addition to the mixture testing, the team had a meeting with Mr. Gerald Reinke of Mathy construction, who introduced a new method for measuring the effect of warm mix additives by using the normal force in the DSR. The meeting resulted in identifying a protocol to measure normal force using a shear rate sweep in the DSR. The meeting also resulted in identifying a new hypothesis on warm mix additives in which wetting of aggregates at lower temperature is the main effect of warm mix additives, rather than the reduction in viscosity. It is speculated that the normal force measured in the DSR is an indirect measure of the surface tension, which in turn affects wetting ability of binders at a given viscosity. Initial experiments have started and the results are being analyzed. It is clear that film thickness has a great effect on normal force measured in the DSR. Using very thin films ranging between 0.05 mm and 0.150 mm is under investigation.

The research team also had a meeting with the UNR research team and Granite Construction engineers. Granite Construction has just set up one of their production facilities with a water spray system that is produced by AsTech. The system is based on foaming of binders just before mixing with aggregates. Several trials will be conducted, at which time the team from UNR will collect samples and send them to UW-Madison for testing. A joint working plan is being developed with UNR and Granite to evaluate this emulsification/foaming technology.

Based on the meeting and based on gathering cost information the research teams of UNR and UW will be looking into setting up a laboratory foaming device to simulate the process used by Granite to evaluate the effect on mixing and compaction temperatures. A detailed plan will be developed next month for discussion.

<u>Significant Results</u>

Some of the most important findings are as follows:

- Neat binders are sensitive to mixing temperature when 300 kPa is used in the SGC.
- Advera shows comparable performance to traditional HMA mixing and compaction practices at reduced temperatures.

The Advera additive shows a significant improvement on both CDI and TDI, compared to the neat binder compacted at higher temperature. On the other hand Sasobit seems to worsen both CDI and TDI indices. This could be due to the compaction temperature being right around the freezing temperature of the wax. Compaction at slightly higher temperatures could show a different trend.

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

No significant issues were encountered during this quarter.

<u>Work Planned Next Quarter</u>

This ongoing project will continue to evaluate the effect of compaction temperature on HMA both in the field and in the lab. All specimens were mixed at conventional temperatures. The team will also continue work on the mechanism that allows coating of aggregates at reduced temperatures in the presence of warm mix additives.

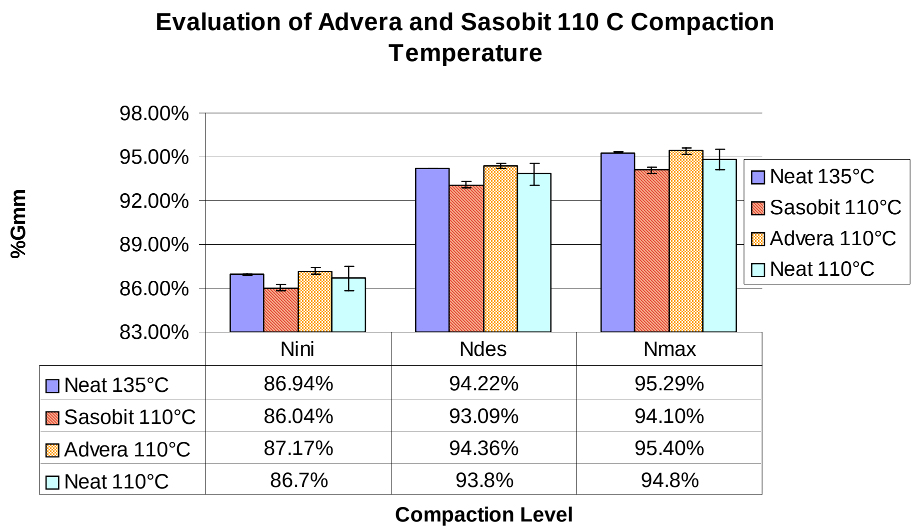
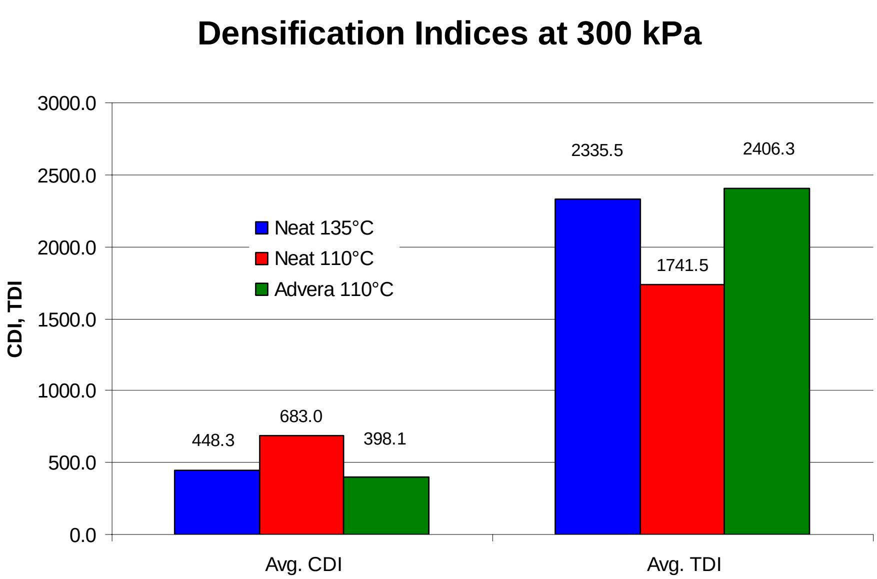


Figure E1c-1.1. Graph. Evaluation of compaction temperature for binders with and without additives.



Constructability*	
Mixture Type	*Maximum CDI*
E10	360
Traffic Resistance*	
Mixture Type	*Minimum TDI*
E10	1100
**Recommended for 600 kPa*	

Figure E1c-1.2. Graph. Evaluation of densification index for binders with and without additives.

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

<u>Work Done This Quarter</u>

UW focused this quarter on subtask activities i, ii, and iii as defined in the Year 2 Work Plan. The following is a progress update on these.

i. Review of National and International Standards for Emulsions, Aggregates, and Performance Evaluation of Cold Asphalt Applications

   The research team collected and reviewed literature and standards related to surface treatments. Specific focus was on the construction properties of emulsions, namely, viscosity, adhesion/cohesion, rate of breaking, and rate of setting. As part of the literature review for in-service properties of binder used in surface treatments, national and international standards for emulsified asphalt recovery were summarized. The literature review was used to identify a small selection of methods that seem most promising for use in this study.

   In collaboration with Dr. Kim Jenkins University of Stellenbosch, UW-Madison submitted a paper titled "Performance Grading of Bitumen Emulsions for Sprayed Seals." The paper was accepted with revision and will be finalized in the next quarter.

ii. Create an International Advisory Group for the Project

   The research team attended organized meetings with the following organizations to discuss the project and collaboration opportunities:

   - The National Center for Pavement Preservation (Gayle King)
   - SemMaterials
   - Asphalt Emulsion Manufacturers Association

   A draft list of organizations and potential names was developed and will be discussed April 4, 2008, with SemMaterials. The first meeting of the advisory group is tentatively scheduled for late May and will be held in Madison, Wisconsin.

iii. Identify Potential Performance Related Tests

   The research team reviewed and modified a procedure developed by Anton Kucharek of McAsphalt (2007). The procedure involves using a strain sweep after different time intervals (2, 4, 6, and 24 hours) to measure stiffness and strain tolerance and their time dependence. The procedure was modified to include consideration of the effect of surface mineralogy/chemistry on development of stiffness and strain tolerance as the emulsion sets. Tests were conducted using one emulsion (CRS-2) and two surfaces: granite and limestone. An emulsion of known weight was poured onto an enclosed surface of known area to ensure that constant film thickness was maintained. Film thickness for the testing was approximately 200 microns.

Significant Results

The strain sweep test was successful in showing both the development of stiffness and strain tolerance as the emulsion set. Figures E1c-2.1 and E1c-2.2 show examples of the test results.

Figure E1c-2.1 shows the development in stiffness and strain tolerance over time. The figure shows that the emulsion residue subjected to open air curing in the lab exhibits similar properties to the neat binder in terms of both stiffness and strain tolerance after 6 hours of curing. After 24 hours, there is not a discernible difference between the emulsion residue and the neat binder.

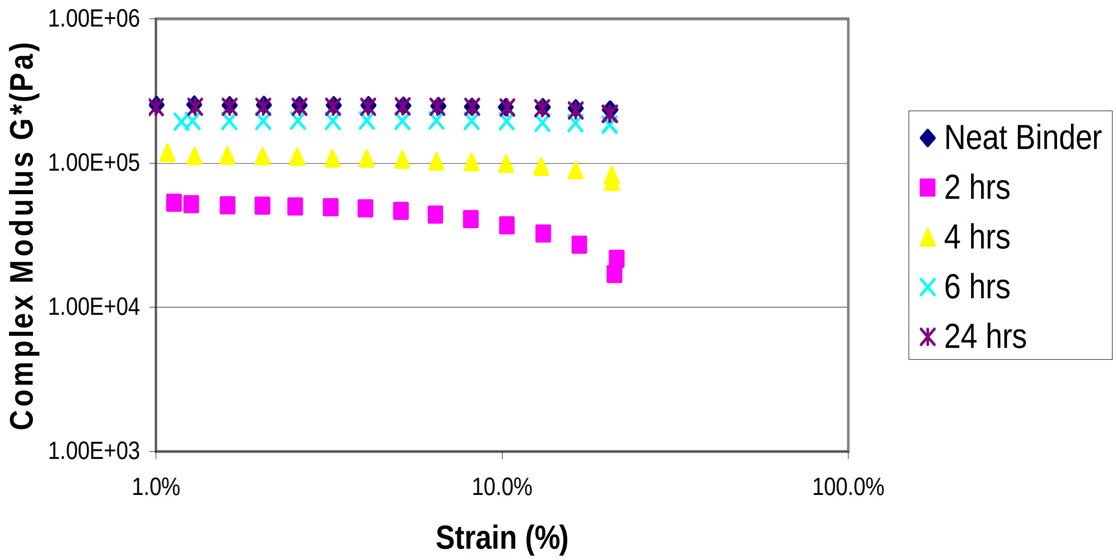


Figure E1c-2.1. Graph. Strain sweep results with granite substrate.
Tests were conducted at 20 ºC.

Figure E1c-2.2 compares granite and limestone surfaces in terms of stiffness and strain tolerance gain for a given time and compares them to the properties of the base binder. It clearly shows that curing on the limestone surface results in a much higher rate of strength gain relative to the granite surface. At the time of this report, data for 24 hour curing were not available.

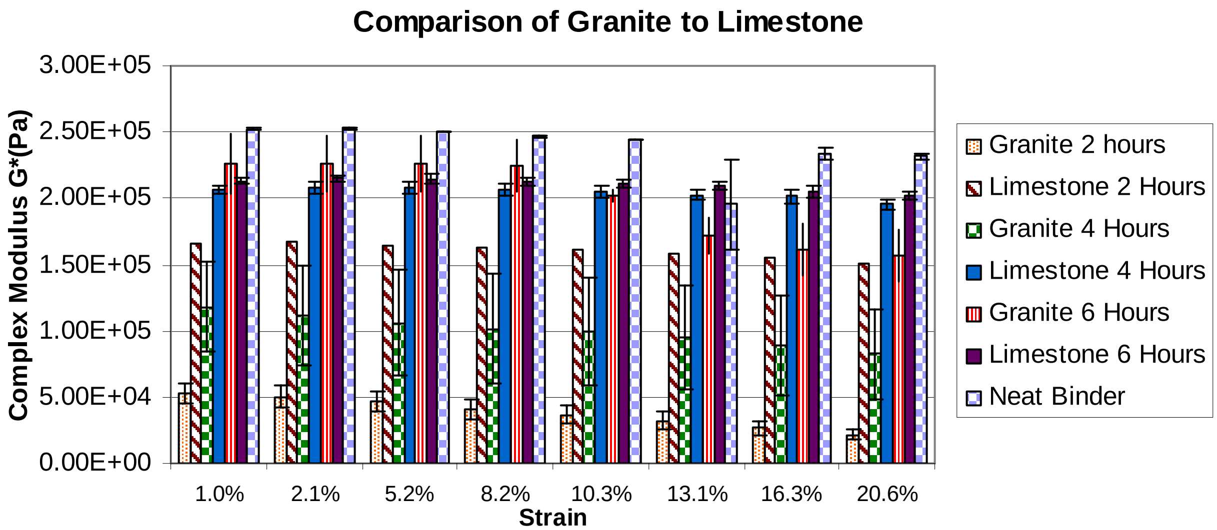


Figure E1c-2.2. Graph. Strain sweep results comparing emulsion setting on limestone and granite surfaces over time.

Significant Problems, Issues and Potential Impact on Progress

The strain sweep method described in activity iii above must be evaluated for repeatability. Thus far, variability is high at the 2- and 4-hour curing times, especially for the granite. A portion of this is due to the dynamic nature of the material as it is setting. The procedure must be refined to minimize the effects of all other sources of variability.

The difference in behavior between mineralogies must be explained. The results to date are the opposite of what was expected. The data were collected late in the quarter, so future efforts will be dedicated to explaining some of the trends.

The team needs to procure equipment for the ASTM D7000 sweep test, including an emulsion mill or local supplier and a fixture for the DSR to measure viscosity of the emulsion and its change over time.

Work Planned Next Quarter

i. UW will complete the literature and standards review and summarize it in a document for distribution to the advisory committee. The review will focus on surface treatments and include topics related to emulsions, performance, and aggregates.
ii. Advisory committee members will be identified, with the first meeting to be held in Madison, Wisconsin in late May.
iii. The team will develop a methodology for data analysis and evaluation criteria for strain sweep results. This will include evaluation of repeatability and strain tolerance.

The team will expand testing plan to include other types of emulsion in terms of modification, set time, and charge in order to evaluate the sensitivity of the test to emulsion type. Other performance-based tests of adhesion/cohesion (such as the tack test and the sweep test) will be conducted to examine correlation between strain sweep results and tests that quantify asphalt aggregate adhesion and binder cohesion.

Cited References

Kucharek, A., 2007, "Measuring the Curing Characteristics of Chip Sealing Emulsions." Presentation in the Joint ARRA-ISSA-AEMA Meeting, Bonita Springs, CA, 2007. Asphalt Emulsion Manufactures Association and McAsphalt, Scarborough, Ontario, 2007.

CATEGORY E2: DESIGN GUIDANCE

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

Work Done This Quarter

No activity this quarter. (Year 2 start)

Significant Results

N/A

Significant Problems, Issues and Potential Impact on Progress

N/A

Work Planned Next Quarter

Begin the work plan after approval of the AOTR.

Work element E2b: Design System for HMA Containing a High Percentage of RAP Material (Year 1 Start)

Cooperation Efforts

The ARC researchers are cooperating with the NCAT researchers on the impact of extraction methods on the properties of RAP aggregates. The NCAT researchers are conducting the same experiment as the UNR researchers on two aggregates sources from the eastern part of the US.

The RAP ETG has recommended the formation of a working group to work closely with the ARC researchers consisting of: Jon Epps, Gerry Huber, John D'Angelo, and Jim Musselman. The working group will meet with the ARC researchers prior to the meeting of the RAP ETG and go over the various activities with the ARC researchers in details that will not be feasible during the full ETG meeting. The group will be able to give their input on the research activities. A summary of the research and the group's input will be presented to the full RAP ETG.

Work Done This Quarter

The work on evaluating the impact of extraction technique on the properties of RAP aggregates started. The mix designs for two aggregate sources were completed: Nevada, andesite and California, granite. For each aggregate source a 12.5 mm nominal maximum aggregate size mix was designed with a PG64-22 binder following the Superpave volumetric mix design for a traffic level of 3-6 millions ESALs. Each mix will be long-term oven aged to simulate RAP mixtures. The properties of the aggregates from each mix will be evaluated before and after extraction through: reflux, centrifuge, and ignition oven.

RAP materials from South Carolina and Southern California were processed and their gradations were evaluated.

The evaluation of using the bending beam rheometer (BBR) to evaluate the properties of RAP-#8 mortars continued. During this quarter, the research concentrated on developing a sample preparation technique to obtain a smooth beam with the RAP-#8 mortar. The normal process of preparing BBR beams was insufficient when used with the RAP-#8 mortar. It was necessary to Teflon-coat the BBR sample molds in order to break the bond between the molds and the RAP-#8 mortar. Initial data showed that this technique significantly improved the quality of the prepared samples. The key elements of the testing procedure are to ensure that significant deformations are achieved in the beam sample without exceeding the capacity of the BBR machine and to conduct measurements that are sensitive to the properties of the RAP binder. In this respect, it is necessary to optimize the size of the beam and the amount of virgin binder to be mixed with the RAP-#8 mortar while keeping the RAP binder at a significant level.

Significant Results

During this quarter, the research concentrated on developing a sample preparation technique to obtain a smooth beam with the RAP-#8 mortar. The normal process of preparing BBR beams was insufficient when used with the RAP-#8 mortar. It was necessary to Teflon-coat the BBR sample molds in order to break the bond between the molds and the RAP-#8 mortar. Initial data showed that this technique significantly improved the quality of the prepared samples.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Continue the identification and sampling of the RAP materials. Continue the experiment on the impact of extraction method on the properties of RAP aggregates. Continue the development of the BBR testing of RAP materials. Start the development of the DSR testing of RAP materials.

Meet with TxDOT and Caltrans to discuss the possibilities of constructing field sections with 40% RAP contents with and without changing the binder grade.

Work element E2c: Critically Designed HMA Mixtures (Year 1 start)

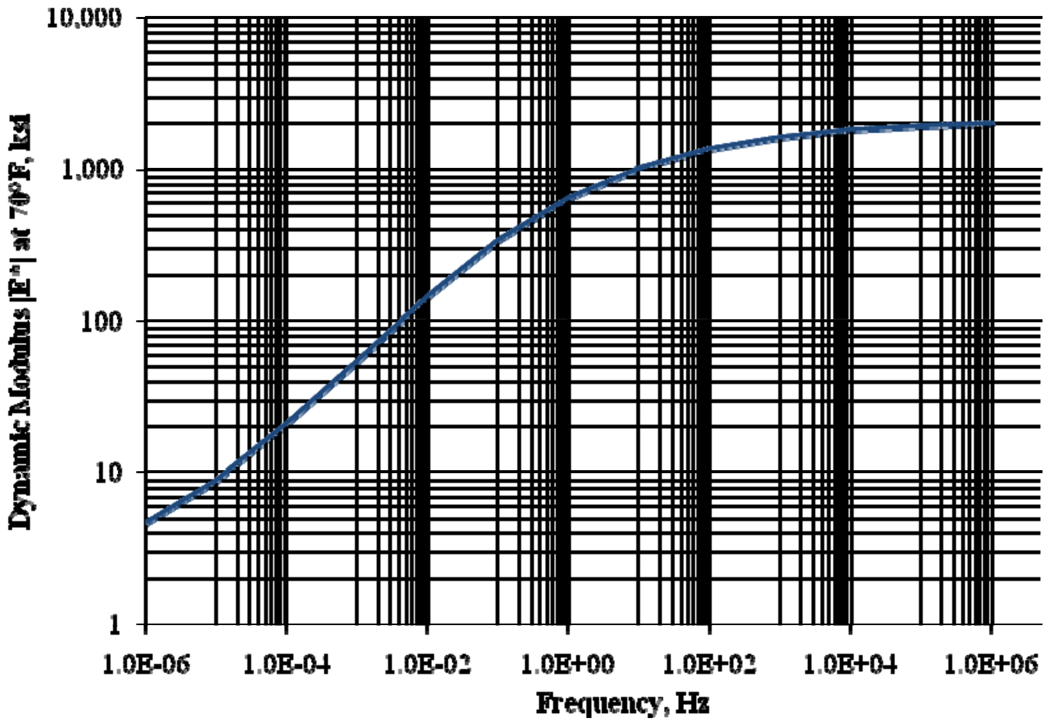
Work Done This Quarter

The 3D-Move software was used to evaluate the stress, strains, and displacement conditions within the HMA layer under a moving 18-wheel truck at different speeds and different pavement temperatures. The pavement structure was subjected to a tractor-semitrailer combination moving on a leveled and a 4% downhill with and without braking. The steering axle consisted of a single axle configuration with single tire, whereas the driving and trailer axles consisted of a tandem axle configuration with dual tires. A tire inflation pressure of 125 psi is used. The pavement responses were computed as a function of time. As the truck rolls over, the pavement response history consists of a loading, unloading, and a rest period that are a function of the truck speed, tire load configuration, and pavement structure.

A 12.5 mm nominal maximum aggregate size mix was designed for the Nevada Lockwood aggregate (andesite) with a PG64-22 asphalt binder following the Superpave volumetric mix design method with a medium traffic level that is equivalent to 3–10 millions equivalent single axle loads (ESAL). The frequency-dependent viscoelastic properties of the HMA layer were used to characterize the rate dependent behavior of the HMA mixture under the slow moving truck.

Significant Results

The dynamic modulus test was used to measure the mixture's stiffness and internal damping as a function of the frequency. Figure E2c.1 shows the E* master curve and the variation of the damping ratio as a function of loading frequency for the Lockwood/PG64-22 mix. This data show that the relationship between damping ratio of the HMA mix and loading frequency is highly complex. In addition, the damping ratio of the HMA mix varies between 8 and 30% and the common assumption of 5% damping of the HMA mix is highly unrealistic. Therefore, ignoring the damping characteristics of the HMA mix leads to the calculation of unrealistic responses of the HMA pavement to dynamic loads.



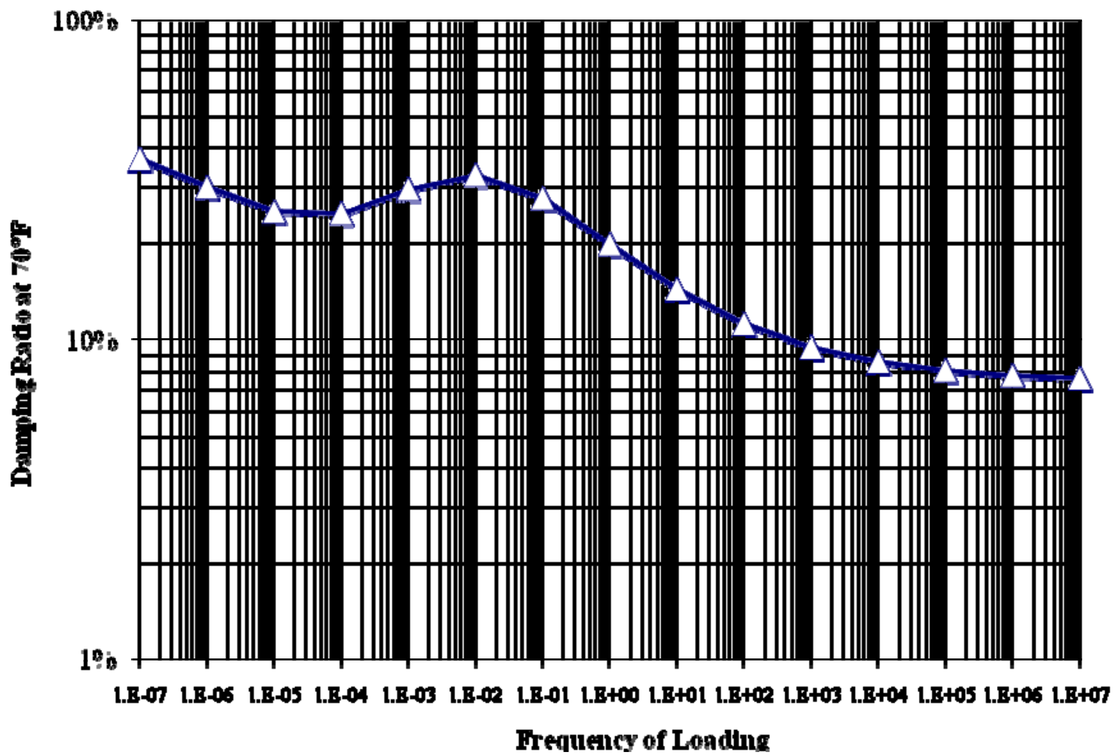


Figure E2c.1. E* Master Curve and Damping Ratio for the Lockwood/PG64-22 mix.

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 designs for the Lockwood aggregate source with PG52-22 and PG58-22 binders and measure their dynamic modulus master curves and damping ratios.

Work element E2d: Thermal Cracking Resistant Mixes for Intermountain States (Year 1 start)

Cooperation Efforts

The ARC researchers are cooperating with the Minnesota Pool Fund study on thermal cracking. The UNR and University of Minnesota (UM) researchers are currently cooperating on the TSRST experiment as indicated in the experimental plan described below.

Work Done This Quarter

Started the long-term oven aging process for the following binders at 100^{o}C 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.

Continued working on analyzing the pavement temperature profiles data from the LTPP and Westrack pavement sections. Conducted condition surveys of the Westrack sections and documented their thermal cracking performance.

The UNR and UM researchers started an experiment to improve the current TSRST method by improving the repeatability of the test results. This will be achieved by completing the following three objectives:

1. Investigate the effect of size and shape of the TSRST specimen.
2. Investigate the effect of cooling rate on the fracture properties of the asphalt concrete and develop correlations that allow for a rapid test procedure.
3. Investigate the behavior of asphalt mixtures subjected to multiple cooling and warming cycles.

The following experimental plan is followed for the investigation of the effect of specimen size and shape:

- Select aggregates with different mineralogy from two different sources.
  - Nevada: Lockwood – andesite.
  - Minnesota aggregate source
- Obtain a neat and a polymer modified asphalt binders typically used in Nevada and Minnesota.
  - Nevada: PG64-22 (neat) and PG64-28NV (polymer modified)
  - Minnesota neat and polymer-modified binders
- Develop two intermediate Superpave gradations with ½ inch and ¾ inch nominal maximum aggregate size for each of the aggregate sources and binder type – total 4 mixes from Nevada and 4 mixes from Minnesota.
- Conduct the Superpave mix design for 6 million ESALs and for a top lift.
- Prepare specimens to test in the TSRST:
  - Compact 6 replicates of 2x2x10 inch beams.
  - Compact 2 sample of 6 inch diameter by 7 inch height using the Superpave Gyratory Compactor (SGC) and then core out of each of the specimen 3 replicates of 2.25 inch diameter and 6 inch height.
  - Compact 3 sample of 6 inch diameter by 7 inch height using the SGC and then core out of the center of one each of the specimens a 2.25 inch diameter and 6 inch height sample.
- Air-Voids: prepare compacted samples from each mixture at two levels of air-voids: 4% and 8%.
- Aging: prepare compacted samples from each mixture at two levels of aging:
  - Short term age the loose mixture following AASHTO R30, 4hr aging.
  - Long term age the compacted mixture following AASHTO R30, 5 days at 185°F.
- Cooling rate: 10°C/hr.
- Use a thermo-couple to measure the temperature inside a dummy sample having the exact dimensions as the tests sample to eliminate the impact of sample size on the mix temperature. This temperature will serve as the control temperature of the test.
- Compare and analyze the test results (stress-temperature relationship) of the TSRST fracture test to check for test repeatability.

In the area of thermal conductivity of binders and mixtures, a new device is being built which will be used to conduct multiple types of testing:

- All binder thermal dilatometric testing, and
- Mixture thermal linear expansion and contraction

Similarly, the modification of the Bending Beam Rheometer (BBR) for Single-Edge Notched Bending (SENB) testing is underway. A detailed 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 equipment will make it possible to evaluate properties of asphalt binder, mastic and possibly mixtures at low temperatures using fracture mechanics.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Continue the aging process of binders and start measuring the properties of the aged binders. Continue the analysis of the temperature profiles data from the LTPP sections and the Westrack. Continue the investigation on the impact of specimen size and shape and start the investigation on the impact of cooling rate.

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

Work Done This Quarter

In the previous quarter (October 1 – December 31, 2007), recommended model improvements were identified and reported. During this quarter, preliminary experimental designs for the laboratory testing were prepared and are included in the Year 2 Work plan.

Significant Results

Improvements have been identified to the Hirsch Model for dynamic modulus, the Resistivity Model for rutting resistance, the Continuum Damage Fatigue Model, and the Permeability Model and an experimental plan has been developed to address the needed improvements.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Upon receipt of authorization to proceed with the Year 2 Work plan, the preliminary experimental plans included in the Year 2 Work plan will be revised based on comments received from the AOTR, and detailed experimental plans will then be prepared. Laboratory testing will commence upon completion of the detailed experimental plans.

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

Work Done This Quarter

In this quarter, the focus was on the following tasks: reviewing literature, evaluating different testing methodologies, collecting asphalt mixtures, testing moisture surface textures, and designing, building and calibrating an acoustical impedance tube.

Significant Results

A number of the different available mixtures were tested to characterize the skid resistance and acoustic properties of mixture. In this quarter, the research team focused its efforts on dense mixtures with different air void content and different aggregate minerals. The research team is testing slab specimens and will begin testing cylindrical specimens in Q2 2008. Obvious questions regarding the finishing of surfaces will 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 surface that will control the skid resistance and acoustic properties of the tested mix specimens.

Skid friction properties.

The surface texture of the selected mixture specimens were tested using the sand path method. It was found that in some specimens, the surface was *too smooth* for the texture characterization using the sand patch test. To help characterizing these "smooth" surfaces, the research team is considering renting the Ames Engineering Model 9200 Laser Texture Scanner (http://www.amesengineering.com). The research team does not expect to find the same problem on the open-grade mixtures to be tested in the coming quarter as these other types of mixture have a much larger macrotexture. Mixture types and results are summarized in table VP2a.1.

Table VP2a.1. Dense mixture and partial sand patch results.

Binder Type	AC	Air Voids	Aggregate	D1 mm	D2 mm	D3 mm	D4 mm	AVG mm	MTD mm
58-40 SBS Flint Hills	OPT	4%	G	97	103	99		99.7	0.385
58-40 SBS Flint Hills	BUMP	4%	G	97	102	96	114	102.3	0.365
58-40 SBS Flint Hills	OPT	4%	LS						
58-34 Elvaloy Murphy	OPT	4%	G						
58-34 Elvaloy Murphy	BUMP	4%	G						
58-34 Elvaloy Murphy	OPT	4%	LS						
58-34 SBS Flint Hills	OPT	4%	G						
58-34 SBS Flint Hills	OPT	4%	LS						
58-28 Plain Seneca	OPT	4%	G	127	142	143	140	138.0	0.201
58-28 Plain Seneca	BUMP	4%	G	120	123	128	125	124.0	0.248
58-28 Plain Seneca	OPT	4%	LS	Unable to detect surface voids					0
58-28 Plain Seneca	BUMP	4%	LS	Unable to detect surface voids					0
58-28 Plain Seneca	OPT	7%	G	120	127	119	1119	371.3	0.028
58-28 Plain Seneca	BUMP	7%	G	100	121	115	105	110.3	0.314
58-28 Plain Seneca	OPT	7%	LS	95	107	104	107	103.3	0.358
58-28 Plain Seneca	BUMP	7%	LS	107	98	107	115	106.8	0.335
58-28 Plain P+D	OPT	4%	G						
58-28 Plain P+D	OPT	4%	LS						
64-34 Elvaloy Murphy	OPT	4%	G						
64-34 Elvaloy Murphy	OPT	4%	LS						
64-34 Black Max Husky	OPT	4%	G						
64-34 Black Max Husky	OPT	4%	LS						
64-28 Plain Seneca	OPT	4%	G	128	135	143	139	136.3	0.206
64-28 Plain Seneca	OPT	4%	LS						
64-28 SBS Seneca	OPT	4%	G	180	183	195		186.0	0.110
64-28 SBS Seneca	OPT	4%	LS						
64-22 Plain Seneca	OPT	4%	G	173	135	138	170	154.0	0.161

Acoustic properties

To evaluate the acoustic absorption characteristics of asphalt mixture, the research team designed, built and calibrated an impedance tube using the ASTM D1050 "Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System." However, the research team has modified the placement of the specimen compared to the ASTM standard. Instead of using a cylindrical specimen inside the tube, the research team is placing the flat surface of a mix specimen at the end of the impedance tube. This modification will allow using impedance tube in the field to evaluate the acoustic characteristics of roads. The validation of the modification is ongoing. If needed, the research team will build a 6-in diameter impedance tube to accommodate gyratory compaction specimens (the cost of each tube is approximately $500). Figure VP2a.1 presents sketches of the impedance tubes.

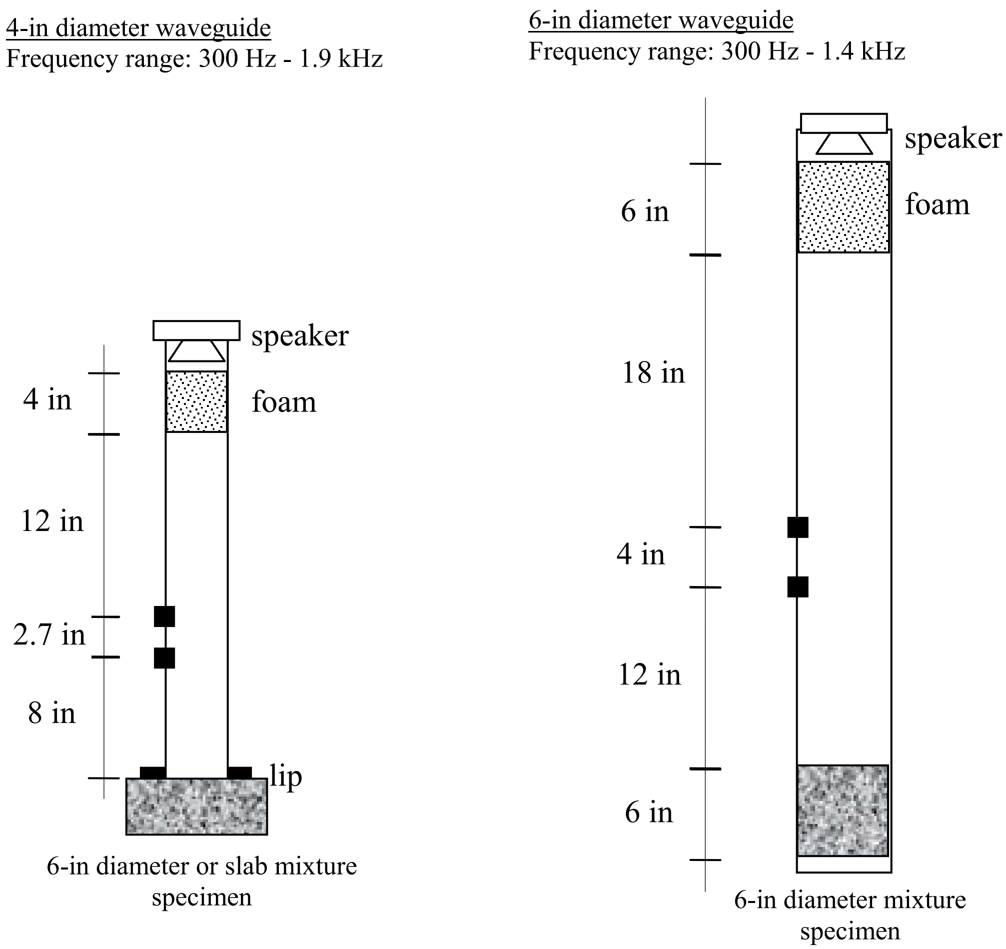


Figure VP2a.1. Diagrams. The impedance tubes to be used in this work element.

Significant Problems, Issues and Potential Impact on Progress

One of the issues the research team is facing is the evaluation of the acoustic and skid resistance performance of mixtures in service and how 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" of pavement surfaces and to prepare specimen surfaces for measurements of macro-texture and noise absorption.

Communication with Dr. Mike Heitzman of NCAT during the TRB meeting in January indicated that Iowa DOT has looked at a procedure to simulate traffic surface abrasion, and a protocol to achieve suitable abrasion is under investigation. The work in this project will be coordinated with Dr. Heitzman, and a protocol for surface preparation will be developed.

Work Planned Next Quarter

During Q2 2008, the research team will:

i. Complete the literature review.
ii. Evaluate the use of the sweep test to simulate polishing by traffic.
iii. Evaluate the effect of aggregate gradation on macro texture and noise.
iv. Run parametric studies as described in the Year 2 Work Plan.

CATEGORY VP3: MODELING

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

Work Done This Quarter

No activity this quarter. This work element will start in Year 2 (beginning April 1, 2008) after approval is received from the AOTR.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

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

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

Samples from the Yellowstone National Park (YNP) warm mix site are being analyzed to determine the difference in aging of the hot-mix control compared with the zeolite (Advera) and Sasobit (Sasol-wax) materials.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

It is planned to continue the evaluation of the differences in aging of the three materials.

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

Work Done This Quarter

Initial contact was made with Dale Rand at Texas DOT about the possibility of constructing a comparative pavement site in Texas.

Discussions were held with FHWA AOTR Mr. Eric Weaver regarding LTPP sections that are going out of service. FHWA LTPP has a considerable amount of data and information on the sections going out of service and Eric feels that the state DOT's would support placing new sections in those areas where sections are going out of service.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Follow-up contact with Dale Rand at Texas DOT regarding the possibility of a new validation section in Texas. Eric Weaver will provide a list of contacts that are likely to support validation sites in states where there are LTPP sections going out of service.

CATEGORY V2: ACCELERATED PAVEMENT TESTING

Work element V2a: Scale Model Load Simulation on Small Test Track (Later 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 ARC will work with FHWA to evaluate the possibilities of using scale-model and full-scale accelerated pavement testing as a method to validate tests and models being developed in the project.

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 (Year 1 start)

Work Done This Quarter

Work continued this quarter on the analysis of binder and mixture creep and recovery. The power law model described in the Q4 2007 report was used for two binders and the estimated creep behavior was compared to mixtures produced with the same binders. The analysis included varying stress and time of loading to find the best correlation between binder and mixture behavior.

The development of a specification framework for the new binder fatigue parameter was started this quarter. The binder test procedure was named the Binder Yield Energy Test (BYET), and the parameter binder parameter yield energy (YE) was selected as a proposed binder measure to be used in specification to replace the $G^*\sin\delta$. The set of binders used in the FHWA-ALF fatigue study were used to determine the relationship between the value of YE and fatigue in the ALF. Based on the limited data available, a matrix of acceptable minimum value of YE for two levels of traffic volumes and two levels of pavement structural capacity (strain level in pavement) was developed. The framework follows ideas similar to those being proposed for the MSCR test, which is under consideration by the binder ETG.

For the low temperature binder cracking test, the development of the notch edge beam test in the BBR system was advanced. Detailed analysis of the literature to define the testing conditions was completed and the criteria for the loading frame, rate of loading, and maximum load were defined. The components required for the new loading frame were ordered. Also, initial testing of one binder was conducted using the mold a simple frame to estimate the range of loads needed for the test.

<u>Significant Results</u>

Binder Rutting Parameter

Figure V3a.1 depicts an example of the non-linear creep behavior of one mixture and one of the binders at various stress levels. Part (a) shows that as the stress level increases, mixture tertiary (non-linear) creep starts at a shorter time. A similar trend is shown in part (b) for the binder B5, which was used in production of mixture shown in part (a) of the figure. In part (c) the binder and mixture creep behaviors are compared at various loading times. The plot in part (c) was generated using binder modeling assuming the stress used equals 40 kPa while mixture was tested at 1.38 MPa. This type of fitting will allow the estimation of the stress that needs to be used in the creep and recovery testing of binders so that it is more representative of conditions in a mixture. As shown in part (c), the role of binders is dependent on the aggregate gradation. It appears that for the gradations used, the same binder stress level gives good correlations with mixture strain.

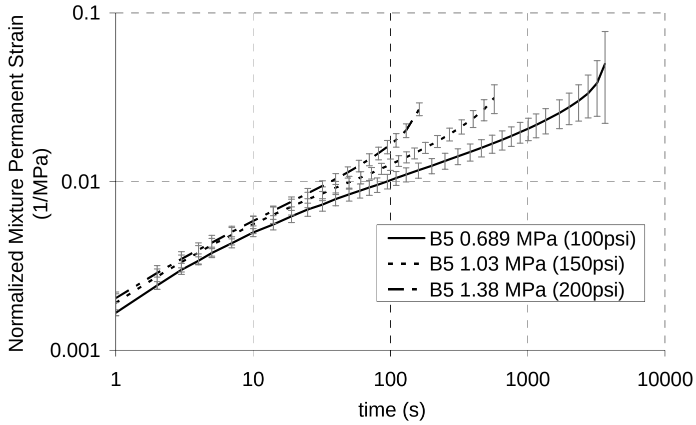


Figure V3a.1.a. Mixture plastic strain.

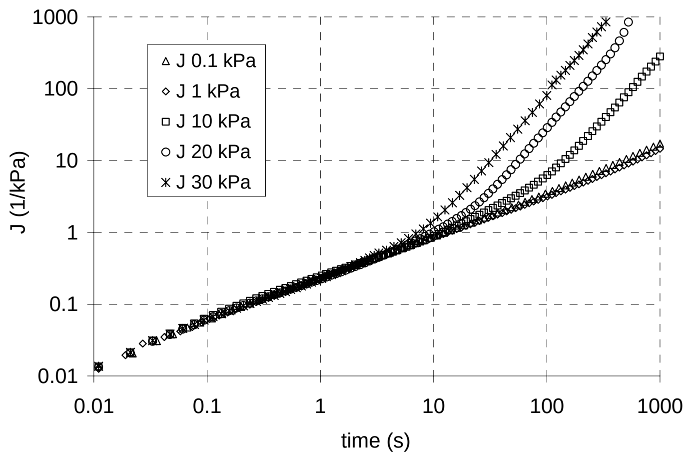


Figure V3a.1.b. Binder permanent strain (compliance) at various stress levels.

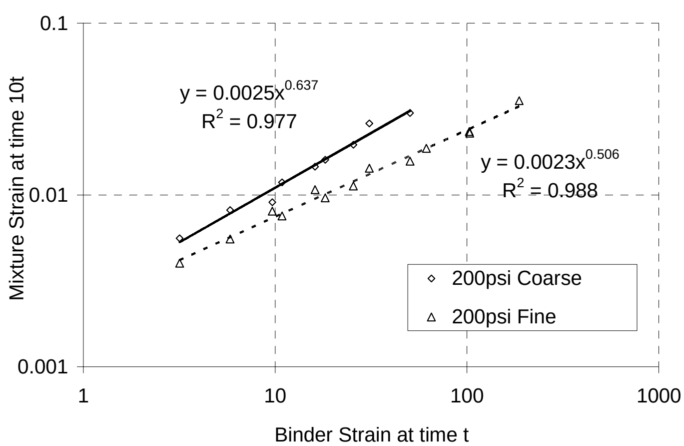


Figure V3a.1.c. Binder versus mixture permanent (plastic) strain at equal time and temperature.

Figure V3a.1. Graphs. Comparison of binder and mixture creep behavior at various stresses and loading times.

Binder Fatigue Parameter

Figure V3a.2 depicts the results of a typical stress-strain plot from which YE is calculated.

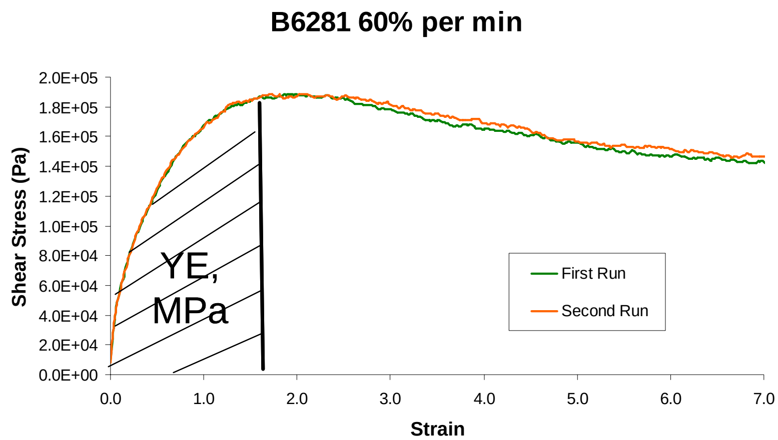


Figure V3a.2. Graph. Method of calculating the binder yield energy (YE) from a monotonic test using the DSR.

The values for the binders used in the FHWA-ALF were compared to the amount of cracking observed. Based on these comparisons, YE values were determined that correspond to average amount of fatigue cracking observed. In addition, a set of binders that included both unmodified and modified binders was tested at the PG-grade intermediate temperatures (IT). It was determined that testing at IT is not optimum, since the monotonic test results do not show a clear maximum value. Instead, the testing temperature was selected to be IT-8, which results in optimum monotonic test. Based on the results of testing 12 binders, a tentative limit for a typical pavement structure and traffic conditions was estimated at 1.0 MPa. Using modeling of binder fatigue, the values for other traffic and pavement strain were estimated as shown in table V3a.1.

Table V3a.1. First estimates for minimum allowable YE values for binders to minimize fatigue cracking in pavements.

Pavement Micro-strain		1000	600	200
	Binder Strain	5%	3%	1%
Traffic ESALs	1,000,000	*1.20*	*0.90*	*0.25*
	3,000,000	*1.35*	<u>*1.00*</u>	*0.30*
	10,000,000	*1.50*	*1.10*	*0.35*

(Adjusted to 1.0 MPa, at IT-8C)

The values in table V3a.1 will be further evaluated using other temperature and binders. Also an attempt will be made to simplify table and reduce the matrix to a two-by-two matrix with two pavement structures and two traffic levels.

Binder Fracture Test

Figure V3a.3 depicts the test geometry of the single edge notch beam, which is based on work by Hesp (2003) and is currently a draft standard under consideration by the Manitoba DOT. Work this quarter resulted in final drawings and specification to build a loading frame that will fit in the BBR bath and allow the measurement of the fracture properties of binders. It is expected that testing of the prototype will start next quarter.

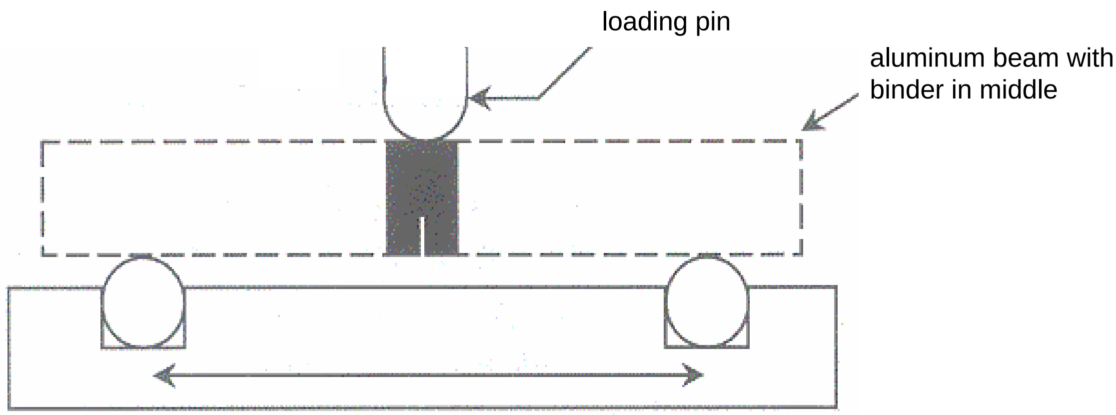


Figure V3a.3. Illustration. Schematic of the geometry of the binder fracture test in bending.

Significant Problems, Issues and Potential Impact on Progress

There are no significant problems at this time.

Work Planned Next Quarter

Next quarter the team plans to:

- Continue the analysis of binder and mixture results and write a summary paper regarding the importance of loading time and stress on binder creep behavior.
- Collect more binder fatigue data and further examine the relationship between the yield energy and fatigue of mixture and pavements. A meeting will be scheduled with key people in the binder ETG to discuss the concepts of the monotonic binder test and the development of a binder fatigue parameter.
- Analyze data collected for the binder fracture bending test and asses the simplicity of the test, repeatability of results, and relationships to *S* (stiffness measured with BBR) and *m* (creep rate measured with BBR) values of binders.

Cited References

Hesp, S.A.M., 2003, An Improved Low-Temperature Asphalt Binder Specification Method. Final Report, NCHRP-IDEA Contract 84 and Ministry of Transportation Ontario Contract 9015-A-000190, December 2003.

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 worked with the Washoe RTC in northern Nevada to develop an MEPDG design for a flexible pavement to be constructed as a validation site in Sparks, Nevada during June 2008.

Significant Results

None.

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 2008/2009, and the Wisconsin DOT in 2009. The researchers are facing difficulties convincing the DOT's to cooperate on the MEPDG sites. The level of this work element may have to be reduced.

Work Planned Next Quarter

Continue discussions 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

At the 2008 Transportation Research Board meeting in Washington, DC, the UW-Madison team called a meeting to discuss procurement of LTPP materials for the validation of preliminary findings at UW. Attendees included representatives from each of the ARC institutions and FHWA. The team discussed the procedures to obtain materials from LTPP MRL contractors.

Following the meeting, the UW team retrieved a list of asphalt binders from LTPP SPS9 available at MRL. Working with the FHWA LTPP support team, a list of asphalt binders were identified which have diverse field performance. These binders also cover different climatic zones. A request to order the binders has been approved by FHWA and is being processed by the contractor.

<u>Significant Results</u>

Table V3b-2.1 shows the complete list of asphalt binders. These binders will be used to validate the findings and possibly develop a specification on fatigue of asphalt binders, as well as verification of theoretical development.

Table V3b-2.1. LTPP asphalt binders ordered.

Agency	Exp. No	SHRP ID	Climate Zone	Fatigue Cracking m^2	Sample Location	Sample Type
CT	9A	90902	WF	0		AC PG 64-28
MT	9	300903	DF	0		64-22
NC	9A	370901	WN	0	BC01A01	AC-20
NC	9A	370902	WN	0	BC01A02	64-22,
NC	9A	370903	WN	0	BC01A03	70-22,
NC	9A	370962	WN	0	BC01A62	PG76-22
WI	9	550903	WF	0		58-72
CT	9A	90960	WF	0.8		AC-10
CT	9A	90961	WF	2.1		PG 58-34
FL	9A	120902	WN	2.2		AC PG 64-16
NC	9A	370961	WN	3.7	BC01A61	PG76-22
CT	9A	90962	WF	4.3		AC PG 58-28
CT	9A	90903	WF	5		PC PG 64-22
PQ	A9	89A902	WN	6.7		52-40
PQ	A9	89A901	WN	8.8		52-34
NJ	9A	340902	WF	11.4	BC01A02	58-28
NC	9A	370963	WN	12.7	BC01A63	AC20
NM	9	350903	DN	15.7		58-22
NC	9A	370965	WN	17.7	BC01A65	PG16-23
NM	9	350902	DN	32		64-22
MO	9A	290963	WF	37.9	BC02A63	64-16
NJ	9A	340901	WF	49.5	BC01A01	64-22
NC	9A	370964	WN	51.1	BC01A64	PG76-22
MO	9A	290901	WF	51.6	BC02A01	64-28
NE	9	310902	DF	65.5		AC
NC	9A	370960	WN	73.1	BC01A60	PG76-22
MT	9	300902	DF	76.2		64-34
NE	9	310903	DF	175.5		AC
NJ	9A	340961	WF	178.8	BC01A61	78-28
AZ	9A	04B901	DN	328		AC BINDER
AZ	9A	04B903	DN	337.9		AC-40, PG 70-10

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

UW will work with LTPP MRL contractors to ship the binders. The team will gather information on pavement structure, traffic, and other information for material evaluation. The team will also start testing on the asphalt binders after they are received.

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

Work Done This Quarter

See Subtask V3b-2 above.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

See Subtask V3b-2 above.

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

Work Done This Quarter

See Subtask V3b-2 above.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

See Subtask V3b-2 above.

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

This is a Year 2 activity beginning April 1, 2008.

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

This is a later start activity.

PROGRAM AREA: TECHNOLOGY DEVELOPMENT

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

Work Done This Quarter

The Early Development projects listed in Table TD1.1 were presented to the Mixtures and Construction and Models and Fundamental Properties Expert Task Group(s) (ETG). Instructions for prioritization of the projects were prepared and the project descriptions were circulated to the members of these two ETGs. Responses were compiled by the AOTR and are summarized in Table TD1.2. Only 13 ETG members provided ratings for the projects. Based on the ETG response, it appears that there is sufficient interest in each of these projects to warrant further consideration by the Consortium.

Table TD1.1. Summary listing of early technology delivery projects.

Project	Product	ETG
Automated Flocculation Titrimetric Analysis	Draft AASHTO Standard Test Method for evaluation the propensity of an asphalt or mixture of asphalts to exhibit phase separation	Binder
Determination of Polymer in Asphalt	Draft AASHTO Standard Test Method to determine the quantity of polymer and the nature of the polymer(s) in asphalt	Binder Mixture and Construction
Dynamic Mechanical Analysis	Draft AASHTO Standard Test Method for torsional fatigue testing of the fine aggregate matrix of asphalt concrete	Mixture and Construction Binder Fundamental Properties and Advanced Modeling
Simplified Continuum Damage Fatigue Test	Draft AASHTO Standard Method of Test for fatigue testing of asphalt concrete that can be used with the Simple Performance Test System	Mixture and Construction Fundamental Properties and Advanced Modeling
Universal Sorption Device	Draft AASHTO Standard Method of Test for measuring the surface free energy components of aggregates	Binder Mixture and Construction Fundamental Properties and Advanced Modeling
Wilhelmy Plate Test	Draft AASHTO Standard Method of Test for measuring the surface free energy components of the asphalt binder	Binder Mixture and Construction Fundamental Properties and Advanced Modeling

Table TD1.2. Summary Listing of Early Technology Delivery Projects.

Reviewer	Rating, 0 = not needed, 5 = critically needed					
	Automated Flocculation Titrimetric Analysis	Determination of Polymer in Asphalt	Dynamic Mechanical Analysis	Simplified Continuum Damage Fatigue Test	Universal Sorption Device	Wilhelmy Plate Test
1	2	1	2	4	3	3
2	1	2	3	3	4	4
3	4	3	2	1	3	3
4	1	1	4	4	2	2
5	1	5	5	5	1	1
6	1	2	3	5	4	3
7	3	3	4	2	5	1
8	1	1	4	5	3	3
9	1	4	4	5	2	2
10	4	4	4	3	3	3
11	1	2	3	5	4	4
12	3	0	4	5	2	1
13	1	2	2	4	5	5
Average	1.8	2.3	3.4	3.9	3.2	2.7
St. Dev.	1.2	1.4	1.0	1.3	1.2	1.3

Significant Results

The initial set of Technology Development projects that were identified by the ARC received favorable responses from the responding reviewers.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

The Consortium partners will review the ETG ratings and comments provided by the AOTR to determine if a detailed work plan should be developed for each of the projects. Dr. Bonaquist will then meet with the AOTRs to discuss the disposition of each of the Early Technology Development Projects. For those that will continue, detailed work plans for the development effort will be developed.

Work element TD2: Develop Early Products (Year 2)

Work Done This Quarter

None. Project statements were under ETG review.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Detailed work plans for those projects approved by the AOTRs will be prepared and submitted.

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

This activity is planned for later in Year 2 (beginning April 1, 2008).

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. Quarterly progress reports, the ARC Newsletter, and the ARC presentations at ETG meetings have been posted.

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 was prepared. It will be published by the end of April 2008.

Significant Results

None.

Significant Problems, Issues and Potential Impact on Progress

None.

Work Planned Next Quarter

Publish the second ARC Newsletter. Prepare materials for the third ARC Newsletter to be published in September 2008.

Work element TT1c: Prepare Presentations and Publications

Work Done This Quarter

Following the 87th Annual Transportation Research Board meeting, a project review for the ARC research and the WRI Fundamental Properties of Asphalts and Modified Asphalts III research was presented to invited reviewers. The ARC members presented a selection of research topics to the reviewers.

ARC members made presentations at the Binder, Mix and Construction, and Fundamental Properties and Advanced Models Expert Task Group meetings in Tampa, Florida during the week of February 25, 2008.

ARC members also attended the RAP Expert Task Group meeting in San Diego, California on March 5 & 6, 2008 that was hosted by CalTrans. Dr. Peter Sebaaly of the University of Nevada Reno presented on overview of the planned RAP research in the ARC and discussed important issues with CalTrans staff and others.

Work Planned Next Quarter

Dr. Dallas Little from Texas A&M University presented the paper "A Framework to Quantify the Effect of Healing in Bituminous Materials Using Material Properties" at the European Asphalt Technology Association conference in Lyon, France in April 2008. The paper was very well received by the audience. The paper has been published by the International Journal of Road Materials and Pavement Design and the full reference is:

> Bhasin, A., D. N. Little, R. Bommavaram and K. L. Vasconcelos, 2008, A Framework to Quantify the Effect of Healing in Bituminous Materials Using Material Properties. *International Journal of Road Materials and Pavement Design*, Vol. 9, pp. 219-242.

ARC members are planning to attend the next Fundamental Properties and Advanced Models Expert Task Group meeting in Chicago, Illinois on June 19 & 20, 2008. It is expected that presentations will be made.

Work element TT1d: Development of Materials 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 detailed materials management plan and a framework for the materials database.

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.