State Planning and Research Program
Quarterly Report

PROJECT TITLE:
TPF-5 (132) Investigation of Low Temperature Cracking in Asphalt Pavements - Phase II (MnROAD Study)

OBJECTIVES: The main objective of this study is to validate the laboratory test procedures, models, and pavement design procedures that come out of Phase I of this study. This will be accomplished by monitoring two new test sections at the Minnesota Road Research Facility (MnROAD). Phase I was aimed at developing a fracture mechanics-based specification for a better selection of asphalt binders and mixtures with respect to their resistance to crack formation and propagation. This fracture mechanics approach will also be used to investigate the detrimental effects of aging and moisture on the fracture resistance of asphalt materials.

PERIOD COVERED:
April 1, 2009 – June 30, 2009

PARTICIPATING AGENCIES:
CT, IA, MN, ND, NY, WI, LRRB

PROJECT MANAGER: Benjamin Worel **LEAD AGENCY**: Mn/DOT **PRINCIPAL INVESTIGATOR**: TBD by TAP	**SP&R PROJECT NO**: TPF-5 (132)	PROJECT IS: ____ Planning __X__ Research & Development

ANNUAL BUDGET: $525,000 Total Funding = $475K Contract + 26K Admin (meetings) + 24K Admin (Agency Discretion)	**PROJECT EXPENDITURES TO DATE**: • First State Meeting held March 11, 2008 (Travel expenses from CT, ND, NY, WI were processed) • No other expenses

WORK COMPLETED:

1 - December 2007 - Project was just work plan developed and approved
2 - March 11, 2008 Agency Kickoff meeting held in Minnesota
3 – June 17, 2008 - Contract finalized between University of Minnesota and Mn/DOT – work starts. University of Minnesota has subcontract with Iowa State and working on the other two universities.
4 – October 2008 MnROAD Test cells are completed on the mainline for this study.
5 – March 2009 State meeting (20 minutes) in Minneapolis at AAPT (Handout attached).
6 - See the University Report following this cover sheet for individual task completions.

SUMMARY OF ACTIVITIES EXPECTED TO BE PERFORMED NEXT QUARTER:

1. Contractors continue to work this quarter doing much of the lab testing this summer.
2. Setup state meeting to review the process after the work is done this summer. Expect the meeting to be held in October 2009 in Minnesota. Emails will be sent out to organize a date.

STATUS AND COMPLETION DATES:
More details see Mihai's task summary attached to this document.

Task 1 – Update on low temperature cracking research - Completed: 98%

Task 2 – Expand Phase I test matrix with additional field samples – 10% - Expect much of this lab testing work to be done this summer 2009

Task 3 – Develop low temperature specification for asphalt mixtures - Nothing to report.

Task 4 - Develop Improved TCMODEL – ~25% - some work done to date
Task 5 - Modeling of Asphalt Mixtures Contraction and Expansion Due to Thermal Cycling - Nothing to report.
Task 6 – Validation of new specification - Nothing to report
Task 7 - Development of draft AASHTO standards and Final Report – Nothing to report

Handout at the AAPT Meeting (March 2009)

Location	Construction Date	Description	Mix	Binder
MnROAD 33	September 2007	58-34 Acid only no RAP	X	Sent
MnROAD 34		58-34 SBS + Acid no RAP	X	To
MnROAD 35		58-34 SBS only no RAP	X	Mihai
MnROAD 77		58-34 Elvaloy + Acid no RAP	X	Ben
MnROAD 20	August 2008	58-28, 30% non-fractionated RAP, level 4 SP, wear & non-wear	X	X
MnROAD 21		58-28, 30% fractionated RAP, level 4 SP, wear & non-wear	X	X
MnROAD 22		58-34, 30% fractionated RAP, level 4 SP, wear & non-wear	X	X
Wisconsin 9.5 mm SMA	2008	Wisconsin will provide materials	X	X
New York "Typical Mix"	2008	New York with PG 64-22 binder and an aggregate other than limestone and granite.		

Loose Mixture Inventory

A. Minnesota Received Sept- 08

	Labeled	buckets	kilogram
cell 33	cell 33 layer…	6+3*	180
cell 34	cell 34 layer…	6+3*	180
cell 35	cell 35 layer…	6+3*	180
cell 77	cell 77 layer…	6+3*	180
cell20	cell 20 SPWEB 440B	6+3*	180
cell21	cell 21 SPWEB 440B	6+3*	180
cell22	cell 22 SPWEB 440C	6+3*	180

3* buckets are for Urbana, but will be compacted at U of M

B. Wiscosin loose mix received 12/1/2008

Mix design number	% of Binder	% of Rap	Bags
506607	5.3	6	12
506607	5.3	9	3
506607	5.2	7	3
506607	5.1	7	1
506607	5.0	7	1
		Total	**20**

C. NY loose mix
none

A. Minnesota binder
PG 58-28 1 bucket 10/15/2008
PG 58-34 1 bucket 10/15/2008

B Wisonsin binder
unlabeled 4 quarts 12/1/2008

Investigation of Low Temperature Cracking in Asphalt Pavements
National Pooled Fund Study – Phase II
WO103
Quarterly Report for April 1 - June 30, 2009

Task 1 – Update on low temperature cracking research

The literature review is being updated with papers from the Proceedings of the 7th International RILEM Symposium ATCBM09 on Advanced Testing and Characterization of Bituminous Materials, Rhodes, Greece, 27-29 May, 2009 and will be delivered at the beginning of next quarter.

Percent completed: 98%.

Task 2 – Expand Phase I test matrix with additional field samples

All mixture samples, except the mixture from NYS, which has not been delivered (Chris Euler will send the loose mix next quarter) were compacted and are in the process of being cut into experimental test specimens. It is expected that next quarter, all test specimens will be delivered to the different universities and testing will start.

Subtask on Physical Hardening

Time-temperature superposition principle was used to quantify physical hardening of asphalt binders, by estimating isothermal shift factors, as discussed last quarter. Conventional shift factors were used to build the master curve of a binder; it is well documented that such shift factors can be fitted by a linear function of temperature. Analysis of data collected so far has shown that sample subjected to isothermal conditioning for different times yield different values for shift factors. Specifically, shift factors obtained for different conditioning time are fitted from linear equations with varying parameters: slope and intercept of the lines increase logarithmically with conditioning time (Figure 1). On this basis, it is possible to develop a model to predict the shift factor for every temperature and conditioning time from limited acquired data. Work on such model has been started in the last quarter and will continue during next one: amount and nature of necessary input data to optimize results are being discussed at this stage.

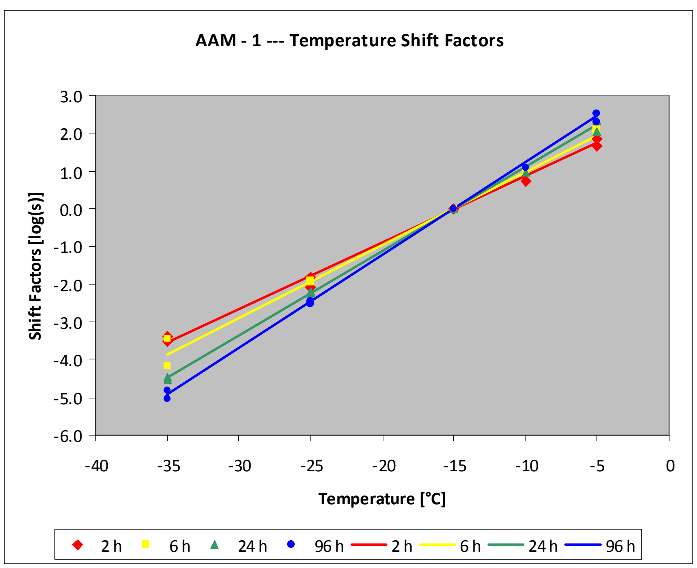


Figure 1 – Fitting lines for shift factors obtained for different temperatures and conditioning times.

Experimental investigation on binders provided by University of Minnesota has begun. Binders are being tested at -18 °C, after 1, 4, 8, 24, and 96 hours. Table 1 and Figure 2 show results of BBR tests on 35 SBS binder unaged. Table 2 and Figure 3 show results for another binder tested.

Table 1 – Results of BBR tests on 35 SBS unaged.

	SAMPLE 1	1 h	4h	8h	24h	96h
35 SBS unaged -18°C	Loading Time [s]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]
	8	108	121	125	137	141
	15	80.5	91.4	95.4	105	109
	30	56.8	65.5	68.8	76.8	80
	60	39.1	45.7	48.3	54.6	57.6
	120	26.3	31	33.1	37.8	40.7
	240	17.2	20.5	22.1	25.4	28.1
	SAMPLE 2	2 h	4h	6h	24h	96h
	Loading Time [s]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]
	8	103	112	120	124	132
	15	77.4	84.5	91.4	95.3	102
	30	54.8	60.8	66.2	69.6	75.1
	60	37.6	42.7	46.7	49.7	53.9
	120	25.1	29.3	32.2	34.8	37.8
	240	16.3	19.7	21.6	23.8	25.9

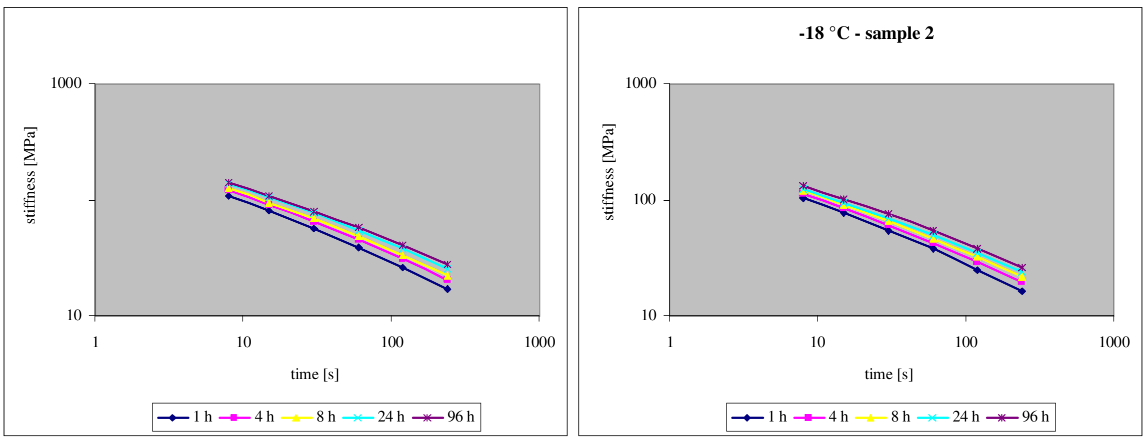


Figure 2 – Stiffness curves for 35 SBS unaged for different conditioning times.

Table 2 – Results of BBR tests

	SAMPLE 1	1 h	4h	8h	24h	96h
LTC2 unaged -18°C	Loading Time [s]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]
	8	230	299	307	327	347
	15	191	244	254	273	290
	30	152	191	201	218	234
	60	117	146	156	171	185
	120	88.2	109	118	132	144
	240	64.6	80	87.7	99.3	109
	SAMPLE 2	2 h	4h	8h	24h	96h
	Loading Time [s]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]	Stiffness [MPa]
	8	254	299	323	325	326
	15	208	244	267	270	280
	30	163	190	212	216	232
	60	125	145	165	169	188
	120	92.9	108	125	130	149
	240	67.5	79	93.4	97.7	115

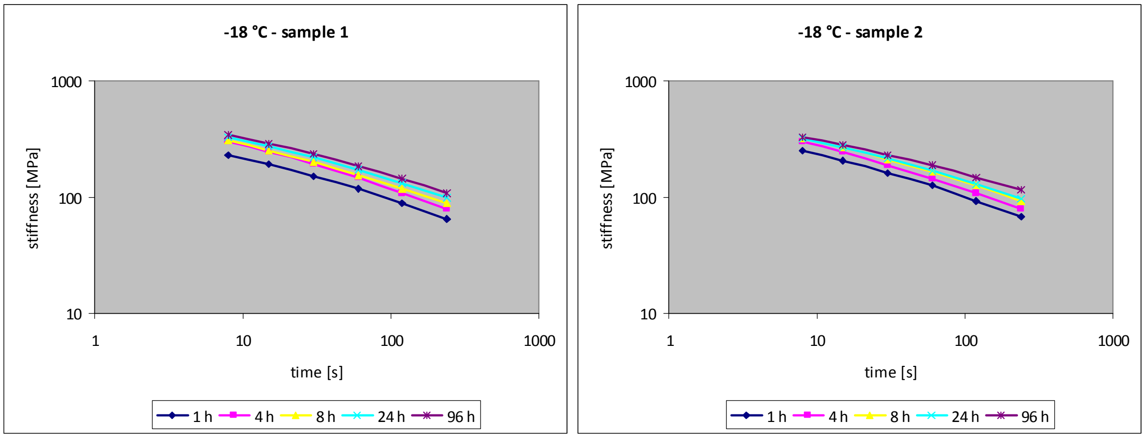


Figure 3 – Stiffness curves for unaged binder for different conditioning times.

In the next quarter all binders will be tested unaged and after PAV aging, at -6 °C, -18 °C and -24 °C, and results will be analyzed. In terms of glass transition measurements, work has been focused on improving the equipment for measurement of Tg in asphalt binders. The issue with leaks in the sealing of the dilatometric cells has been addressed and solved with the introduction of Buna gaskets. Work on next quarter will involve calibration of the dilatometric cells and tests on binders.

Task 3 – Develop low temperature specification for asphalt mixtures

No work has been performed so far.

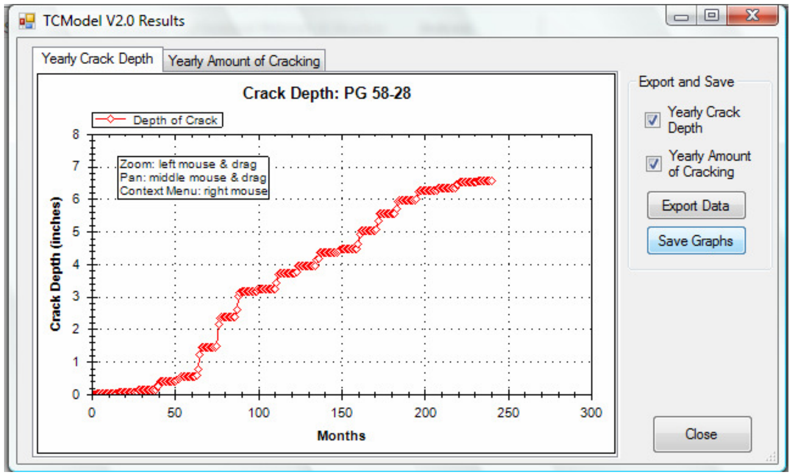
Task 4 - Develop Improved TCMODEL

The main research and development focused on dealing with the development and implementation of new thermal cracking prediction software. The research efforts for this task are two pronged. The first portion is on the development of a user-friendly, stand-alone graphical user interface (GUI) for the existing and future thermal cracking prediction models tentatively called "Visual LTC." The second focus area is on the development of a purely mechanistic thermal cracking prediction model that utilizes fundamental viscoelastic and fracture properties of asphalt concrete (NEWTCMODEL). The progress reports for both of these subtasks are as described below.

Visual LTC

Visual LTC, the graphical user interface (GUI) linking analysis tools for the prediction of thermal cracking, is in the final stages of development. The major coding for the development of Visual LTC is complete and now final testing and debugging is being conducted. Important changes were made to Visual LTC with respect to data storage, which is now done through input files and working directories. The data storage configuration allows users to save projects and mixes created with Visual LTC and provides access to modifications in subsequent runs of the program. The functionality of Visual LTC is in place; the program collects data from the user, creates necessary input files for external analysis tools, runs executable analysis programs and collects and displays results. The following executable programs are currently run: Master.exe, which creates the master creep compliance curve and TCModel.exe, which predicts the amount of thermal cracking. All data is saved and the user has the option of exporting results for further analysis. The figure below shows the results of one Visual LTC run.

The final stage of development is to incorporate the Integrated Climatic Model (ICM) into Visual LTC. The input files for ICM will be created automatically by Visual LTC. Execution of ICM will result in the temperature profile of the asphalt pavement, which will be fed to TCModel. Sample output files from ICM are currently being used to run Visual LTC.



Finite-Element Based Thermal Cracking Prediction Engine

The new thermal cracking prediction model is being developed in the form of a viscoelastic finite element analysis code with a recursive time-integration scheme. The recursive formulation is utilized to minimize the computational time and the memory usage, which is a critical requirement for a practitioner-friendly design and analysis tool. The code is based on the time-temperature superposition principle that accounts for temperature dependent bulk material behavior. A cohesive zone fracture model capable of capturing the crack nucleation, initiation and propagation is being utilized for mechanistic representation of thermal cracking in asphalt pavements. The generalized Maxwell model (Prony series form) is being used for the viscoelastic representation of asphalt concrete. Similar to the current AASHTO MEPDG procedure, the bulk material property inputs to this new procedure will be in the form of creep results from the AASHTO-T322 test. The key material inputs for the cohesive zone fracture model are the tensile strength and the fracture energy measured using AASHTO-T322 and ASTM-D3717 test specifications respectively. The theoretical formulations for the code have been already developed and the implementation of several of these tasks is currently underway. The development steps and current status for the finite-element based thermal cracking prediction model are as follows:

(1) Built-in mesh generator (development complete)
(2) Thermo-viscoelastic analysis using recursive time-integration scheme (formulation completed and verified, implementation in-progress)
(3) Bi-linear cohesive zone fracture model (formulation completed and verified, implementation also complete)
(4) Integration of the finite-element engine with the Visual LTC GUI (to be performed in Q3 and Q4 of 2009)

Task 5 - Modeling of Asphalt Mixtures Contraction and Expansion Due to Thermal Cycling

Nothing to report.

Task 6 – Validation of new specification

Nothing to report.

Task 7 - Development of draft AASHTO standards and Final Report

Nothing to report.