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**Project Title:** Investigation of Low Temperature Cracking in Asphalt Pavements - National Pooled Fund Study  
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**CTS Project #** 2005008      **Contract #** 81655      **Work Order #** 128      **Authorization Date:** 8/9/2004

**Funding Source:**

Mn/DOT

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**Task Update**

**1 Literature review**

A comprehensive literature review of previous and current research efforts in the area of low temperature performance of asphalt pavements will be conducted at the beginning of the project. The review will include research performed in asphalt materials characterization, experimental results analysis and modeling, pavement system analysis and modeling and pavement performance related to low temperature behavior of asphalt pavements.

**Deliverables:** Literature Review-summary report

**Task Budget** \$15,000.00

**Task Due Date (calculated):** 12/9/2004

**Date Delivered (reported by PI):**

**Task Approved:** No      **Date Approved (CTS received task approval) :**

**Progress:** The literature review has been 99% completed. Additional information about new testing recently published will be added and the review will be submitted at the end of this quarter.

A letter report will be submitted by January 15, 2006.

**2 Identify pavement sites and laboratory materials**

Two sets of materials will be investigated in this study. The first set consists of materials that have been used in already built pavements for which performance information is well documented and readily available. The second set consists of laboratory prepared specimens following a statistically designed test matrix.

**Deliverables:** Description of field sites, field specimens and laboratory materials used in the analysis-summary report

**Task Budget** \$20,000.00

**Task Due Date (calculated):** 12/9/2004

**Date Delivered (reported by PI):**

**Task Approved:** No      **Date Approved (CTS received task approval) :**

**Progress:** This task has been almost completed.  
Minnesota has delivered field samples from all seven sites.  
Wisconsin has delivered field samples from both sites (with help from MTU research team)  
Illinois has delivered samples from one of the two sites selected (with help from UIUC research team)  
North Dakota has delivered a limited number of core from one of the sites that was not selected as a top priority (18)

At the December meeting between the four universities and MnDOT it was decided to submit task 2 report with the information available at the end of this quarter. Additional information related to this task will be added in the final report

A letter report will be submitted by January 15, 2006.

**3 Laboratory specimen preparation and experimental testing**

In this task both current testing protocols, such as creep and strength for both asphalt binders and mixtures and DSR for asphalt binders and newly developed testing protocols, such as hollow cylinder test, single edge notched beam (SENB) test, semi circular bend (SCB) test, will be performed on a common set of asphalt binders and mixtures. This approach will allow determining the best testing protocol and data analysis for selecting the most fracture resistant asphalt materials. It also allows bringing together the asphalt binder and asphalt mixture specifications. In order to minimize the effect of specimen preparation on the test results, all gyratory compacted specimens will be prepared at the MTU facility. For the beam specimens, MTU will prepare the specimens required for the TSRST and UIUC will prepare the specimens for the SENB test. MTU will also extract and recover the binders from the field mixture samples investigated. The University of Wisconsin will perform the aging of the 10 binders used in the test matrix shown in table 2. The polymer-

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modified binders will be RTFOT-aged using a modified RTFOT procedure developed under NCHRP 9-10 project. The test methods used to evaluate mechanical and physical properties of the asphalt binders and mixtures are summarized in Table 3. The laboratory tests will be conducted on the field collected samples and the specimens prepared in the lab as described in Tables 1 and 2. It is suggested that for the fracture, creep, and strength the PG 40 and 34 binders and mixtures tests will be performed at 36, -30, and -24°C and for the PC 28 and -22 binders and mixtures at 30, -24, and -18°C. For the TSRST different cooling rates that simulate real field thermal conditions will be used. The fracture tests and TSRST on asphalt mixtures performed at the University of Minnesota will be monitored using acoustic emission (AE) techniques to investigate the crack propagation mechanism at micro structural level. University of Wisconsin will be responsible with determining, using dilatometric methods, the coefficient of thermal expansion /contraction for the asphalt mixtures and binders investigated that represents a critical parameter in the development of thermal stresses in asphalt materials.

Deliverables: Description of the laboratory procedures used in the experimental investigation and of the raw data-summary report (includes test results data base)

Task Budget \$350,000.00

Task Due Date (calculated): 12/9/2005

Date Delivered (reported by PI):

Task Approved: No Date Approved (CTS received task approval) :

Progress: The next paragraphs detail the progress for each of the participating universities.

#### Michigan Tech/Iowa State

Michigan Tech acquired the remaining PG58-40 binder from Flint Hills of Minnesota. The remaining gyratory samples were compacted and delivered to the research team with the exception of the PG58-40 ones not being delivered. The samples for compacting the slabs were batched out and are ready for compaction. The MTU/ISU research team summarized all of the bulk specific gravity test results and mix designs.

Iowa State will deliver the remaining binders and gyratory compacted samples to the appropriate research team members. Iowa State will also complete the procurement of all slabs in the next quarter and will deliver them to the research team members. The ISU team will put together a database for sharing with other researchers the characteristics for samples procured to facilitate a common set of data for analysis. The Iowa State research team begin conducting some statistical analysis on mix and binder test results.

#### UW at Madison

Out of the 10 binders, 8 were aged. The two missing binders will be delivered by MTU by the end of January 2006. Additional aging will be performed on all ten binders to increase the amount needed for rheological testing and glass transition measurements.

The asphalt core mixtures supplied so far were cut and trimmed to the standard size used for the Tg test. A number 42 samples were prepared and are ready for Tg test.

Currently the Tg machine is undergoing calibration and as soon as the calibration is finished testing will commence a full speed. It is the desire of Wisconsin team to complete all the Tg tests (for both binders and mixtures) before the end of the first quarter of 2006.

#### UIUC

UIUC researchers have begun fracture tests on the laboratory mixtures and samples from MnRoad. The results follow expected trends; i.e., higher fracture energy at the higher temperature, higher energy for lab samples as compared field samples, and higher fracture energy for mixtures with more ductile (modified) binders.

The environmental chamber and refrigeration unit at the ATREL lab has been successfully upgraded to allow testing down to -42°C, the lowest temperature required for this study. In addition, the cutting equipment has been modified that it can now accommodate all size beam samples from the field for sample fabrication.

#### UofM

IDT creep and strength tests and SCB fracture tests were finished on the first 7 mixtures received from MTU. All test specimens were cut and notched for the laboratory prepared mixtures delivered by MTU. Only one mixture set is missing, the PG-58-40, which will be delivered by the end of January.

#### 4 Analysis of experimental results

All experimental results from testing field samples and laboratory specimens will be incorporated into an Access database that will be delivered at the end of the project as part of the final report. The database will also include any relevant information about the material tested, such as construction information, pavement system information (layer thickness, granular materials and soil information, etc), and environmental information for the field samples, as well as volumetric, sample preparation and aging and any other relevant information for the laboratory prepared specimens. University of Minnesota and MTU will be primarily responsible for developing the database. The analysis of the test results will involve all four universities. The analysis will focus on finding the most promising experimental parameter for selecting the most crack resistant materials and for correctly analyzing the crack propagation mechanism in the pavement system and predicting performance. The comprehensive test matrix detailed in Table 2 will allow investigating the effect of the test method on material parameters, such as the fracture toughness obtained in the SENB and SCB configurations. It will also allow developing useful correlations between the different material parameters obtained from the different test methods include in the test matrix. For example

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correlations between the rheological and the fracture properties of asphalt materials will be investigated. Particular emphasis will be placed on the role of temperature on the mechanical properties of asphalt materials. An important priority will be given to investigating the contribution of each of the asphalt mixture components and their interactions to the fracture resistance of the mixture, with emphasis on the role played by the asphalt binder and the binder-aggregate interaction. A series of statistical analyses will be done consistent with the developed experimental plan. The analyses will include means tests, such as Student-Newman Keuls and Duncan's Multiple Range Test, to examine the effects of the independent experimental variables on thermal cracking for the various performance tests. The analyses will also provide a relative ranking of importance of the independent variables on thermal cracking potential. Additional statistical methods such as Ridge Regression will also be considered as appropriate. It is expected that this task will result in testing protocols that will improve the current selection process of asphalt binders and mixtures with enhanced low temperature cracking resistance. They will also provide better temperature dependent material parameters that will be incorporated in the analysis tools developed in task 5 to reasonably predict the field performance of asphalt pavements exposed to low temperatures.

Deliverables: Analysis of test results-summary report

Task Budget \$113,700.00

Task Due Date (calculated): 2/9/2006

Date Delivered (reported by PI):

Task Approved: No Date Approved (CTS received task approval) :

Progress: The analysis of the experimental results has started and progresses almost at the same pace as the experimental work progress. It is expected that significant progress will be made toward the completion of this task once the majority of the specimens and samples are tested and analyzed.

#### 5 Modeling

In developing a rigorous understanding of thermal cracking mechanisms, an integrated study involving bench-scale laboratory fracture testing and full-scale experiments and field sections is essential. Fracture modeling is a critical element to this approach, as it provides two critical "links," namely:

1) the ability to properly interpret bench-scale laboratory test results (to obtain fundamental material properties/minimize size effects), and 2) the ability to accurately extend fracture models to full scale, in order to develop an accurate and complete description of thermal cracking mechanisms. A key component of this study will involve the reexamination of the mechanisms of thermal cracking by applying modern computational fracture mechanics models. As a short summary, discrete fracture and damage tools will be utilized to model crack initiation and propagation in pavement systems using the finite element method code I-FRANC2D (Illinois Fracture Analysis Code in Two Dimensions). The research team will also utilize cohesive fracture models and damage models in specially designed subroutines developed for the commercially available finite element code ABAQUS. These models can predict crack nucleation, initiation, and propagation in 2D or 3D, and have been applied recently to examine mixed-mode crack propagation (tension and shear), which would obviously be present if traffic loads were to combine with thermal loads to create a critical condition. This work will also include refining a simple model recently developed at the University of Minnesota to predict the crack spacing and the lateral movement of the crack using 2D (or 3D if necessary) viscoelastic analysis based on the cohesive-frictional characteristics of the subgrade, the constitutive properties of the asphalt mixture and the thermal history of pavement system.

Once the mechanisms of thermal cracking are better understood, the researchers will be in a much better position to determine the best approach for recalibration and/or modifying the existing TCMODEL program in the 2002 Design Guide and to recommend appropriate testing protocols to support this approach. One area where considerable emphasis will be placed is in the evaluation of the current crack propagation model in TCMODEL. While thermal fatigue cracking might be a contributor to pavement deterioration in some areas, the control of single event thermal cracking must remain a top priority due to its devastating effect on pavements in cold climates.

Furthermore, the control of single-event thermal cracking in many cases should provide an inherent factor of safety against thermal fatigue cracking.

It is anticipated that the new analysis tools proposed herein will allow researchers to:

Apply a true fracture propagation model in the study of thermal cracking mechanisms.

Improve response modeling to include 3-D effects (current model is 1D).

Utilize data from low-temperature fracture tests.

Allow consideration of multiple AC layers, and material property gradients within layers (both temperature and aging related should be considered).

Combine thermal and mechanical loads (thermo-mechanical analysis).

Integrate testing and modeling program

Deliverables: Modeling-Summary Report

Task Budget \$113,000.00

Task Due Date (calculated): 6/9/2006

Date Delivered (reported by PI):

Task Approved: No Date Approved (CTS received task approval) :

Progress: UIUC team has completed the development of simplified reference solutions for thermal crack development and thermal crack spacing in asphalt pavements. Closed-form 2D solutions were developed and compared to earlier 1D predictions and 2D solutions generated by the finite element method. We have also employed some available micromechanical models in a unique manner which will allow us to better understand links between binder and mixt test results.

In the next quarter, we will begin the simulation of thermal crack development in field sections. We will begin to compare the results of the thermal cracking model in the current AASHTO ME design guide software (TCMODEL) to those predicted by the finite element method using the mixture fracture properties obtained in this study. This task w

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continue over the next two quarters.

**6 Draft Final Report**

A draft final report detailing the work performed in the previous five tasks will be delivered at the end of this task. The draft final report will be prepared, following the Mn/DOT publication guidelines, to document project activities, findings, and recommendations. This report will be submitted through the publication process for technical and editorial review. The report will also contain the following:

Access database containing all the experimental results as well as additional information on the field samples and laboratory prepared specimens.

Proposed test protocols (experimental set up and data analysis) for selecting asphalt binders and mixtures with enhanced fracture resistance to low temperature thermal cracking Software and documentation describing a new fracture mechanics-based thermal cracking program (improved TCMODEL).

Deliverables: Draft final Report

Task Budget \$20,000.00

Task Due Date (calculated): 8/9/2006

Date Delivered (reported by PI):

Task Approved: No Date Approved (CTS received task approval) :

Progress: Nothing to report

**7 Final Report Completion**

During this task, technical and editorial comments from the review process are incorporated into the document as appropriate. Reviewers will be consulted for clarification or discussion of comments. A revised final report will be prepared and submitted for publication.

Deliverables: Final Report

Task Budget \$33,300.00

Task Due Date (calculated): 12/9/2006

Date Delivered (reported by PI):

Task Approved: No Date Approved (CTS received task approval) :

Progress: Nothing to report

**Future Plans:** The PI has contacted Tom Harman at FHWA, who agreed in principle to let the research team use the TSRST equipment existent at Turner Fairbanks and offer guidance in performing TSRST tests once the laboratory prepared beams become available. Further details will be discussed at TRB in January. A brief project meeting between the Universities and the participant states available will be held at TRB on Sunday January 19. A full blown meeting will take place at MnDOT Maplewood facility on February 6 and 7.

**Problems Encountered/Actions Taken.** The Iowa State research team will transfer the responsibility of testing indirect tensile test specimens to the University of Minnesota and reduce the total contract amount from \$135,500 at Michigan Tech and Iowa State to \$117,500. The remaining contract monies are \$92,276.67 and have expired at Michigan Tech on December 1, 2005. A new sub contract at Iowa State will need to be signed for the remaining monies in the amount of \$74,276.67 which takes into account the aforementioned transfer of \$18,000 to the University of Minnesota for the indirect tensile testing.