QUARTERLY REPORT 10/1/2004 - 12/31/2004

CENTER FOR TRANSPORTATION STUDIES

Project Title: Investigation of Low Temperature Cracking in Asphalt Pavements - National Pooled Fund Study 776

CTS Project # 2005008 **Contract #** 81655 **Work Order #** 128 **Authorization Date:** 8/9/2004

Funding Source:

Mn/DOT

Administrative Liaison: Jim Klessig **Technical Liaison:** Ben Worel

Principal Investigator: Mihai Marasteanu **Department:** Civil Engineering

Phone Number (612) 625-5558 **E-Mail Address:** maras002@tc.umn.edu

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 from MN/DOT) :

Progress: The University of Minnesota continues work on the literature review. Additional information is expected to come from UIUC researc team.
The review will be delivered in the next quarter to allow incorporating some new developments that will bepresented at TRB meeting in January.

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 from MN/DOT) :

Progress: A from was developed and sent out to all participating states. Based on the nominated sites a priority list will be developed and detailed sampling instruction for the selected sites will be sent out. A meeting is scheduled during TRB in January 2005 to discuss the progress of the field sampling.

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-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 -24ºC and for the PG 28 and -22 binders and mixtures at 30, -24, and -18ºC. 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 from MN/DOT) :

Progress: Michigan Tech team has identified and acquired the two aggregates to be used for preparing the laboratory specimens. The two binder sources will be identified following the project meeting at TRB.
University of Minnesota has started work to refine their acoustic emission detection capabilities and to perform fracture tests on asphalt binders.
University of Illinois started work on the use of the compact tension test for low temperature fracture testing.

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 parameters 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 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 from MN/DOT) :

Progress: No activities to report.

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 from MN/DOT) :

Progress: University of Illinois research team started to look at some of the various analyses that can be used for the activities required in this task. More details are provided below:

Elastic fields of a pavement resting on a granular base or fully bonded to an elastic base have been studied in the first quarter of the pooled fund study considering the presence of thermal cracks typically observed in cold climates. The analysis endeavors towards the accurate prediction of crack spacing in asphalt pavements, but will also provide a valuable series of closed-form solutions that can be used by pavement modelers to verify numerical solutions (i.e., finite element results) against rigorously established standard solutions.
• A two-dimensional theoretical solution is derived and validated by comparison to numerical simulations. This theory has been applied to calculate the energy release rate of thermal cracking and to measure the fracture toughness of the pavement materials. A simple method for obtaining an approximation of crack spacing is presented, which involves comparison of the energy release rate and the fracture toughness of the pavement at low temperature. It is found that, given the fracture toughness of the pavement and the maximum thermal loading, there is a critical thickness of the overlay below which no crack will initiate. This critical thickness not only depends on the fracture quantities of the overlay, but also on the elastic modulus or the frictional coefficient of the base layer.
An extension of this work to rigorously consider crack initiation and crack propagation in the pavement and to visualize the elastic field evolution with the thermal loading is underway. For the current work, the pavement materials are assumed to be linear elastic, but a viscoelastic constitutive model for the bulk material and nonlinear temperature field along the depth of the pavement will ultimately be considered. FEM simulations by DIANA will be proposed and compared with the theoretical work.
• UIUC is also in the process of recruiting a Ph.D. student who would be responsible for all mechanical testing at U of I, and would also assist with field work, laboratory data breakdown, analysis, and would conduct some numerical simulations in conjunction with Dr. Huiming Yin and the two faculty PIs on the project. An offer has recently been made to an outstanding candidate.

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 crackingSoftware 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 from MN/DOT) :

Progress: No activities 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

QUARTERLY REPORT 10/1/2004 - 12/31/2004

CENTER FOR TRANSPORTATION STUDIES

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 from MN/DOT) :

Progress: No activities to report

Future Plans:

Problems Encountered/Actions Taken:

Michigan Tech University and University of Wisconsin are still working on submitting the paperwork for starting the subcontract.