QUARTERLY REPORT 1/1/2006 - 3/31/2006

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: Yes Date Approved (CTS received task approval) : 4/14/2006

Progress: A letter report was submitted on February 14, 2006.

2 Identify pavement sites and laboratory materials

The University will investigate two sets of materials 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: Yes Date Approved (CTS received task approval) : 4/14/2006

Progress: A letter report was submitted on February 15, 2006.

3 Laboratory specimen preparation and experimental testing

The University will perform 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) 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 -24C and for the PG -28 and -22 binders and mixtures at -30, -24, and -18C. 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 progress of the testing activites part of task 3 are detailed in an excel spreadsheet on the pooled fund web site.

Iowa State
Iowa State delivered the remaining gyratory compacted specimens to the University of Minnesota and University of Illinois. All of the remaining asphalt binders were delivered to the University of Wisconsin via University of Minnesota. Iowa State established an initial spreadsheet database for the research team members to populate. Suggested revisions to the database are in progress.

Next quarter, the compaction of the slabs for the TSRST and dilatometric test will be started. IT is anticipated that the work will be finished by the end of the next quarter.

UW at Madison
New devices were designed and installed to Tg equipment. The new devices enable automation of Tg measurement under various thermal loading conditions. The system was fully calibrated and interfaced with a computer to control temperature changes and to automatically measure pressure as a function of time. Due to the unexpected delays in the development of the set-up, it was decided to postpone this development and utilize the manual method used before for the first phase of the project. The task of development of the automated system will be continued only if the PI and the research team will agree to it. Discussion of the data will be scheduled for the next research team meeting in MN.

A new software was installed to control the temperature change rate. This was necessary due to changes in the liquid nitrogen set-up used for cooling. The new software was made more users friendly and the temperature reading were validated several times to assure accuracy.

After calibration of new equipment, the Tg for all binders were determined. At the time this report was written analysis continued and there are some concerns about agreements between the two dilatometers used. Due to accidental breakage of one of the capillary tubes, it is suspected that the internal diameter is causing the difference. This will be carefully resolved in the next 2 weeks and a detailed report of the TG values for all binders will be delivered.

UIUC
All Superpave Gyratory Compacted samples have been delivered to UIUC, for a total of 28 mixtures. Of these samples, 29.9% have been tested for the Disc-Shaped Compact Tension [DC(T)]. We have not conducted any Single-Edge Notched Beam [SE(B)] tests. 11 field sample sets have been delivered for both DC(T) and SE(B) testing. Overall, we have completed 30.3% of the DC(T) testing and 45.5% of the SE(B) testing for field samples.
We have completed all of our testing at -42C and are one testing day away from finishing at -36C. Based on the samples remaining, and their corresponding testing temperatures, we should be completed with all DC(T) testing within 28 testing days.
UIUC has completed the testing and preliminary analysis of the SE(B) samples from MnROAD.

Over the next quarter, UIUC plans to finish testing the lab produced samples for the DC(T). In addition, we will perform IDT creep, E*, and Coefficient of Thermal Expansion and Contraction verification for three mixtures.

UofM
The Semi Circular Bend fracture test was finalized for all 28 mixtures; this required testing a total of 252 SCB specimens cut from gyratory compacted cylinders. One out of three replicates was monitored using Acoustic Emission.
IDT creep and strength testing was performed on 9 of the 28 mixtures. It is anticipated that this testing will be completed by the middle of the next quarter.

Next quarter:
Testing will be started in the second part of the next quarter on the field samples. It is expected that all SCB and IDT work will be done by the end of the next quarter.
Also, the TSRST work will be started by UofM grad student at Turner Fairbanks facility. It is expected that this work will be finalized by the end of July.

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) :

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), ntegrate 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: Analytical baseline solutions for thermal cracking have been completed, the details of which have been discussed in previous quarterly reports and project meetings. The UIUC research team is currently in the midst of developing numerical thermal cracking models, which will be used to study the field projects in the LTC study. A demonstration of the models will be given at the next project meeting. In addition to pavement modeling, we have also made some progress in the development of models which can be used to predict asphalt mixture low temperature properties from binder low temperature properties. This is important, since many agencies will not have access to mixture mechanical test equipment in the foreseeable future; however, they do have Superpave PG binder data routinely available. The following sections provide some details concerning this progress.

Pavement Modeling Progress at UIUC

A two-dimensional cohesive zone model for low temperature cracking of asphalt pavements is under development with the finite element code ABAQUS. A bilinear traction-separation law is employed to simulate the crack nucleation and propagation. Viscoelastic properties of bulk materials are used in the finite element code. A real time simulation of low temperature cracking in MnROAD sections will be conducted this quarter using the testing data from the University of Illinois and the University of Minnesota. The results will be further compared with the proposed analytical model and field observation.

Mixture Property Prediction Model Progress at UIUC

Asphalt materials exhibit viscoelastic behavior across a large temperature range, which is often described by complex moduli. Micromechanical models have been directly adopted to predict the effective complex modulus of asphalt materials from the mechanical properties of their constituents. Unfortunately, two important issues are ignored: the micromechanics models employed are based on elastic theory, which does not rigorously consider the viscous effect of binders, and the models were originally developed for composites containing equally-sized spherical particles, and thus, an upper limit of the volume fraction of aggregate particles is implied. However, because the size and the shape of aggregates are not normalized, the effective volume fraction of aggregates can significantly exceed the valid working range of these models. As a result, previous efforts to fit experiments have been conducted by introducing additional phenomenological parameters that increased the complexity of the models.

To address these deficiencies, a viscoelastic solution for one particle embedded in the infinite domain has been developed. Based on various micromechanics-based homogenization methods, four models have been adapted and evaluated, as the follows:1.The dilute model; 2.The self-consistent model; 3.The Mori-Tanaka model; 4.The generalized self-consistent model.

The connection and difference between these models have been studied, and the predictions compared with the experimental data for asphalt mastics. The self-consistent model provides the best agreement with the experimental results; the Mori-Tanaka model and the generalized self-consistent model underestimate the viscoelastic properties; whereas the dilute model considerably overestimates the experimental results. The analyses presented herein also suggest that the conventional assumptions of incompressible binders and rigid fillers are invalid for asphalt mastics at low temperatures. The extension of this study to asphalt mixtures is underway, in which the high volume fraction of aggregates should be carefully addressed.

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: a) Access database containing all the experimental results as well as additional information on the field samples and laboratory prepared specimens, b) 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) :

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 research teams and staff from Mn/DOT and some of the participant states met in February at University of Minnesota. The research teams presented the progress of their work and received comments and suggestions from the state participants. Except for the delay due to the difficulties in obtaining the materials required to prepare the laboratory specimens the activities are on track. At the end of a very constructive meeting details of the phase-II of the project were discussed. Phase II has already been posted by Mn/DOT.

All four universities are working on completing task 3 as soon as possible to be able to finalize the bulk of the analyses by August. Although the completion of the draft final report will be slightly delayed, the research team is confident that most of the significant findings and conclusions of this work will be presented at the TAP meeting at the beginning of August.

Problems Encountered/Actions Taken: The PI submitted a no cost time extension requesting a 6 month extension. At the same time, a revised work plan that divides task 3 in ten smaller tasks, and task 5 in two smaller tasks was also submitted for approval.

Iowa State and the University of Minnesota are in negotiations on the subcontract at this time. The subcontract stipulates that Iowa State will procure slabs for the University of Illinois for their mix testing program. The original contract stipulated that the University of Illinois would procure their own slabs for mix testing.