QUARTERLY REPORT 1/1/2005 - 3/31/2005

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

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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 University of Minnesota continued to work on the literature review. Additional information was also received from UIUC research team focusing in the area of TCMODEL and recent recalibration efforts under NCHRP 1-37A, fracture testing of HMA, and advanced modeling of flexible pavement systems to consider viscoelasticity and fracture. The final version of the literature review is in its final stage and it will be delivered at the begining of next quarter.

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: Two meetings were held at TRB and AAPT national meetings and the final details of the site nominations process have been finished. It is expected that the site selection will be finalized at the very begining of the next quarter and that the field samples will be collected by the end of the next quarter.

The MTU team has done the following for the laboratory prepared specimens study:

1. Identified asphalt binders for use in the study with Marathon, Seneca and Murphy.
2. Ordered and drop shipped 5-gallon buckets to Marathon for collecting asphalt binders.
3. Identified the two aggregate sources to be used in the study from Wisconsin (granite and limestone).
4. Arranged for sampling and picking up the granite aggregate.

The asphalt binders from Marathon are ready to be picked up. MTU just picked up earlier this week some of the granite aggregate and are in the midst of drying, splitting, characterizing and verifying the supplied mix design.

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) :

Progress: The UofM team is continuing the laboratory activities in preparation for testing the mixture samples and lab prepared specimens and have made further progress with the acoustic emission analysis and with the asphalt binder fracture testing.

University of Illinois continued work on the use of the compact tension test for low temperature fracture testing. The UIUC ATREL laboratory (Advanced Transportation Research and Engineering Laboratory) is being prepared for the receipt of specimens and start of fracture testing. Machine calibration, sample receiving procedures, and sample storage preparations are being coordinated in anticipation of the samples being collected and prepared by the Michigan Tech team. The team is collaborating with the UIUC NSF GOALI reflective cracking team (led by prof• s Paulino and Buttlar) to share testing and data analysis techniques that are applicable to the LTC study via weekly combined project meetings.

The following upcoming publications (accepted and/or in press) related to fracture testing are relevant to the LTC project and will be gladly furnished to any interested LTC participants upon request:

Wagoner, M. P., Buttlar, W. G., and G. H. Paulino, • Disk-Shaped Compact Tension Fracture Test: A Practical Specimen Geometry for Obtaining Asphalt Concrete Fracture Properties,• Experimental Mechanics, In Press, 2005.

Wagoner, M. H., Buttlar, W. G., and G. H. Paulino, • Development of a Single-Ended Notched Beam Test for Fracture Testing of Asphalt Concrete,• Accepted for Publication in the ASTM Journal of Testing and Evaluation, 2005.

Wagoner, M. P., Song, S.H., Buttlar, W. G., Paulino, G. H., and P. I. Blankenship, • Investigation of the Fracture Resistance of Hot-Mix Asphalt Concrete Using a Disk-Shaped Compact Tension Test,• Accepted for Publication in the Journal of the Transportation Research Board, National Research Council, National Academy Press, Washington, D.C., 2005.

University of Wisconsin has finalized the contract agreement and is in the process of finalizing the last details of the dilatometric tests to be performed starting with the next quarter.

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: No activity reported.

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: Dr. Huiming Yin of the UIUC research team has made significant progress in developing a model to predict the heat flux and temperature distribution in layered pavements. A multiscale model has been developed to solve the effective thermal conductivity of asphalt mixtures considering particle (aggregate) interaction. This comprehensive model can also predict the effects of material gradients such as vertically-graded air void levels, graded moisture content above the groundwater table, and intermingling of coarse aggregates along the interface between different layers. Once the temperature field is known, the thermal stress in the pavement can be computed using the mechanical boundary condition of the pavement structure and the estimated effective coefficient of thermal expansion (CTE) of the asphalt mixtures. The UIUC team will work with the Wisconsin research team to validate the new models with laboratory-measured thermal coefficients. The extension of the model to predict viscoelastic mixture properties from the properties of the binder and aggregate is possible, and will be pursued towards the end of the LTC project if time permits.

The finite element program Diana has been received by the UIUC team and preliminary use of the new program is underway. This model will be used to study the mechanisms of thermal crack development and propagation. This sophisticated model can handle viscoelasticity, frictional sliding/contact surfaces, cohesive zone fracture modeling, and thermo-mechanical loading. It can be used to model laboratory fracture tests so that suitable data interpretation methods can be developed.

Next quarter
The development of a viscoelastic constitutive model for the bulk material is just underway and will be completed by

the UIUC research team in the next quarter. Modeling of laboratory tests and preliminary models of field sections will be developed in the next quarter. In particular, we will begin to develop a model to simulate the TSRST test based using a viscoelastic analysis with crack initiation and propagation. We will study the importance of end effects and accelerated cooling rates on test results. The main challenges in the development of this model will be to extend the 2D cohesive zone fracture model to 3D (underway) and to add temperature- and loading-rate sensitivity to the fracture model. Similar models will be developed for the other laboratory fracture tests that will be used in this project. Ultimately, the models will allow researchers to develop improved analysis methods for data interpretation and will assist in the selection, development, and hopefully simplification of laboratory tests for use in mixture design.

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) :

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

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: No activities to report.

Future Plans:

Problems Encountered/Actions Taken: