QUARTERLY REPORT 7/1/2005 - 9/30/2005
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

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) :

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. More references will be added to better reflect the devlopment and use of the TSRST test.

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 completed; no formal report has been submitted due to possible problems with obtaining all the binders in the test matrix. At the meeting at the binder ETG in Madison, WI in July it was decided to replace one of the PG58-40 binders with a PG62-22. It was also decided not to use the PG70-22 at this time although the binder was collected by MTU.
The only missing binder is the PG58-40 that will become available in November.

In terms of field samples no progress was made with the sites selected in North Dakota. It is expected to collect the field samples from Wisconsin and Illinois by the end of next quarter. All samples from Minnesota have been collected already.

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 next paragraphs detail the progress for each of the participating universities.

MTU (Iowa State)
Work Complete
Michigan Tech acquired all but one asphalt binders for the research project. One binder, PG58-40, remains unavailable for the research project. Flint Hills of Minnesota is anticipating producing the last binder towards the end of the 2005 construction season. Michigan Tech completed procuring all of the gyratory compacted specimens for the granite mix design with the exception of three binders. The limestone mix design was completed. All of the granite and limestone aggregates have been dried and sieved. Two field projects were sampled by the Wisconsin DOT with the assistance of Michigan Tech and the field samples delivered to the other three research universities. Michigan Tech also delivered MN/Road samples and granite mix design samples to the University of Wisconsin and the University of Illinois.

UW at Madison
After receiving asphalts and mixture beams, the different tasks done are the following:

• Aging of binder (RTFO and PAV): To be on the safe side aging of all binders was done at WisDOT labs, according to their schedule. The materials aged were:

1• PG 58-34 elvaloy
2• PG 58-28 neat
3• PG 58-28 neat
4• PG 64-34 elvaloy
5• PG 64-28 neat
6• PG 64-28 sbs
7• PG 64-22 neat
8• PG 70-22 sbs

• Cutting mixture beams: some trial cuts in the Geological Department at UW were made, after proofing the saw equipment. The time consumed for each beam is around 8 hours and it is necessary to check regularly how the saw is working. The cut beams are from all core section.
Total cut beams: 10 beams

• Preparing sample to start Glass Transition Test:
Total samples: 8

UIUC
The University of Illinois Urbana-Champaign (UIUC) has made steady progress in the Investigation of Low Temperature Cracking in Asphalt Pavements, National Pooled Fund Study 776. So far we have received seven different mixtures of Superpave Gyratory Compactor laboratory samples from Iowa State for Disc-Shaped Compact Tension (DC(T)), coefficient of thermal expansion and contraction (α), dynamic modulus (E*), and creep compliance testing; field cores and beams from five MnRoad sections; field cores and beams from two Wisconsin highways; and field cores and beams from two Illinois highway sections. We have enough field cores and beams to adequately perform DC(T), α, E*, creep compliance, and Single-Edge Notch Beam (SE(B)) testing.

UIUC began testing for DC(T) on five of the mixtures from Iowa State. We have DC(T) data collected for two 58-28 neat mixtures, one 64-28 neat mixture, and one 64-28 modified mixture at -30C and -18C with 4% air voids and one 58-28 neat mixture at -30C and -18C with 7% air voids. We also have DC(T) data collected on two of the sections from MnRoad, the 58-28 neat section and the 120/150 neat section, at -30C and -18C. We will continue to test field samples from MnRoad, Wisconsin, and Illinois for the DC(T). We are currently in the middle of compiling and analyzing the DC(T) data and will present it, plus the data that we collect this month, at the next LTC meeting in December.

Lastly, the environmental chamber at UIUC is being upgraded for the LTC project. Currently, the environmental chamber is only rated to reach -30C. We solicited and accepted a quote to modify our environmental chamber to reach -45C in order to test the -34 and -40 binders to their lowest temperatures. This modification should be done by the end of the year.

UofM
IDT creep and strength tests and SCB fracture tests are in progress on the 7 mixtures received from MTU. It is expected that the tests on these laboratory prepared specimens will be completed by the middle of 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: The analysis of the experimental results has started and progresses almost at the same pace as the experimental work progress. A meeting of the four universities and the lead state Minnesota is scheduled for December 12; it is expected that additional coordination between the analyses performed by the four universities will be discussed at that meeting.

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: In addition to their progress in testing, UIUC has been working on the modeling of asphalt mixtures in relation to low temperatures. To develop micromechanical models for asphalt materials, a viscoelastic solution for one spherical particle embedded in the infinite viscoelastic matrix is considered. Various homogenization methods were adopted to obtain particle and matrix• s averaged strains changing with the external sinusoidal loading, and thus several micromechanics-based models were developed. A critical evaluation of these models for viscoelastic mixtures was conducted by comparisons with the existing experimental data and parametric analysis. Along with developing micromechanical models for viscoelastic asphalt materials, we proposed a differential scheme to simulate the high volume fraction of asphalt mixtures. Finally, we simulated the fracture behavior of asphalt pavements by investigating the elastic solution for asphalt overlay bonded to different substrates such as granular, flexible, and rigid substrates. Fully and partially cracked overlays were considered. The following page is a summary of journal papers and conference presentations and papers from the LTC project.

Journal Papers:
1. H.M. Yin, G.H. Paulino, W.G. Buttlar, L.Z. Sun, Effective thermal conductivity of functionally graded composites, Journal of Applied Physics, 98, 063704, 2005.
2. H.M. Yin, W.G. Buttlar, G.H. Paulino, Periodic thermal cracking in an asphalt overlay bonded to a rigid pavement, Journal of Structural Engineering - ASCE (Submitted).
3. H.M. Yin, G.H. Paulino, W.G. Buttlar, L.Z. Sun, Micromechanics-based thermoelastic model for functionally graded particulate materials with particle interactions, Journal of the Mechanics and Physics of Solids (Submitted).

Conference Presentations and Papers:
1. H.M. Yin, W.G. Buttlar, G.H. Paulino, 2006, Micromechanics-based viscoelastic model for asphalt mastics and mixtures, 10th International Conference on Asphalt Pavements. August 12-17, Quibec, Canada (Accepted).
2. H.M. Yin, W.G. Buttlar, G.H. Paulino, 2005, Investigation of low temperature cracking in asphalt pavements, Abstract book of 8th U.S. National Congress on Computational Mechanics. July 24-28, Austin, TX.
3. H.M. Yin, G.H. Paulino, W.G. Buttlar, 2005, Effective thermal conductivity of graded particulate composites, Abstract book of 8th U.S. National Congress on Computational Mechanics. July 24-28, Austin, TX.
4. H.M. Yin, W.G. Buttlar, G.H. Paulino, 2005, A two-dimensional elastic model of pavements with thermal failure discontinuities, 3rd MIT Conference on Computational Fluid and Solid Mechanics, p. 539-542, June 14-17, Boston, MA.

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: 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: Delays in the preparation of the laboratory gyratory and slab-compacted mixtures due to problems with obtaining the raw materials (aggregates and binders) and with the delivery of specimens will most likely extend the duration of task 3 to the end of June next year. Most likely the other tasks will be impacted less in terms of their delivery date. It is not clear at this time if North Dakota will deliver their field samples in due time for the completion of this project.

Problems Encountered/Actions Taken: Any budget issues related to the delay in the completion of task 3 will be discussed at the meeting between MnDOT and the four universities at the beginning of December.