Low-Temperature Cracking in Asphalt Pavements
Low-Temperature Cracking

- Adequate fracture resistance essential for asphalt pavements in northern US and in Canada

- Low-temperature cracking represents the prevalent distress in Minnesota and neighboring states
National Technical Advisory Panel

Provides technical insight to the participating states and the four Universities

August 2003 Initial Meeting
University of Minnesota
Low Temperature Cracking Pooled Fund
State Participation

Connecticut
Idaho
Iowa
Illinois
Kansas
Minnesota
North Dakota
New York
Vermont
Wisconsin
Washington

FHWA

http://www.pooledfund.org
Low Temperature Cracking Pooled Fund (Overall Plan)

- State Field Samples (Good / Poor Performance)
- Laboratory Prepared Samples

Laboratory Testing

Verify Models

Field Validation of Results (Test Sections)

Phase 1

Phase 2
Pooled Fund Study Goals

- Development of test methods / protocols for LTC
  - What is the best test for binders and mixtures?
- Validate / refine MEPDG thermal cracking model
- Establish guidelines for MnROAD field validation
Current status

- Field sites were selected from nominated sites submitted by participating states
  - Coring finished
- Laboratory prepared specimens
  - Iowa State finished preparing most specimens
- Testing in progress at the U, UIUC and WISC
- Development of model and analysis tools in progress at UIUC
## Field Samples

<table>
<thead>
<tr>
<th>State</th>
<th>Road</th>
<th>Asphalt Binder</th>
<th>Performance (1=Good) (5=Bad)</th>
<th>Age (Years)</th>
<th>Pavement Comment</th>
<th>Recommendation</th>
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</thead>
<tbody>
<tr>
<td>IL</td>
<td>US-20</td>
<td>AC-10, AC-20</td>
<td>2</td>
<td>20</td>
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<td>IL</td>
<td>I-74</td>
<td>AC-20</td>
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<td>15</td>
<td>original surface will soon be milled and replaced</td>
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<td>MN</td>
<td>Cell 33</td>
<td>PG 58-28</td>
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<td>ND</td>
<td>SH-18</td>
<td>120/150</td>
<td>4</td>
<td>8</td>
<td>A thin lift overlay has been placed over part of this project</td>
<td>Not recommended: overlay placed on original pavement</td>
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<td>US-45</td>
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<td>subbase stabilized with asphaltic base course</td>
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Field Samples

LVR - Cell 33

- 25' core area
- 500'
- Wheel path
- 102 kip
- Wheel path
- 80 kip
- Wheel path
- Sta 63+75 (up close to edge)
- Sta 68+75 (up close to edge)
- 6" core
- 6" core
- 6" core
- 6" core
- 6" core
- 6" core
- (3) 6" x 18" x depth beams
- 24" center to center
- 18" slight spacing if necessary
MnROAD Coring
MnROAD Slab Cutting
MnROAD Sample Extraction
IL US20 Slab Extraction
# Field Samples Information

## Beams - received Spring 2005

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<thead>
<tr>
<th></th>
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<th>Spot</th>
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<td>Aggregate 2 Limestone</td>
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## Laboratory Prepared Specimens

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<th>Test Type</th>
<th>MTU</th>
<th>UIUC</th>
<th>UMN</th>
<th>WISC</th>
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<td>Creep and Strength</td>
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<td>Mixture Fracture Test</td>
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<td>Disc Compact Tension</td>
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<td>Mixture Fracture Test SCB</td>
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<td>Mixture Thermal Stress Test</td>
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<td>Binder Low Temperature</td>
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<td>Mixture and Binder</td>
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<tr>
<td>Dilatometric Measurements</td>
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</table>
Mixture and Binder Test Temperatures

- Test at 3 temperatures
  - Match 2 out of 3 temperatures for binders and mixtures
    - For mixtures 6°C do not lead to big change in properties
- Binders:
  - PG +10°C (for a -28 it will be -18°C), 6°C below it (-24°C) and 12°C below it (-30°C)
- Mixtures:
  - PG +10°C, 12°C below it, 12°C above it.
Fracture Testing - UIUC

- Disc Shaped Compact Tension
  - DC(T)
  - 1 mm/min CMOD
  - 150mm

- Single Edge Notched Beam
  - SE(B)
  - 1 mm/min CMOD
  - 50x75x375mm
Fracture Energy - $G_f$ (J/m²)

- **Fracture Energy**
- **CMOD**
- **Load**
- **Peak Load**
- **Softening**
- **Time to Peak Load**
- **$G_f$**
Effect of Temperature on Fracture Energy

Fracture Energy (J/m²)

Mixture Type

-18°C
-30°C
SCB

Frame from Bottom Support

Metal Button

Roller

Metal Button

Extensometer (for deflection)

Extensometer (for CMOD)
Fracture Energy

\[ W_f = \int Pdu \]

\[ G_f = \frac{W_f}{A_{lig}} \]

- \( W_f \): work of fracture
- \( A_{lig} \): area of the ligament
**Stress Intensity Factor $K_I$**

![Diagram of stress intensity factor calculation](image)

$$K_I = \sigma_0 \sqrt{\pi a} Y_I$$

$$\frac{K_I}{\sigma_0 \sqrt{\pi a}} = Y_I \left( \frac{s_0}{r} \right) + \frac{\Delta s_0}{r} B$$

$$Y_I(s_0/r) = C_1 + C_2 (a/r) + C_3 \exp(C_4 (a/r))$$

$$B = 6.55676 + 16.64035 \left( \frac{a}{r} \right)^{2.5} + 27.97042 \left( \frac{a}{r} \right)^{6.5} + 215.0839 \left( \frac{a}{r} \right)^{16}$$
SCB Test Plots

SCB - temperature effect on $K_{IC}$ and $G_f$
IDT - Creep and Strength

- Specification type tests
- In addition:
  - Limited creep tests at different load levels
  - Limited strength tests at different loading rates
IDT Creep Data
IDT Creep Data (BBR)
IDT Creep Data (BBR)

Test temp. -12°C
PG 70-22 modified
Granite, 4% air voids
Design asphalt content

BBR on mixture beams - 9 replicates
IDT - 3 replicates
IDT Strength Data

Graph showing the relationship between temperature (°C) and tensile strength (MPa) for different materials labeled D1, D5, E1, F1, H1, and I1.
To be performed at Turner Fairbanks

- Lab prepared beams
- Field beams
Acoustic Emission

\[ d_i = c_p (t_i - t_o) + \varepsilon_i \]

\[ d_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + (z_i - z_0)^2} \]

- \( C_p \): Wave speed - from calibration
- \( T_i \): Event arrive time - from recording
Acoustic Emission Energy

- $E_i$: the AE energy for channel $i$
- $V_i$: recorded voltage transient for channel $i$
- $t_{ae}$: the duration of the event for channel $i$.

$$E_i = \int_0^{t_{ae}} V_i^2(t) dt$$
Acoustic Emission

[Graph showing loading and AE count over time]

[Graph showing load and AE energy over time]
Acoustic Emission Event Location
Binder Testing

- Binders used to prepare laboratory mixtures
- Binders recovered from top layer of field samples
- Test methods
  - BBR - 1000s
  - DT - 3%/min
  - DENT - 1.8%/min
  - All three after 1h and 20h conditioning
Dilatometric Measurements

- Precision Capillary Tube
- Silicon Rubber O-ring
- Stainless Steel Fitting
- Polypropylene Washer
- Housing
- Base Cup
- Binder Specimen
- Silicon Paper
Experimental Data Analysis

- Compare results obtained from the different mixture testing
  - Similar information?
  - Choose the simplest test that provides reasonable parameters
  - Address the issue of specimen preparation
    - Gyratory vs. beams
- Similar approach for binder data
- Correlate binder and mixture data
  - Can binder data predict mixture fracture properties?
Modeling

- Use experimental data to model fracture behavior of mixtures at low temperatures
  - Based on “Cohesive Zone Model”
Modeling

- Asphalt overlay resting on a thick base-layer through a frictional interface or a fully bonded interface.
- The analysis endeavors towards the accurate prediction of crack spacing in asphalt pavements.
- For full-depth cracks, a two-dimensional closed form elastic solution is derived, in which periodically distributed cracks are formed within the overlay due to the tensile thermal stress.
- This solution is applied to calculate the energy release rate of three-dimensional channeling cracks.
- From the relation between the energy release rate and the material fracture toughness, the crack spacing can be predicted.
Fig. 21 Schematic illustration of thermal cracking in asphalt overlays: (a) top-down plane strain cracking and (b) three-dimensional channeling
Further Work

- Factor in loading rate
  - ✓ Both mixture testing and binder testing
- Understand the role of physical hardening of the binders
- Improve fracture model using viscoelastic analysis
  - ✓ Possibly moving into thermo-viscoelasticity
- Explore the use of small samples to investigate the aging effect with depth
- Obtain reliable pavement temperature data and thermal properties of mixtures
Daily mean, max, and min surface temperature for test cell 33, Jan 1 – Dec 31, 2004
Distribution of surface temperature for test cell
33, Jan 1 2001 - Dec 31, 2005
Further Work

- Current study represents a very comprehensive effort of understanding the fracture behavior at low temperatures through mechanical testing.

- What’s missing?
  - Chemical analysis of the same set of materials
    - In particular the field samples
    - May offer valuable information in the effort to understand the evolution and effect of aging on fracture properties of asphalt materials
Thank you!