Evaluation of Temperature and Laboratory Aging on Pavement Cracking Performance Fracture Tests

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Overview

- Introduction
  - Motivation and Objectives
  - DCT and SCB Fracture Tests
- Methodology and Materials
- Results
  - Temperature Effects
  - Aging Effects
- Summary & Conclusion
Balanced Mix Design

- Asphalt mix design using *performance tests* on appropriately *conditioned* specimens that address *multiple modes of distress* taking into consideration mix *aging*, *traffic*, *climate* and location within the pavement structure.
# Motivation

- White House: 65 percent of America’s major roads are rated in less than good condition
- Performance tests are starting to become mature and field validation data is becoming available for developing performance related/based specifications
- Fracture testing based cracking tests are starting to get adopted
- There is need for understanding of effects of aging and temperature on fracture behavior of asphalt mixtures
Fracture Test Geometries

- Fracture tests on HMA date back to 1971

- Single-edge Notched Beam (SE(B))
- Direct Tension
- Semi-Circular Bend (SCB)
- Disk-shaped Compact Tension (DCT)

Fenix Test
Disk-Shaped Compact Tension (DCT) Test

- ASTM D7313-13
- Loading Rate:
  - Crack Mouth Opening Displacement
  - CMOD Rate = 1.0 mm/min
- Measurements:
  - CMOD
  - Load
Semi-Circular Bend (SCB) Test

- Multiple variants exist
  - Early work in Europe
  - Simultaneous cold (Marasteanu et al. – MN) and intermediate temperature (Mohamed et al. – LA) versions
  - Recent work from Al-Qadi et al. (IL) → AASHTO TP 105

- AASHTO TP 107
  - Line load control, loading rate = 50 mm/min
  - Test temperature = 25 deg. C

- Measurements:
  - Displacement
  - Load

- Outcomes
  - Fracture Energy
  - Flexibility Index (FI)
Fracture Parameters

Fracture work: Area under Load-Displacement curve

Fracture Energy, $G_f$: Energy required to create unit fracture surface

$$G_f = \frac{\text{Fracture Work, } S_f}{\text{Fracture Area}}$$

Flexibility Index, $FI$: $FI = \frac{G_f}{m}$
Current Adoption Efforts of Fracture Tests

- Semi-Circular Bend
  - LA Version Intermediate Temperature → Louisiana DOTD
    - Wisconsin for High RAM Projects (Hanz et al. NEAUPG 2015)
  - IL and MN Version at Intermediate Temperature:
    - Illinois in pilot implementation stages

- Disk-shaped Compact Tension
  - City of Chicago
  - Illinois Tollways
  - Wisconsin for High RAM Projects (Hanz et al. NEAUPG 2015)
  - Minnesota Department of Transportation
    - Pilot implementation on 7 projects in 2013
    - Multi-lab round-robin testing in 2015 (17 projects)
    - Fabrication and conditioning process effects in 2015-16 (11 projects)
    - Provisional specification is now available
Current Specifications / Adoption Approaches

- **Illinois Research on SCB Flexibility Index:**
  - *Single Test Temperature = 25 deg. C*
  - *Short term aged specimens following AASHTO R30*

- **Wisconsin High RAM Projects**
  - SCB testing at 25 deg. C
  - DCT testing at specified PG LT + 10 deg. C
  - Both SCB and DCT on AASHTO R 30 long term aged procedure
    - *5 days at 85 deg. C on compacted specimens*

- **Minnesota Specification**
  - DCT testing at 10 deg. C warmer than required 95% reliability PG LT (in other words, without 6 deg. C rounding)
  - AASHTO R30 short term aging

- **Challenges:** Is 25 deg. C temperature suitable for all locations? How to handle reheating and long term aging?
Effect of Temperature on Fracture Energy

Mix 1 = MNRoad 19
Mix 2 = US50 (RCRI)
Mix 3 = I-74
Mix 4 = AI AAPTP
Effect of Temperature is Not Uniform: PG64-22 vs. PG58-28

Fracture Energy, $G_f$ (J/m$^2$)

- PG58-28
- PG64-22

Temperature, $T$ (°C)

$G_f = 627.1 \exp^{0.041 \times T}$

$G_f = 1299.3 \exp^{0.047 \times T}$

$r^2 = 0.564$
Effects of Aging on Fracture
(Braham et al., 2009)

- Fracture Energy vs. Aging Time
- Load vs. CMOD with Aging Time
- Fracture Energy vs. Aging Condition
Effect of AASHTO R30 Lab Aging (Dave et al., 2011)

+/-13% for most mixes
2 mixes showed significant difference

Section 34 ➔ SBS+PPA, NY ➔ Unmodified
Section 33 ➔ PPA and Section 35 ➔ SBS

Aging and Temperature Effects on Cracking, Eshan Dave, NEAUPG 10/20/2016
MnDOT DCT Implementation Aging Evaluation Study

Fracture Energy (J/m²)

- **Mix Design**
- **No-Reheat**
- **Reheats**

<table>
<thead>
<tr>
<th>Location</th>
<th>Mix Design</th>
<th>No-Reheat</th>
<th>Reheats</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH 59 Roundabout</td>
<td>TH 59 N. D.L.</td>
<td>TH 61 Little Marais</td>
<td>TH 61 Lutsen</td>
</tr>
<tr>
<td>PG 64-34</td>
<td>PG 58-28</td>
<td>PG 58-28</td>
<td>PG 58-28</td>
</tr>
<tr>
<td>CSAH 3</td>
<td>TH 11</td>
<td>TH 29</td>
<td>TH 62</td>
</tr>
<tr>
<td>PG 58-34</td>
<td>TH 65</td>
<td>TH 86</td>
<td>CSAH 3</td>
</tr>
<tr>
<td>PG 58-28</td>
<td>PG 58-34</td>
<td>PG 64-28</td>
<td>PG 58-28</td>
</tr>
</tbody>
</table>
Objectives

- Assess effects of long term laboratory aging on cracking (fracture) performance tests

- Determine effects of test temperature on cracking performance parameters from SCB and DCT tests

Secondary Outcomes:
- What can we learn from fracture behavior regarding asphalt mixtures?
  - Effect of RAP amount
  - Effect of binder type
Overview

- Introduction
  - Motivation and Objectives
  - DCT and SCB Fracture Tests

- Methodology and Materials

- Results
  - Temperature
  - Aging Effects

- Summary & Conclusion
## Testing Matrix

### Age Conditioning

<table>
<thead>
<tr>
<th>Mix</th>
<th>PG</th>
<th>RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>PG 64-22</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30%</td>
</tr>
<tr>
<td>New Hampshire</td>
<td>PG 64-28</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30%</td>
</tr>
</tbody>
</table>

### Test Temperature Study:

<table>
<thead>
<tr>
<th>Mix</th>
<th>PG</th>
<th>RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virginia</td>
<td>76-22</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>70-22</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>64-22</td>
<td>40%</td>
</tr>
<tr>
<td>Vermont</td>
<td>52-34</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>52-34</td>
<td>40%</td>
</tr>
</tbody>
</table>

- Short Term Aging: Plant Production
- Long Term Aging: NCHRP 09-54
- Long term oven aging of loose mix
  - Aging Temperature = 95 ºC
  - Aging Duration → Geography and structure specific
  - Current study: 0, 14 and 21 days
- All tests on plant mix, lab compacted samples
- SCB and DCT tests at multiple temperatures
  - SCB: 25, 13 and 1ºC
  - DCT: PG LT + 10 ºC
- All tests on plant mixed, plant compacted samples
Specimen Preparations

- Gyratory Specimen
- 50 mm (2 inch) Disk
- Cut disk into two halves
- Core loading holes
- Notched

Images of Gyratory Specimen, 50 mm Disk, Core loading holes, Notched specimens, DCT, and SCB.
### Specimen Distribution

<table>
<thead>
<tr>
<th>NH 0% RAP</th>
<th>NH 30% RAP</th>
<th>NY 0% RAP</th>
<th>NY 30% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short-term aged</strong></td>
<td><strong>Short-term aged</strong></td>
<td><strong>Short-term aged</strong></td>
<td><strong>Short-term aged</strong></td>
</tr>
<tr>
<td>Discs</td>
<td>AV</td>
<td>test</td>
<td>Discs</td>
</tr>
<tr>
<td>1.A</td>
<td>6.6%</td>
<td>SCB</td>
<td>1.A</td>
</tr>
<tr>
<td>1.B</td>
<td>6.5%</td>
<td>DCT</td>
<td>1.B</td>
</tr>
<tr>
<td>2.A</td>
<td>6.5%</td>
<td>SCB</td>
<td>2.A</td>
</tr>
<tr>
<td>2.B</td>
<td>6.3%</td>
<td>DCT</td>
<td>2.B</td>
</tr>
<tr>
<td>2.C</td>
<td>5.8%</td>
<td>DCT</td>
<td>2.C</td>
</tr>
<tr>
<td><strong>14 days aged</strong></td>
<td><strong>14 days aged</strong></td>
<td><strong>14 days aged</strong></td>
<td><strong>14 days aged</strong></td>
</tr>
<tr>
<td>Discs</td>
<td>AV</td>
<td>test</td>
<td>Discs</td>
</tr>
<tr>
<td>1.A</td>
<td>5.5%</td>
<td>Extra</td>
<td>1.A</td>
</tr>
<tr>
<td>1.B</td>
<td>5.6%</td>
<td>DCT</td>
<td>1.B</td>
</tr>
<tr>
<td>2.B</td>
<td>6.5%</td>
<td>SCB</td>
<td>2.B</td>
</tr>
<tr>
<td>2.C</td>
<td>6.3%</td>
<td>DCT</td>
<td>2.C</td>
</tr>
<tr>
<td><strong>21 days aged</strong></td>
<td><strong>21 days aged</strong></td>
<td><strong>21 days aged</strong></td>
<td><strong>21 days aged</strong></td>
</tr>
<tr>
<td>Discs</td>
<td>AV</td>
<td>test</td>
<td>Discs</td>
</tr>
<tr>
<td>1.A</td>
<td>6.5%</td>
<td>DCT</td>
<td>1.A</td>
</tr>
<tr>
<td>1.B</td>
<td>6.1%</td>
<td>SCB</td>
<td>1.B</td>
</tr>
<tr>
<td>2.A</td>
<td>6.5%</td>
<td>DCT</td>
<td>2.A</td>
</tr>
<tr>
<td>2.B</td>
<td>6.4%</td>
<td>DCT</td>
<td>2.B</td>
</tr>
<tr>
<td>2.C</td>
<td>6.3%</td>
<td>SCB</td>
<td>2.C</td>
</tr>
</tbody>
</table>
Test Conditions

- **Aging Study**
  - Plant Production (Short Term)
  - Loose mix oven aging @ 95 °C
  - 0, 14 and 21 days
  - Total: 3 conditions, 2 test types

- **Temperature Study**
  - All specimens are plant mixed, plant compacted
  - Total: 1 condition, 2 test types, 3 temperatures

\[ \text{SCB: 25°C} \]
\[ \text{DCT: -12 or -18°C} \]
\[ \text{SCB: 25, 13 and 1°C} \]
\[ \text{DCT: -12 or -18°C} \]
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**Temperature Study: Low Temperature Performance**

- Minimal difference between VT 20% and 40% RAP mixtures
- Substantial difference between VA mixtures
VT Mixtures
Blue: 20% RAP, PG 58-34
Red: 40% RAP, PG 58-34

VA Mixtures
Green: 0% RAP, PG 76-22
Blue: 20% RAP, PG 70-22
Red: 40% RAP, PG 64-22
Effect of Temperature on SCB Results

![Graph showing SCB fracture energy at different temperatures and asphalt contents.]

- SCB Fracture Energy, J/m²
- 1 C, 13 C, 25 C
- VT 20% RAP, VT 40% RAP, VA 0% RAP, VA 20% RAP, VA 40% RAP
Effect of Temperature on Fracture Behavior at Intermediate Temperatures

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Material</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1°C</td>
<td>VT 20% RAP, PG 58-34</td>
<td></td>
</tr>
<tr>
<td>13°C</td>
<td>VA 20% RAP, PG 70-22</td>
<td></td>
</tr>
<tr>
<td>25°C</td>
<td>VT 20% RAP, PG 58-34</td>
<td></td>
</tr>
<tr>
<td>25°C</td>
<td>VA 20% RAP, PG 70-22</td>
<td></td>
</tr>
</tbody>
</table>
VA 40% RAP, PG 64-22

Trial 1: 13°C & 50mm/min
Trial 2: 25°C & 50mm/min
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### Aging Study Results

- **SCB Fracture Energy at Intermediate Temperature**

![Fracture Energy Graph]

- Drop in fracture energy with increasing aging levels
- Extent of drop is not consistent with RAP amount
Effect of Aging on Fracture Behavior

Green: Short-term aged
Blue: 14 days at 95 deg. C
Red: 21 days at 95 deg. C

NH 0% RAP, PG 64-28

NH 30% RAP, PG 64-28
Aging and Temperature Effects on Cracking, Eshan Dave, NEAUPG 10/20/2016

Aging Study Results

- SCB Flexibility Index at Intermediate Temperature

![Graph showing SCB Flexibility Index at Intermediate Temperature](image-url)
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Summary and Conclusions

- Effect of temperature on fracture behavior of asphalt mixtures:
  - Increasing temperature → Lower peak load (lower fracture stress) and Increased ductility
  - Non unique response between mixtures
  - Transition from ductile to brittle is mix (binder and other constituent) dependent
  - Use of single 25 deg. C for all regions may not be a good idea!
Summary and Conclusions (cont.)

- Effect of aging on fracture behavior of asphalt mixtures:
  - New draft aging protocol from NCHRP 09-54 was evaluated here
    - Big drop in cracking resistance from short term to 14 day aging, small change from 14 to 21 day aging
  - Aging substantially changes fracture behavior at intermediate temperature
  - Age conditioning should be included in cracking (fracture) performance test
Summary and Conclusions (cont.)

- Performance testing can provide insight into mixture behavior:
  - 20% and 40% VT RAP mixes showed similar cracking performance at intermediate and low temperatures
  - Sensitivity to effects of aging were comparable between 0% and 30% NH and NY mixes
  - 40% RAP VA mixture with “PG HT only” grade bumping led to substantial drop in cracking resistance
Thank you for your attention!

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Questions / Comments?

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