Evaluation of Laboratory Performance Tests for Fatigue Cracking of Asphalt Pavements

April 2015 Mix ETG

FHWA Cooperative Study at Asphalt Institute
Project

• Principal Investigator
  • Mike Anderson, Asphalt Institute

• Evaluation of current cracking performance tests
Objective

• To assist with deployment of a fatigue cracking test that is:
  • Sensitive properties of mix components
  • Sensitive to mixture aging
  • Repeatable and reproducible
  • Easy to implement
  • Practical, low cost
Plan

• An experimental study to examine various cracking tests
• Evaluate capability of the tests in discerning the factors of interest
• Evaluation on practicality and ease of use
Primary Factors

• Asphalt grade
• Mix properties
• Load range (test strains/stresses)
• Asphalt aging and hardening
• RAP/RAS content
• Warm-mix additives
Phase 1 Test Plan

• Test devices: 7

• Binder:
  • PG 64-22

• Aggregates:
  • Virgin mix
  • 9.5 mm NMAS, dense mix

• Aging:
  • 4-hour loose mix aging at 135°C
  • 24-hour loose mix aging at 135°C
## Initial Testing Plan

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Temperature</th>
<th>Test Strain / Load Rate Condition</th>
<th>Equivalent Test Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-Point Bending Beam Fatigue</td>
<td>15°C &amp; 20°C</td>
<td>300 &amp; 600με; sine &amp; haversine</td>
<td>300με = 0.16mm/0.1sec or 98mm/min; 600με = 195mm/min</td>
</tr>
<tr>
<td>AMPT Push/Pull Fatigue (S-VECD)</td>
<td>18.0°C</td>
<td>Various</td>
<td></td>
</tr>
<tr>
<td>Indirect Tensile Strength (IDT)</td>
<td>25°C &amp; 4°C</td>
<td>12.5 mm/min for low temp (AASHTO T322) 50mm/min for mid-temp. strength (ASTM D6931)</td>
<td>12.5 mm/min</td>
</tr>
<tr>
<td>Disk-Shaped Compact Tension [DC(t)]</td>
<td>-12°C</td>
<td>1.0 mm/min</td>
<td>1.0 mm/min</td>
</tr>
<tr>
<td>Texas Overlay</td>
<td>25°C</td>
<td>0.6mm/5sec</td>
<td>72 mm/min</td>
</tr>
<tr>
<td>Dissipated Creep Strain Energy (DCSE)</td>
<td>TBD</td>
<td>Standard Methods</td>
<td>NA</td>
</tr>
<tr>
<td>Semi-Circular Bending (SCB)</td>
<td>25°C</td>
<td>0.5 mm/min</td>
<td>0.5 mm/min</td>
</tr>
</tbody>
</table>
Phase 1 Testing Plan

• Lab Standard Mix

• Aging:
  • 4-hour loose mix aging at 135°C
  • 24-hour loose mix aging at 135°C
Why 24 Hour Loose Mix Aging

• Focus on aging of the top ~1-2 inches
• University of Illinois – study on in-place mixtures
  • Andrew F. Braham, William G. Buttlar, Timothy R. Clyne

AAPTP non-load associated cracking study
  • Also found that 18hr loose mix $\approx$ 20hr PAV

KY density study
  • Correlates 24hr loose mix conditioned, fatigue testing to field cracking
AMPT Push/Pull Fatigue (S-VECD)

- Draft AASHTO standard by Richard Kim
- $18^\circ C / 23^\circ C$
  - Not recommended to run over $21^\circ C$
- Various Strains
- Software builds curve based on three tests
Data Inconclusive

• Good test for design
• Not intended for 24 aged mixtures
Indirect Tensile Strength (IDT)

- ASTM D 6931
- Related AASHTO T322
- 25.0°C and 4.0°C
- Rate of Movement: 12.5 and 50 mm/min
Indirect Tensile Strength (IDT)

Simplest test, but just says that mix gets stiffer

IDT Average Peak Strengths at 25°C and 12.5mm/min

- 4-hour Conditioning @ 135°C, 25°C test
- 24-hour Conditioning @ 135°C, 25°C test
Indirect Tensile Strength (IDT)

IDT Average Peak Strengths at 4°C and 12.5mm/min

- 4-hour Conditioning @ 135°C, 4°C test
- 24-hour Conditioning @ 135°C, 4°C test

IDT Peak Strengths, kN

- 35.1
- 39.5
Indirect Tensile Strength (IDT)

IDT Average Peak Strengths at 4°C and 50mm/min

- 4-hour Conditioning @ 135°C, 25°C test: 40.4 kN
- 24-hour Conditioning @ 135°C, 25°C test: 43.2 kN
Indirect Tensile Strength (IDT)

So what can we learn? Confirms that we need correct temperature/loading rate for cracking sensitivity. Peak load alone is not the answer.
So what can we learn? Confirms that we need correct temperature/loading rate for cracking sensitivity. Peak load alone is not the answer…but combine with time/distance $\Rightarrow$ FRACTURE ENERGY
4-Point Bending Beam Fatigue

- 4-point bending beam fatigue (1950’s / SHRP)
- AASHTO T321 & ASTM 7460
- Examined
  - 20.0°C & 15.0°C
  - Sine & haversine waves
- Rate of Movement: 10Hz, various strains (strain rates)
  - Ex: 300 ms = 0.16mm/0.1sec or 98mm/min
- 2 beams for average (per strain)
Beam fatigue device has been used to better understand pavement cracking potential.

The graph shows a linear relationship between the total cracking from field survey in feet per mile and the number of cycles to cracking failure in the beam fatigue test. The equation of the line is:

\[ y = -1650 \ln(x) + 23848 \]

with a coefficient of determination \( R^2 = 0.9254 \).

Key data points:
- **KY98**: 10.7% cracking, 9000 ft/mile
- **US42**: 12.9% cracking, 8000 ft/mile
- **US60**: 13.2% cracking, 7000 ft/mile
- **KY55**: 11.5% cracking, 6000 ft/mile
- **KY85**: 11.6% cracking, 5000 ft/mile
Beam Fatigue – What strain do I use?

- **Low strain**: Classic fatigue/bottom up cracking (NCHRP 9-29, 5-10” pavement & ALF).
- **Medium Strain**: Correlated with surface cracking / brittleness (KY density study).
- **High strain (up to 2000ms)**: Bridge decks & reflective cracking (Blankenship Bennert).

**ASTM D4760 4-point Flexural Fatigue**

Cycles*Stiffness Analysis

20°C Test Temperature
Beam Fatigue – 20°C & sine

ASTM D4760 4-point Flexural Fatigue
Cycles*Stiffness Analysis
20°C Test Temperature

Cycles to Failure (Nf)

Test Strain (µε)

4-hour Conditioning @ 135°C, 20°C test

24-hour Conditioning @ 135°C, 20°C test

y = 1E+17x^{-4.454}
R² = 0.9905

y = 4E+19x^{-5.463}
R² = 0.9679
Beam Fatigue – 20°C & sine

Multiple Strain Comparison
ASTM D4760 4-point Flexural Fatigue
Cycles*Stiffness Analysis
20°C Test Temperature

Average Cycles to Failure (Nf)

- 4-hour Conditioning @ 135°C, 20°C test
- 24-hour Conditioning @ 135°C, 20°C test

<table>
<thead>
<tr>
<th>Strain (με)</th>
<th>4-hour Conditioning Nf</th>
<th>24-hour Conditioning Nf</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 με</td>
<td>1,208,484</td>
<td>1,180,142</td>
</tr>
<tr>
<td>600 με</td>
<td>55,835</td>
<td>26,232</td>
</tr>
</tbody>
</table>
Beam Fatigue - 15°C & sine

ASTM D4760  4-point Flexural Fatigue
Cycles*Stiffness Analysis
15°C Test Temperature

\[ y = 4E + 19x^{-5.509} \]
\[ R^2 = 0.9725 \]

\[ y = 3E + 17x^{-4.829} \]
\[ R^2 = 0.9584 \]

- 4-hour Conditioning @ 135°C, 15°C test
- 24-hour Conditioning @ 135°C, 15°C test
Beam Fatigue - 15°C & sine

Multiple Strain Comparison
ASTM D4760 4-point Flexural Fatigue
Cycles*Stiffness Analysis
15°C Test Temperature

Average Cycles to Failure [Nf]

- 4-hour Conditioning @ 135°C, 15°C test
- 24-hour Conditioning @ 135°C, 15°C test

300 με:
- 939,728 cycles
- 344,828 cycles

600 με:
- 22,026 cycles
- 11,584 cycles
Sinusoidal vs. "Haversine" with 4 & 24hr Aging, 600 microstrain
ASTM D4760  4-point Flexural Fatigue
Cycles*Stiffness Analysis
20°C Test Temperature

Average Cycles to Failure (Nf)

<table>
<thead>
<tr>
<th></th>
<th>4hr Aging</th>
<th>24hr Aging</th>
<th>4hr Aging</th>
<th>24hr Aging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sine</td>
<td>55,835</td>
<td>26,232</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haversine</td>
<td></td>
<td></td>
<td>67,757</td>
<td>12,361</td>
</tr>
</tbody>
</table>
Dissipated Creep Strain Energy (DSCE)

- Draft standard by Rey Roque
- Uses IDT configuration
- Creep based on load & time
- 10°C
- 3 samples for average
Dissipated Creep Strain Energy (DSCE)

Note: Roque models not for 24hr aged mixture, but FE limit does shoe difference. COV’s usually 7%.
Disk-Shaped Compact Tension [DC(t)]

- ASTM D 7313
- Run at +10°C from critical low temp PG
- -12.0°C
- Rate of Movement: 1 mm/min
- 3 samples for average
Disk-Shaped Compact Tension [DC(t)]

Average Fracture Energy, -12°C

Fracture Energy from CMOD, J/m²

- 4-hour Conditioning @ 135°C
  - 358.2

- 24-hour Conditioning @135°C
  - 314.5

Note: COV’s usually 10%
Texas Overlay Test

- Tx DOT Standard
- Tex-248-F
- 25°C
- Rate of Movement: 0.6 mm/5 sec and returns (fatigue) or 7.2mm/min
- 0.1 Hz
- 6 samples for average
Note: High error. Data is usually trimmed average.
Semi-Circular Bending (SCB)

- Draft AASHTO standard by Louay Mohammad
- 25°C
- Rate of Movement: 0.5 mm/min
Semi Circular Bend (SCB) Test

- Fracture mechanics
- Temperature: 25°C
- Half-circular Specimen
  - Laboratory prepared
  - Field core
  - 150mm diameter X 57mm thickness
  - simply-supported and loaded at mid-point
- Notch controls path of crack propagation
  - 25.4-, 31.8-, and 38.0-mm
- Loading type
  - Monotonic
  - 0.5 mm/min
  - To failure
- Record Load and Vertical Deformation
- Compute Critical Strain Energy: Jc
Semi-Circular Bend Test Results, 25°C

Note: Can have high error. Usually based on 6 samples.
## Test Summary

<table>
<thead>
<tr>
<th>Test</th>
<th>Cost – saw/coring not included</th>
<th>Sample Prep.</th>
<th>Run Test</th>
<th>Data Analysis</th>
<th>Speed of Test (3x)-conditioning not included</th>
<th>Sensitive to Aged (24hr) vs. Unaged (4hr) Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-Point Bending Beam Fatigue</td>
<td>$50,000</td>
<td>3-trim 4x; 2 beams</td>
<td>2</td>
<td>2-normalized cycles</td>
<td>3-24 hours</td>
<td>Yes</td>
</tr>
<tr>
<td>AMPT Push/Pull Fatigue (S-VECD)</td>
<td>$10,000 to $15,000 to upgrade</td>
<td>5-trim 2x, core, glue, instrument; 3 samples</td>
<td>5</td>
<td>5-specialized software</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Indirect Tensile Strength (IDT)</td>
<td>$0 – could use TSR device at 25°C</td>
<td>1-trim 1x; 3 samples</td>
<td>1</td>
<td>1-direct reading</td>
<td>10 min.</td>
<td>Yes, but just shows stiffness without time/movement analysis</td>
</tr>
<tr>
<td>Disk-Shaped Compact Tension [DC(t)]</td>
<td>$ to upgrade AMPT</td>
<td>5-trim 2x, core, notch (2 samples), instrument; 3 samples</td>
<td>2</td>
<td>3-area under curve</td>
<td>30 min</td>
<td>Yes</td>
</tr>
<tr>
<td>Texas Overlay</td>
<td>$ to up to upgrade AMPT</td>
<td>4-trim 1x, glue; 6 samples</td>
<td>2</td>
<td>1-cycles to failure</td>
<td>1-3 hours</td>
<td>Yes</td>
</tr>
<tr>
<td>Dissipated Creep Strain Energy (DCSE)</td>
<td>$70,000</td>
<td>2-trim 2x and instrument; 3 samples</td>
<td>3</td>
<td>3-area under curve</td>
<td>30 min</td>
<td>Yes</td>
</tr>
<tr>
<td>Semi-Circular Bending (SCB)</td>
<td>&amp; to upgrade AMPT</td>
<td>3-trim, cut, notch 2x; 6 samples</td>
<td>2</td>
<td>3-area under curve</td>
<td>30 min</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Refer to NCHRP 9-57 for Further Info

NCHRP 9-57

Experimental Design for Field Validation of Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures
Conclusions

- We need to condition mixtures to simulate proper field conditions at 7 to 10 years.
- All tests seem to recognize the conditioned mixtures except for the IDT strength.
  - Strength alone is not enough.
  - S-VECD is meant more for design. Good test but in different “league”.
- Need to accept tests for what they are and designed to do.
- Begin to adjust tests for climates.
Thank you
Phase 2 Test Plan

• Test devices: 7
• Binder:
  • PG 64-22, 76-22, 58-34
• Aggregates:
  • Virgin mix, RAP/RAS
  • 9.5 mm NMAS, dense mix; 12.5mm
• Aging:
  • 4-hour loose mix aging at 135°C
  • 24-hour loose mix aging at 135°C
Phase 2 Test Plan

• Other suggestions from Mix ETG:
  • Add ALF mixture to validate
  • Possible DOT mixtures