Assessments of Cracking Tests: A Transportation Pool Fund Study

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Outline
- Background
  - Mechanical test
  - Cracking
- Objectives
- Materials & Test Sections
- Methodologies
- Results & Discussion
  - Discriminating potential to mixture components
  - Ranking capability with reference to ALF fatigue performance experiment
- Summary and Conclusions
Components Materials Used In Asphalt Mixture

- Asphalt Binder
  - Petroleum-Based (refined crude oil)
  - 4-8% by weight
- Aggregates (CA, FA)
  - 92-96% by weight
- Additives

Sustainable Development

- "Meets the needs of the present without compromising the ability of future generations to meet their own needs"
  - World Commission on Environment and Development, 1987

Sustainability: quality that reflects the balance of three primary components -- triple-bottom line

- Economic Sustainability
  - Balanced cost-revenue relationship
- Environmental Sustainability
  - Friendly to the ecosystem
  - Minimize use of natural resources
  - Reduce greenhouse gas emissions
- Social Sustainability: Materials Performance
  - Better or same performance
  - Meet society's needs

Components Materials Used In Asphalt Mixture

- Asphalt Binder
  - Petroleum-Based (refined crude oil)
  - 4-8% by weight
- Aggregates (CA, FA)
  - 92-96% by weight
- Additives
- Sustainability
  - Replace portions of component materials
  - RAP, RAS, ...
  - Aged asphalt binders
  - aggregates
Asphalt Mixture Design

- **Volumetrics**
  - Voids in the Total Mix, VTM
  - Voids in the Mineral Aggregate, VMA
  - Voids Filled with Asphalt, VFA

- **Densification**
  - Stages during lab compaction

Asphalt Mixture Design: Concern

- Optimum asphalt binder content
  - Quantity
    - NOT QUALITY
      - Aged Binders
        - Replace virgin binder
        - RAP and/or RAS

Laboratory Performance Assessments
Laboratory Test Methods to Characterize Fatigue/Fracture Resistance

- Four Point Bending Fatigue Test
- Disk-shaped Compact tension Test
- Texas Overlay Tester
- Dissipated Creep strain Energy Test
- Indirect tensile strength (IDT) test
- Simplified Viscoelastic Continuum Damage
  - Pull-Push Test
  - IDT Fracture Energy
  - SCB test
  - Intermediate Temperature
  - ...

Objectives

- Compare laboratory performance tests with respect to
  - mixture-discriminating capability as per material composition
  - correlation with pavement performance

Materials

- Participating agencies
  - FHWA ALF (10 mixtures)
  - Colorado DOT (2 mixtures)
  - Florida DOT (2 mixtures)
  - Louisiana DOT (2 mixtures)
Materials

- Participating agencies
  - FHWA ALF
    - Colorado DOT (2 mixtures)
    - Florida DOT (2 mixtures)
    - Louisiana DOT (2 mixtures)

Materials & Test Sections

- FHWA ALF Mixtures

<table>
<thead>
<tr>
<th>Mixture Designation</th>
<th>RAP* (%)</th>
<th>RAS* (%)</th>
<th>Base Binder</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALF-L1</td>
<td>--</td>
<td>--</td>
<td>64-22 HMA</td>
<td>HMA</td>
</tr>
</tbody>
</table>
| ALF-L2              | 40      | --      | 64-22 Water
foam       | HMA     |
| ALF-L3              | --      | 20      | 64-22 HMA   | HMA     |
| ALF-L4              | 20      | --      | 64-22 Evotherm | HMA |
| ALF-L5              | 40      | --      | 64-22 HMA   | HMA     |
| ALF-L6              | 20      | --      | 64-22 HMA   | HMA     |
| ALF-L7              | --      | 20      | 58-28 HMA   | HMA     |
| ALF-L8              | 40      | --      | 58-28 HMA   | HMA     |
| ALF-L9              | 20      | --      | 64-22 Water foam | HMA |

ALF-L11

- 40 -- 58-28 Evotherm

Note: * Expressed in terms of RBR (recycled binder ratio)
Design Asphalt Content: 5.0

A Transportation Pool Fund Study

11/21/2019
Materials & Test Sections

- FHWA ALF lanes design facts
  - 10 cm asphalt layer
  - 56 cm crushed aggregate base
  - Subgrade

- ALF fatigue loading facts
  - Single wide-base tire
    - 63.2 kN wheel load
    - 889 kPa contact pressure
  - Loading speed: 4.9 m/s
  - Asphalt layer temperature: 20°C
  - Surface cracking monitored

Six Fracture/fatigue tests

<table>
<thead>
<tr>
<th>Test Temp</th>
<th>Protocol</th>
<th>Test Mode</th>
<th>Geometry</th>
<th>Engineering Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF</td>
<td>20°C</td>
<td>ASTM D7460</td>
<td>Cyclic, 10 Hz</td>
<td>Crack initiation</td>
</tr>
<tr>
<td>OT</td>
<td>25°C</td>
<td>Tex-248-F</td>
<td>Cyclic, 0.1 Hz</td>
<td>Crack initiation &amp; propagation</td>
</tr>
<tr>
<td>SVECD</td>
<td>18°C</td>
<td>AASHTO T378</td>
<td>Cyclic, 10 Hz</td>
<td>Crack initiation</td>
</tr>
<tr>
<td>SCB</td>
<td>25°C</td>
<td>ASTM D8044</td>
<td>Monotonic, 0.5 mm/min</td>
<td>Crack propagation</td>
</tr>
<tr>
<td>I-FIT</td>
<td>25°C</td>
<td>AASHTO TP124</td>
<td>Monotonic, 50 mm/min</td>
<td>Crack propagation</td>
</tr>
<tr>
<td>IDT</td>
<td>10°C</td>
<td>UF draft</td>
<td>Cyclic</td>
<td>Crack initiation</td>
</tr>
</tbody>
</table>

Methodologies

- Four-point bending beam fatigue
  - AASHTO T 321
  - Sample: 380×63×50 mm
  - Air void: 7 ± 1%
  - LTA AASHTO R30
  - Temperature: 20°C
  - Frequency: 10 Hz sinusoidal
  - Control mode: deflection
  - Fatigue failure: 50% drop in stiffness
Methodologies

- Texas overlay
  - Tex-248-F (2017)
  - Sample: Ø150 x 76 x 38 mm
  - Air void: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 25°C
  - Frequency: 0.1 Hz triangular
  - Control mode: displacement

- Simplified viscoelastic continuum damage (S-VECD)
  - AASHTO T 378-17, AASHTO TP107
  - Sample: Ø100 x 130 mm
  - Air voids: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 18°C
  - Frequency: 10 Hz
  - Control mode: displacement

Fracture/fatigue testing

- Direct Tension Cyclic Fatigue – SVECD
  - AASHTO TP 79-15: Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)
  - Stiffness

- AASHTO TP 107-14: Standard Method of Test for Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests
  - Damage characteristic curve (C vs. S)
Methodologies

- Semi-circular bend (SCB)
  - ASTM D6044
  - Sample: ø150×57 mm
  - Notch depths: 1", 1.25", 1.5"
  - Air voids: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 25°C
  - Loading rate: 0.5 mm/min
  - Control mode: displacement

Methodologies

- Illinois flexibility index (I-FIT) test
  - AASHTO TP124
  - Sample: ø150×50 mm
  - Notch depth: 15 mm
  - Air voids: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 25°C
  - Loading rate: 50 mm/min
  - Control mode: displacement

Methodologies

- Indirect tension (IDT) test
  - Univ. Florida draft procedure
  - Sample: ø150×38 mm
  - Air voids: 7 ± 0.5%
  - LTA AASHTO R30
  - Temperature: 10°C
Methodologies

- Indirect tension (IDT) test
  - Dynamic Modulus Test
    - Frequency: 10 Hz, 50 cycles
    - Horizontal strain: 50 ± 5 με
  - Creep Test
    - Creep time: 1000 s
    - Maximum horizontal strain: 150-250 με
  - Strength Test
    - Displacement rate: 50 mm/min.

Test Results

Four-point bending beam

- Performance parameter: $N_{f,BF}$
  - Interpolated at 340° microstrain (average of tensile strain responses at the bottom of asphalt layers in ALF lanes)

Four-point bending beam

Texas overlay test -- Analysis

- Performance parameters
  - Fatigue life $N_{f,OT}$
    - maximum tensile load drops by 93%
  - Critical Fracture Energy (CFE)
    - indicative of resistance to crack initiation
  - Crack Propagation rate (CPR)
    - indicative of resistance to crack propagation

Texas Overlay Test - Analysis

- Critical fracture energy & crack progression rate
Texas overlay test

ANOVA using Fisher’s LSD method:
- L9 exhibited highest fatigue life
- L3 & L7 exhibited lowest fatigue life

Texas overlay test

CFE represents resistance to crack initiation. Higher values are desired.
Results appear to be contrary to what was expected.
Not a good indicator of cracking resistance. CFE was positively related to mixture stiffness.

Texas overlay test

CRI represents the crack progression rate. Lower values are desired.
- L5, L7, L3 exhibited highest CRI
S-VECD

- damage characteristic relationship
  - correlating material structural integrity $C$ and an internal state variable for damage intensity $S$

Path along which an asphalt mixture loses its structural integrity due to accumulation of damage (microcracks)

S-VECD

- Performance parameter: MFS*
  - Material fatigue sensitivity (MFS)
  - Lower MFS, higher fatigue resistance


S-VECD

L1 and L2 yielded highest fatigue resistance
L3, L5, and L7 lowest MFS
**SCB**

- Performance parameter: $J_c$
  - Critical strain energy release rate
  - Higher $J_c$, higher resistance to fracture

**SCB**

L1 and L2 yielded highest cracking resistance, followed by L1 control.
L3, L5, and L7 the worst performers.

**I-FIT**

- Performance parameter: $F_I$
  - Flexibility index
  - Higher $F_I$, higher resistance to fracture
I-FIT

L11 and L11 highest cracking resistance.
L3, L5, and L7 the worst performers.

IDT

- Performance parameter: DCSE
  - Dissipated creep strain energy
  - Higher DCSE, higher resistance to crack initiation

DCSE = PE - \frac{1}{2} \frac{E}{\varepsilon}

IDT

L1 highest cracking resistance.
L5, L7 lowest cracking resistance.
L3 ranked third best. Considered among the worst as per the other evaluation parameters.
Test Variability

- Test variability indicator:
  - Beam fatigue: difference in $N_{f,BF}$ < 0.787 in double-log scale for replicates
  - Others if applicable: coefficient of variation (CoV)

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Test Variability

- Results:
  - Beam fatigue: difference in $N_{f,BF}$ in double-log scale ranged between 0.03 and 0.72, with an overall average of 0.24

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Parameter</th>
<th>CoV</th>
<th>Range</th>
<th>CoV</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas overlay</td>
<td>$N_{f,B}$</td>
<td>24%</td>
<td>0.03 - 0.72</td>
<td>0.03 - 0.72</td>
<td>0.24</td>
</tr>
<tr>
<td>CPR</td>
<td>$N_{f,B}$</td>
<td>10%</td>
<td>0.03 - 0.72</td>
<td>0.03 - 0.72</td>
<td>0.24</td>
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<tr>
<td>S-VECC MFS</td>
<td>$N_{f,B}$</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>Not Applicable</td>
<td>0.24</td>
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<tr>
<td>SCB Jc</td>
<td>$N_{f,B}$</td>
<td>13%</td>
<td>0.03 - 0.72</td>
<td>0.03 - 0.72</td>
<td>0.24</td>
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<tr>
<td>I-FIT FI</td>
<td>$N_{f,B}$</td>
<td>25%</td>
<td>0.03 - 0.72</td>
<td>0.03 - 0.72</td>
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<tr>
<td>IDT DCSE</td>
<td>$N_{f,B}$</td>
<td>18%</td>
<td>0.03 - 0.72</td>
<td>0.03 - 0.72</td>
<td>0.24</td>
</tr>
</tbody>
</table>

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Sensitivity to Mixture Component

- Sensitivity to composition factors
- Effect of recycled asphalt materials
- Performance parameters were normalized with respect to values of the control mix

<table>
<thead>
<tr>
<th>Material Type</th>
<th>AP-11</th>
<th>AP-15</th>
<th>AP-16</th>
<th>AP-18</th>
<th>AP-19</th>
<th>AP-20</th>
<th>AP-22</th>
<th>AP-23</th>
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<td>Aggregate</td>
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</tbody>
</table>

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Effect of recycled materials

All four mixtures were HMA with PG 64-22 base binder.

Correlation with ALF fatigue performance

<table>
<thead>
<tr>
<th>Grouping</th>
<th>N_{L1}</th>
<th>N_{L9}</th>
<th>N_{L11}</th>
<th>CPR</th>
<th>MFS</th>
<th>Jc</th>
<th>FI</th>
<th>DCSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best Three</td>
<td></td>
<td></td>
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<td>L1</td>
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<td>L2</td>
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<td>L3</td>
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</tbody>
</table>

| Moderate Four |       |        |         |     |     |    |    |      |
| L4       | L4     | L4     | L4      | L4  | L4  | L4 | L4 | L4   |
| L5       | L5     | L5     | L5      | L5  | L5  | L5 | L5 | L5   |
| L6       | L6     | L6     | L6      | L6  | L6  | L6 | L6 | L6   |

| Worst Three |       |        |         |     |     |    |    |      |
| L7       | L7     | L7     | L7      | L7  | L7  | L7 | L7 | L7   |
| L8       | L8     | L8     | L8      | L8  | L8  | L8 | L8 | L8   |
| L9       | L9     | L9     | L9      | L9  | L9  | L9 | L9 | L9   |
Correlation with ALF fatigue performance

- Rank correlation – Kendall’s tau coefficient
  - Numerical indicator that measures degree of agreement in ranking.
  - Varies between
    - -1 fully different (reverse order)
    - 1 identical rankings
  - Ranking reference
    - ALF fatigue performance experiment

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Kendall's tau coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALF L3</td>
<td>0.73</td>
</tr>
<tr>
<td>Nf,OT</td>
<td>0.66</td>
</tr>
<tr>
<td>MFS</td>
<td>0.47</td>
</tr>
<tr>
<td>Jc</td>
<td>0.47</td>
</tr>
<tr>
<td>CPR</td>
<td>0.42</td>
</tr>
<tr>
<td>NTBF</td>
<td>0.28</td>
</tr>
<tr>
<td>ICI</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Summary and Conclusions

- Cracking resistance of 10 plant-produced asphalt mixtures with different composition factors using six laboratory performance tests
- Mixture discriminating potential of these test methods
- Compare test methods ranking capability to fatigue performance form ALF experiment
- Increase in RAP content generally led to reduction in cracking resistance according to evaluation parameters.
  - Texas overlay, SCB Jc, and S-VECD tests reasonably ranked mixtures L3 and L6 with the same RBR but the former having the more oxidatively aged asphalt binder from RAS
Summary and Conclusions

- Effect of two warm-mix technologies was not conclusive
  - no consistent observation from laboratory tests
  - generally, water-foaming and Evotherm processes produced WMA mixtures with similar cracking resistance as compared to conventional counterparts

- Correlation between evaluation parameters and ALF fatigue performance experiment
  - beam fatigue, Texas overlay, S-VECD, and SCB Jc tests exhibited similar ranking capabilities

Acknowledgement

- Participating Agencies
  - Colorado
  - FHWA
  - Florida
  - Louisiana

- Staff at LTRC
  - Wei Cao
  - Peyman Barghabany
  - Lab technicians
  - ...
Become an AAPT Member!

- Have access to a wealth of information and emerging technologies including free webinars
- Be an integral part of a technical community comprised of individuals from all parts of the asphalt industry (material suppliers, researchers, agency owners, consultants, and equipment manufacturers)
- Enjoy the camaraderie of colleagues in the field during annual meetings at attractive venues
- Be a part of lively debates on important technical issues
- Belong to a North American-based organization with significant international membership and focus
- Be a member of an association that operates without organizational biases; policies set by and for individual members by an elected Board.
- Support the next generation of asphalt technologists through a robust student scholarship program

http://asphalttechnology.org/membership.html

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Rank  Team
1  LSU Louisiana State University

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SCB at Intermediate Temperature

- Data Analysis

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Thank you!