Comparison of Asphalt Binder and Mixture Durability/Fatigue Cracking to FHWA ALF Performance

Thomas Bennert, Ph.D.
Rutgers University, NJ
Center for Advanced Infrastructure and Transportation (CAIT)
Acknowledgements

- FHWA Turner-Fairbanks
  - Nelson Gibson (formerly), Jack Youtcheff, Terry Arnold, Regis Carvalho

- Rutgers staff
  - Christopher Ericson (Binder Testing)
  - Edward Haas and Edward Wass (Core Prep and Testing)
Background
Recently completed High Recycle with WMA Fatigue Cracking Experiment
Focus on fatigue cracking, temp. controlled at 20°C
- No high temperature rutting*
Three year completion
- 2 years of loading
- 2 ALF units allow simultaneous loading
Unmodified binder for all lanes, but 2 different grades
WMA Technology which does not change PG grade
10 kip single wheel = 20 kip equivalent axle
4-inch total asphalt thickness
FHWA Accelerated Loading Facility (ALF)

- ALF Loading Conditions
  - Controlled 20°C @ 20mm depth
  - Loading only in one direction
  - Lateral wander
  - 425 Super Single Tire
  - 100 psi inflation
  - 14,200 lb load
# FHWA Accelerated Loading Facility (ALF)

<table>
<thead>
<tr>
<th>ALF Lane</th>
<th>% RBR</th>
<th>Virgin Binder PG</th>
<th>WMA Process</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RAP</td>
<td>RAS</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>-</td>
<td>64-22</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>-</td>
<td>58-28</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>20</td>
<td>64-22</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>-</td>
<td>64-22</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>-</td>
<td>64-22</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>-</td>
<td>64-22</td>
</tr>
<tr>
<td>7</td>
<td>-</td>
<td>20</td>
<td>58-28</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>-</td>
<td>58-28</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>-</td>
<td>64-22</td>
</tr>
<tr>
<td>11</td>
<td>40</td>
<td>-</td>
<td>58-28</td>
</tr>
</tbody>
</table>
FHWA Accelerated Loading Facility (ALF)

- Cracking performance measured and quantified in two indices
  - Number of cycles until 1\textsuperscript{st} Crack observed
  - Cracking Rate
Question: How well do asphalt mixture and binder tests correlate to field measured fatigue performance?
- RAP, RAS, WMA
- 10 cores taken from each lane
- Mixture and binder testing conducted on bottom 2 inches of field core to minimize surface aging
Performance Testing – Asphalt Binders
Asphalt Binder Testing

- Asphalt binders recovered using solvent extraction and Rotovapor Recovery
- Binder testing included;
  - PG grading (Intermediate Temp)
  - Master curves
    - Rheological Properties
    - Glover-Rowe Parameter
  - Double Edge Notched Tension (DENT)
Ductility has always been correlated to fatigue performance of asphalt mixtures and clearly decreases with aging.

As asphalt binders age, the relaxation properties (m-value) are negatively affected at greater rate than the stiffness (S).

The difference between the low temperature cracking grade of m-value and S is defined as the $\Delta T_c$

$$\Delta T_c = T_c, S - T_c, m-value$$

AAPT (Anderson et al., 2011) showed that the $\Delta T_c$ correlated to non-load associated cracking on airfields (i.e. – cracking mainly due to aging), as well as ductility.
Due to equipment and material size restraints, Ductility testing may not be available.

Rowe (AAPT, 2011) proposed the DSR master curve analysis to calculate the “Glover-Rowe” parameter:

- As G-R parameter increases, the binder is more prone to fatigue cracking.
- Correlates to both ductility and BBR ΔTc.
- Laboratory testing at Rutgers U. has shown the parameter correlates to lab fatigue performance.
Double Edge Notched Tension (DENT) Test – AASHTO TP113

- Test evaluates the energy required for fracturing ductile materials
  - Test measures the Work of Fracture and Critical Opening Displacement (CTOD)
  - CTOD represents ultimate elongation, or strain tolerance, in the vicinity of a crack (i.e. – notch)
  - As CTOD increases, more resistant to fracturing
Performance Testing - Mixtures
Mixture Testing

- Due to field cores, test methods limited to evaluated fatigue cracking performance of mixtures
- Three different tests conducted at identical test temperature of 25°C:
  - Overlay Tester
  - SCB - Illinois Flexibility Index
  - SCB – LTRC Procedure
Sample size: 6” long by 3” wide by 1.5” high

Loading: Continuously triangular displacement 5 sec loading and 5 sec unloading

Definition of failure
- Discontinuity in Load vs Displacement curve
SCB – Illinois Flexibility Index

- Semi-circular test specimen
- Set up for a 3 point test with a notch depth of 15 mm
- Deformation rate 50 mm/min
- Analysis uses the fracture energy and slope of post peak curve

![Diagram of load-displacement curve with labels: Peak Load, Slope at inflection point (m), Opening at Peak Load (w_o), Critical Displacement (w_p). Formula for Flexibility Index (Fl) = A x (G_f x 1/|m|).]
SCB – LTRC Method

- Semi-circulate test specimen
- Test measures the potential energy at failure for 3 notch depths
- Potential energy plotted vs notch depth to compute Critical Strain Energy ($J_c$)
- Deformation rate of 0.5 mm/min
Testing Results – Asphalt Binders
Intermediate PG Grade vs Cycles to 1\textsuperscript{st} Crack

![Graph showing the relationship between Intermediate PG Temperature Grade (°C) and ALF Loading Cycles Until 1st Crack. The graph includes data points for As-Received and 20 Hr PAV conditions, with R\textsuperscript{2} values of 0.6324 and 0.3955.]

- R\textsuperscript{2} = 0.6324
- R\textsuperscript{2} = 0.3955
$\Delta T_c$ vs Cycles to 1$^{st}$ Crack

ALF Loading Cycles Until 1st Crack

- 50,000 100,000 150,000 200,000 250,000 300,000 350,000 400,000

$\Delta T_c$

- 50,000 100,000 150,000 200,000 250,000 300,000 350,000 400,000

20 Hr PAV

As-Received
Glover-Rowe Parameter vs Cycles to 1st Crack

\[ R^2 = 0.6322 \]

\[ R^2 = 0.8381 \]

- G-R (AS-Received)
- G-R (20 Hr PAV)
DENT CTOD vs Cycles to 1\textsuperscript{st} Crack

\[ R^2 = 0.6806 \]

\[ R^2 = 0.839 \]

DENT CTOD (mm) vs ALF Loading Cycles Until 1st Crack

- 25C
- Equi-Stiffness Temp

\textbf{Note:} The graph shows the relationship between DENT CTOD and ALF Loading Cycles Until 1st Crack for different temperatures, with a best-fit line for each condition.
Intermediate Temp PG vs Cracking Rate

\[ R^2 = 0.6212 \]

\[ R^2 = 0.6004 \]
$\Delta T_c$ vs Cracking Rate

![Graph showing the relationship between $\Delta T_c$ and Cracking Rate. The graph includes data points for As-Received and 20 Hr PAV conditions.](image-url)
Glover-Rowe Parameter vs Cracking Rate

\[ R^2 = 0.3539 \]

\[ R^2 = 0.6113 \]

- As-Received
- 20 Hr PAV

Glover-Rowe (G-R) Parameter (kPa) vs Cracking Rate
Overview of Asphalt Binder Testing

- Glover-Rowe Parameter correlated best with Crack Initiation (Cycles to 1st Crack)
  - DENT CTOD using equi-stiffness temperature also correlated well
  - $\Delta T_C$ had moderate correlation – believe it was due to only 20 hour PAV, most likely needed 40 hours to differentiate binders with high recycle contents
- Glover-Rowe and DENT CTOD again provided best correlation to Cracking Rate
Testing Results – Asphalt Mixtures
Overlay Tester vs Cycles to 1st Crack

$R^2 = 0.6208$

Overlay Tester Fatigue Life (cycles)

ALF Loading Cycles to 1st Crack

- 0
- 50,000
- 100,000
- 150,000
- 200,000
- 250,000
- 300,000
- 350,000
- 400,000

- 0
- 100
- 200
- 300
- 400
- 500
- 600
SCB FI vs Cycles to 1st Crack

R² = 0.7725

ALF Loading Cycles to 1st Crack vs SCB Flexibility Index
LTRC SCB vs Cycles to 1\textsuperscript{st} Crack

\[ R^2 = 0.421 \]
Overlay Tester vs Cracking Rate

R² = 0.3761
SCB FI vs Cracking Rate

R² = 0.6505
LTRC SCB vs Cracking Rate

\[ R^2 = 0.5626 \]
Overview of Mixture Testing

- SCB Flexibility best correlated to both Crack Initiation (Cycles to 1st Crack) and Crack Growth (Cracking Rate)
  - Overlay Tester good correlation to Crack Initiation
  - LTRC SCB good correlation to Cracking Rate
- Other SCB Flexibility Index benefits
  - Only 3 specimens
  - Typical core thickness
  - Quick test (50 mm/min)
  - Can be run on typical Marshall equipment
There is an interest by state agencies to have a “fatigue” asphalt binder test for purchase specification, as well as a mixture test to ensure fatigue performance.

Field cores from ALF Fatigue Cracking Experiment was used to evaluate different binder and mixture tests.

- ALF provided different levels of performance for comparison.
- Testing conducted on plant produced materials (cores).
Asphalt Binder Testing

Both Glover-Rowe and DENT CTOD provided good correlations to field cracking performance
  - Glover-Rowe “stiffness” based on correlation to ductility
  - DENT CTOD “fracture” based

From practical standpoint, Glover-Rowe requires much less material and can be conducted on current DSR’s
  - DENT CTOD requires special equipment and much more material

May need to reassess aging condition – collected data suggest $\Delta T_C$ should have done better, but perhaps not conditioned enough

Additional research needed on appropriate temperatures and loading rates
Conclusions on Study

- Asphalt Mixture Testing
  - SCB Flexibility Index correlated best with both modes of field cracking (initiation and propagation)
  - Current test procedure (AASHTO TP124) can be conducted on research grade servo-hydraulic equipment or Marshall Stability/Flow equipment
    - Deformation rate of 50 mm/min
    - Minimal investment for fixture
Thank you for your time!

Questions?

Thomas Bennert, Ph.D.
Rutgers University
609-213-3312
bennert@rci.rutgers.edu