Asphalt Aging and its Impact on the Timing of Preventive Maintenance

Mike Anderson
Asphalt Institute
19th Annual TERRA Pavement Conference
University of Minnesota 12 February 2015
Acknowledgments

• TPF-5(153) Optimal Timing of Preventive Maintenance for Addressing Environmental Aging in Hot-mix Asphalt Pavements
  • MN, MD, OH, TX, WI, LRRB
  • Thomas J. Wood, Lead Agency Contact

• Airfield Asphalt Pavement Technology Program (AAPTP) Project 06-01
  • Techniques for Prevention and Remediation of Non-Load-Related Distresses on HMA Airport Pavements
  • AAPTP sponsors and research panel

• Member Companies of the Asphalt Institute
Team

• Asphalt Institute
• AMEC
  • Doug Hanson, Researcher
• Consultant
  • Gayle King, Researcher
General Concept

• In-service aging leads to oxidation and loss of flexibility at intermediate and low temperatures
  • Block-cracking
    • when environmental (non-load) conditions create thermal stresses that cause strain in the asphalt mixture that exceeds the failure strain
General Concept

• In-service aging leads to oxidation and loss of flexibility at intermediate and low temperatures
  • Preventing or mitigating distress
    • identify a property of the asphalt binder or mixture that sufficiently correlates with its flexibility
  • provide a procedure to monitor when flexibility reaches a state where corrective action is needed
Asphalt Oxidation

• Physical Changes – Ductility
  • Block cracking severity related to ductility at 60°F (15°C) – Kandhal (1977)
    • “Low-Temperature Ductility in Relation to Pavement Performance”, ASTM STP 628, 1977
  • Loss of surface fines as ductility = 10 cm
  • Surface cracking when ductility = 5 cm
  • Serious surface cracking when ductility < 3 cm
1981 CA Durability Study

Kemp, et.al.
Sacramento (62.9C), 7-9% Air Voids, Non-Absorptive Aggregate
Stiffness

Depth

Dynamic Modulus, $E^*$ (GPa)

Depth from Surface (mm)

- $E^*$ Gradient due to both aging and temperature effects
- Fitted Function

Asphalt Surface Course

Asphalt Base (Binder) Course

Subgrade ( Lime Modified)
More Recent Aging Research

• Texas A&M Research (Glover, et.al.)
  • 2005
  • “Development of a New Method for Assessing Asphalt Binder Durability with Field Evaluation”
  • Build on work by Kandhal suggesting block cracking and raveling is related to low binder ductility after aging
  • Identified rheological parameter related to ductility
Dynamic Shear Rheometer

- Mastercurve at 15°C
  - 8-mm parallel plate
  - 5, 15, and 25°C
  - Frequency sweep (0.1 to 100 rad/s)
  - Obtain Texas A&M parameter at 0.005 rad/s
    - $G'/\eta'/G'$
    - Related to ductility at 15°C and 1 cm/min.
Ductility and DSR Parameter

\[ \text{Ductility} = 0.23 \times \left( \frac{G'}{(\eta' \cdot G')} \right)^{-0.44} \]

(Glover et al., 2005)
Asphalt Binders

• Three asphalt binders representing different expected aging characteristics
  • Selected based upon the relative relationships between low temperature stiffness (S) and relaxation (m-value)
  • West Texas Sour (PG 64-16)
    • 3.1°C m-controlled
  • Gulf Southeast (PG 64-22)
    • 1.3°C m-controlled
  • Western Canadian (PG 64-28)
    • 0.6°C S-controlled
Mastercurve Procedure

\[ y = 0.035x^{-0.670} \]

\[ R^2 = 0.853 \]

Ductility at 15°C, 1cm/min (cm)

\[ \frac{G'}{(\eta'/G')} \text{ at } 15°C, 0.005 \text{ rad/s (MPa/s)} \]

WTX  GSE  WC
Relationship between $G'/(\eta'/G')$ and $\Delta T_c$

![Graph showing the relationship between $G'/(\eta'/G')$, MPa/s, and the difference between $T_{c,m}(60)$ and $T_{c,S}(60)$, °C. The graph includes data points for WTX, GSE, and WC.](image-url)
Effect of Aging

Phase Angle, degrees

G*, Pa

1E+03
1E+05
1E+07
1E+09

0 45 90

PAV4  PAV2  PAV

Original
Glover-Rowe Parameter

\[ \frac{G'}{\left( \frac{\eta'}{G'} \right)} = G*\omega((\cos \delta)^2/\sin \delta) \]

<table>
<thead>
<tr>
<th></th>
<th>Ductility 15C, 1 cm/min</th>
<th>Glover-Rowe 0.005 rad/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage Onset:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Raveling</td>
<td>5</td>
<td>180 kPa</td>
</tr>
<tr>
<td>Damage Visible:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface cracking</td>
<td>3</td>
<td>600 kPa</td>
</tr>
</tbody>
</table>
Glover-Rowe Plot in Black Space:
DSR on Aged Binders (15°C; 0.005 rad/s)
• Past research
  • Some relationship between ductility (conducted at an intermediate temperature) and the durability of an asphalt pavement
  • Texas A&M research validated through identification of DSR parameter, $G'/\eta'/G'$, at 15°C and 0.005 rad/s
• Current research
  • Confirmed relationship of Texas A&M DSR parameter, $G'/(\eta'/G')$, at 15°C and 0.005 rad/s, to ductility
  • Identified similar parameter through BBR testing, $\Delta T_c$, which quantifies the difference in continuous grade temperature for stiffness and relaxation properties
  • Parameters appear to quantify the loss of relaxation properties as an asphalt binder ages
• Laboratory and Field Evaluation of MnROAD and Other Test Sections
  • Critical fracture parameters monitored throughout the life of the pavement
    • Appropriate remedial action can be taken as the critical limit is approached
  • Simple tests to be used for field monitoring purposes
    • Physical properties from simple tests correlated to crack predictions from DC(t) or other more sophisticated fracture tests.
MnROAD Cores: Recovered Binder Testing

- Extraction/Recovery
  - Centrifuge extraction using toluene/ethanol
  - Recovery using Rotavapor
- 2 Cores (150-mm diameter x 12.5-mm thickness)
  - ~50 grams asphalt
MnROAD Cores: Binder Testing

• Each Layer
  • DSR Temperature-Frequency Sweep
    • Three temperatures (5, 15, 25°C) using 8-mm plates
    • Rheological mastercurves for modulus (G*) and phase angle (δ)
  • BBR
    • Tc determined to the nearest 0.1°C for S(60) and m(60)
    • Difference in Tc (ΔTc)
MnROAD Cell 24: Effect of Layer Depth

Average Layer Depth, mm

6.25
23.75
41.25

G′/(η′/G′) at 15°C, 0.005 rad/s, MPa/s

24A Non Travel
24B Non Travel
24F Non Travel
Expected Results

Aging Parameter vs. Time

- Unsealed
- Sealed Immediately
- Cracking Onset
G-R Parameter: MnROAD Cell 24 Bottom Layers

![Bar chart showing G-R Parameter at 15°C, 0.005 rad/s (kPa) for different years and cell types.](image-url)
Black Space Diagram: Progression of Aging

- G-R Parameter = 180 kPa
- G-R Parameter = 600 kPa
- Cell 24F-Top
- Cell 24F-Bottom
- PG 52-34

G*, Pa vs. Phase Angle, degrees
Experiment Results

Aging Parameter vs. Time

- **Sealed Immediately**
- **Unsealed**

Cracking Onset
Disk-Shaped Compact Tension Test: DC(T)
Fracture Energy: MnROAD Cell 24 Top Layers

[Bar chart showing CMOD Fracture Energy (J/m²) for different years and cell types.]

- Cell 24F-Top
- Cell 24A-Top
- Cell 24B-Top
- Cell 24C-Top
- Cell 24D-Top
- Cell 24E-Top
Fracture Energy: MnROAD Cell 24F Top

Fracture Energy, J/m² vs. Years after Construction

\[ y = -79.91x + 756.52 \]
\[ R^2 = 0.94 \]

- Cell 24F-Top
- Threshold
Key Findings from MnROAD Cell 24

• MnROAD Cell 24 Test Section
  • Binder Test Results
    • Aging of the asphalt pavement, as measured using several asphalt binder properties, was shown to be significantly higher near the surface (within the top 12.5 millimeters) than further down in the pavement structure. Near the surface, the asphalt binder shows an increase in stiffness and a decrease in phase angle, indicating a loss of relaxation properties as the binder ages.
Key Findings from MnROAD Cell 24

- MnROAD Cell 24 Test Section
  - Binder Test Results
    - The aging expected to occur as the time is extended from construction to sealing was not readily seen in the asphalt binder properties.
      - Contrary to expectations and initial data analysis all of the subsections, including the Control, exhibited no discernible trend indicating that time from construction to sealing had a significant effect on asphalt binder properties.
        - Only five years of service from construction to the last coring
        - More aging may be needed to see any significant effects.
Key Findings from MnROAD Cell 24

• MnROAD Cell 24 Test Section
  • Binder Test Results
    • Bottom layers illustrated aging with time was observed by a change in the asphalt binder properties.
    • None of the subsections had values for the $G'/(\eta'/G')$ and G-R parameters that were close to the limiting values suggested by other research as thresholds for cracking.
      • Not surprising given the relatively young age of the pavement (five years at the time of the last coring) and lack of cracking noted on any of the test sections from distress surveys.
Key Findings from MnROAD Cell 24

- MnROAD Cell 24 Test Section
  - Mixture Test Results
    - Mixture testing generally did not show any significant trends of aging as the time from construction to sealing increased with the exception of the indirect tensile strength of the Top layers.
      - Cores from subsections sealed in 2009 and later had higher indirect tensile strength values than the Control subsection and the subsection sealed in 2008 (using a CSS-1 emulsion instead of a CRS-2P emulsion).
      - The indirect tensile strength values of all subsections decreased as time increased.
TH56 Test Sections

- TH56
  - two-lane rural highway with ADT of 2000 (reported at time of construction)
  - test sections located between I-90 and Leroy, MN
## TH56 Test Sections

### MINNESOTA TH 56 SITE LAYOUT

<table>
<thead>
<tr>
<th></th>
<th>10 to 11</th>
<th>11 to 12</th>
<th>12 to 13</th>
<th>13 to 14</th>
<th>14 to 15</th>
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<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tbody>
</table>

### Age when treated

<table>
<thead>
<tr>
<th></th>
<th>4 YEAR</th>
<th>3 YEAR</th>
<th>2 YEAR</th>
<th>1 YEAR</th>
</tr>
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<tbody>
<tr>
<td>ORIGINAL CONSTRUCTION - 1999</td>
<td>CRS-2P 0.40 gal/yd²</td>
<td>CRS-2P 0.34 gal/yd²</td>
<td>CRS-2P 0.32 gal/yd²</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CRS-2P 0.38-0.42 gal/yd²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specimen Group ID</td>
<td>Control</td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------</td>
<td>--------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Chip Sealing Year</td>
<td>N/A</td>
<td>2000</td>
<td>2001</td>
<td>2002</td>
</tr>
<tr>
<td>Age at Treatment Time, yr.</td>
<td>N/A</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Emulsion Type</td>
<td>N/A</td>
<td>CRS-2P</td>
<td>CRS-2P</td>
<td>CRS-2P</td>
</tr>
<tr>
<td>Aggregate Type</td>
<td>N/A</td>
<td>New Ulm Quartzite</td>
<td>Dresser Trap Rock</td>
<td>Dresser Trap Rock</td>
</tr>
<tr>
<td>Binder Application Rate, gal/yd&lt;sup&gt;2&lt;/sup&gt;</td>
<td>N/A</td>
<td>0.32</td>
<td>0.34</td>
<td>0.38-0.42</td>
</tr>
<tr>
<td>Chip Application Rate, lb./yd&lt;sup&gt;2&lt;/sup&gt;</td>
<td>N/A</td>
<td>16</td>
<td>17-18</td>
<td>18-22</td>
</tr>
</tbody>
</table>

N/A = not applicable
TH56 Cores

- Cores
  - Remove chip seal (if any)
  - Cut into two 25-mm layers
  - Test for fracture energy (cracking potential)
  - Recover component asphalt to check aging
G-R Parameter: TH56

The diagram shows the G-R Parameter at 15°C, 0.005 rad/s for different depths (Top, Middle, Bottom) and various chips (Chip 00, Chip 01, Chip 02, Chip 03, Control). The y-axis represents the G-R Parameter in kPa, ranging from 1 to 1,000, while the x-axis indicates the depth of the layer.
DC(T) Results: TH-56

TH56: DC(t) Data @ -24°C

Higher fracture energy is better

Fracture Energy from CMOD (J/m²)

Chip Seal Time


- Control-99: 151.2
- 2000 Seal: 277.4
- 2001 Seal: 308.4
- 2002 Seal: 208.0
- 2003 Seal: 182.8

Top 25mm

Bottom 25mm
Experiment Results

DC(T) Fracture Energy vs. Time

- **Unsealed**
- **Sealed 1-2 years post construction**
- **Sealed 3+ years post construction**

Cracking Onset
Key Findings from Minnesota TH56

- Minnesota TH 56 Test Section
  - Binder Test Results
    - Top layers of all the test sections had higher values of asphalt binder aging parameters than their corresponding layers further from the surface.
    - The time between construction and sealing also had an effect on the asphalt binder aging parameters with the earliest chip seal section exhibiting the lowest values (indicating the least aging) and the Control (unsealed) section exhibiting the highest values (indicating the most aging).
Key Findings from Minnesota TH56

• Minnesota TH 56 Test Section
  • Mixture IDT Test Results
    • Generally confirmed the results of the binder testing
    • Decreased indirect tensile strength and increased Critical Cracking Temperature as time from construction to sealing increases.
Key Findings from Minnesota TH56

• Minnesota TH 56 Test Section
  • Mixture DC(T) Results
    • Fracture energy decreased for the first two years after construction and then reached a plateau
      • below the threshold value suggested for cracking
    • Fracture energy of the cores from the 2002 and 2003 Chip Seal sections was the same as the Control (unsealed) section after 12 years of service.
Key Findings from Minnesota TH56

- Minnesota TH 56 Test Section
  - Mixture DC(T) Results
    - The analysis indicates that waiting more than two years after construction to place a chip seal could result in fracture properties that would ultimately be the same as if the pavement were not sealed at all.
    - Not to suggest that other benefits could not be realized by a later chip seal, but rather that the aging that impacts the fracture properties can be mitigated by sealing earlier.
TH56 Findings

• Sealing improves resistance to aging (cracking)
• Sooner is better when sealing
  • Waiting for 3 or more years to seal after construction produced same results as unsealed pavement
  • Sealing after 1 or 2 years showed improvement in resistance to aging (cracking)
Thanks!

R. Michael (Mike) Anderson, P.E.
Director of Research and Laboratory Services
Asphalt Institute
2696 Research Park Dr.
Lexington, KY  40511-8480
859.288.4984  office
859.422.1301  FAX
manderson@asphaltinstitute.org
www.asphaltinstitute.org