TRB Webinar: Asphalt Killers—Fatigue, Formulation, and Old Age in Binders

July 8, 2021
1:00- 2:30 PM Eastern

@NASEMTRB
#TRBwebinar
PDH Certification Information:

• 1.5 Professional Development Hours (PDH) – see follow-up email for instructions

• You must attend the entire webinar to be eligible to receive PDH credits

• Questions? Contact Beth Ewoldsen at Bewoldsen@nas.edu

#TRBwebinar
Learning Objectives

• Make informed decisions about implementing new research to issues of asphalt binders

#TRBwebinar
Questions and Answers

• Please type your questions into your webinar control panel

• We will read your questions out loud, and answer as many as time allows

#TRBwebinar
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#TRBwebinar
What Kills Asphalt?

NCHRP 9-59 Findings

Don Christensen
Advanced Asphalt Technologies, LLC
July 2021
NCHRP 9-59: an improved binder fatigue specification

Bill Ahearn, Pamela Marks, Simon Hesp

ME
State Rt 163 Presque Isle – Mapleton
Severe raveling
10yr (thru wearing course at 5 yr)

Hwy 41 North of Kaladar (1999)

Hesp et al., Proceedings CTAA, 2009
What binder properties do we need to specify to maximize fatigue performance?

$\Delta T_c$?
Glover-Rowe parameter (GRP)?
Extension/ductility?
Elastic recovery?
NCHRP 9-59: Lab Testing
Fatigue life: fatigue strain capacity and fatigue exponent

\[ N_f = \left( \frac{FSC}{\varepsilon_b} \right)^{180/\delta} \]

\[ y = 2.21x \]
\[ R^2 = 85\% \]

Exp = 2 x 90/phase

FSC values calculated from 9-59 & SHRP flexural fatigue

Stiffness/3 or G*, Pa

Failure Strain or FSC, %

- NCHRP 9-59
- SHRP SDENT
- ALF SDENT
- 9-59 SDENT
- DTT
Fatigue Model

Binder rheologic type / \( R' \) value

\( R' \) is \( R \) estimated using a constant glassy modulus of 1.0 GPa.

\( R \) and \( R' \) are related but not equal…
$\Delta T_c$ and $R'$-Value are closely related…
DENT extension vs $G^*$

![Graph showing SDENT Extension vs Specimen Stiffness](image-url)
NEXT is the extension estimated at a constant initial specimen stiffness of 20 kN/m
Factors affecting FSC

Stiffness/3 or G*, Pa

Failure Strain or FSC, %

Higher $\Delta T_c$

Lower R

PMBs

Lower $\Delta T_c$

Higher R
Layered elastic analysis
Based on ALF2 100 mm sections

![Graph showing V. Low Phase PMBs, PMB, R'<2.9, PMB, R' > 2.9, Non-PMB, R' > 2.6, Non-PMB, 1.7 < R' <2.2, Non-PMB, R' = 1.2]
What about Glover-Rowe?

\[ Observed \ FSC = N_f^{\delta/180} \epsilon_b \]
Uniaxial fatigue model

**Stress-based damage**

\[ R^2 = 94\% \]

**Strain-based damage**

\[ R^2 = 88\% \]
Stress-based fatigue model

\[ N_f = \left(\frac{FSSsC}{\sigma_b}\right)^{5.0} \quad ; \quad FSSsC = FSC \times E \]
What kills asphalt...

- High R’ values/low delta Tc values produce weak and brittle binders that are prone to top-down cracking.
- Can be caused by a poor-quality binder (REOB), age-hardening, or both.
- Age-hardening will also increase stiffness, making thermal cracking more likely.
- Polymer modification can dramatically improve fatigue performance.
What kills asphalt…

- Damage due to thermal cracking and traffic loading likely superposes, making it difficult to separate these distress modes
- Minimum $\Delta T_c$, adjusted for modified binders—NCHRP 9-60
- Are binders with low $R'$/high delta $T_c$ values a problem?
Acknowledgements

- Nam Tran and his associates at NCAT
- NCHRP
- The 9-59 Project Panel
- Industry suppliers
- My associates at AAT
Asphalt Killers
Thermal Stress, Formulation, and Old Age in Binders

Outcomes of NCHRP 9-60

Jean-Pascal Planche,
Gayle King, Michael Elwardany,
Don Christensen, Carolina Rodezno
WRI, GHK Inc., AAT, NCAT

TRANSPORTATION RESEARCH BOARD
Introduction – context

NCHRP 9-60 proposal on test methods and specification

9-60 proposal genesis: What drives changes in binder physical properties – thermal, rheological, and failure
- Thermal stress
- Binder formulation
- Aging – oxidative and physical

Summary
• Bitumen chemical complexity  
  • Variable continuum can have an unstable balance

• SuperPave binder specs and quality issues outdated for 2021 binders with high variability  
  • Polymers, Modifiers, RAP/RAS, Recycling Agents, Bio-binders, Conversion residues (IMO 2020), Plastics...

• Characterization methods lack an holistic approach

• Binder quality impacts performance
Binder Impacts on Performance from Agency Survey

Surface Damage

Transverse Cracking

Block Cracking

Misc. Surface Cracking

Raveling

Oxidized...
REOB and...
PPA...
Excessive RAP
Excessive RAS
Others

Binder Issues

0 5 10
Performance and Rheological parameters of PMA’s

- **PMA field proven performance** - Von Quintus, 2005

![Graph showing transverse cracking vs. PMA sections](image1)

- **Rheologically “disproven”?**

![Graph showing complex modulus vs. phase angle](image2)

(Aurilio et al.; CTAA 2020)

![Graph showing ΔTc vs. SBS content](image3)

(Elwardany et al., C&BM, 2020)
Multiphase microstructure (IR microscopy)

- Polymer phase dispersed in an asphaltene rich continuous phase
- Swollen by slightly condensed aromatics and aliphatics
- Influenced by base binder, % polymer, reaction and processing
- Impacts both phase properties – PMA not just “P in A”!

(Mouillet, 2008) (Elwardany et al, C&BM 2020)
9-60 Proposed Specifications
Based on ABCD & BBR and Added to PG

Testing
- RTFO+PAV20
- LPG: BBR + ABCD only for critical binders
- 3 PAV pans - sufficient for both BBR & ABCD Tests

Proposed specifications framework
- Addition to current Climate-based PG
- Universal - blind

- BBR alone when $\Delta T_c > -2°C$ (Accepted)
  $\Delta T_c < -6°C$ (Rejected)
- BBR & ABCD for $-6°C < \Delta T_c < -2°C$
  $\Delta T_f$ min = 7°C at -2°C
  $\Delta T_f$ min = 10°C at -6°C

Proposed Limits

### Testing

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<thead>
<tr>
<th>$\Delta T_f$</th>
<th>$\Delta T_c$</th>
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<tbody>
<tr>
<td>(-10, 10)</td>
<td>(-10, 5)</td>
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<tr>
<td>(-5, 15)</td>
<td>(-5, 10)</td>
</tr>
<tr>
<td>(0, 20)</td>
<td>(0, 15)</td>
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### Proposed Specifications

<table>
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<tr>
<th>$\Delta T_f$</th>
<th>$\Delta T_c$</th>
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</thead>
<tbody>
<tr>
<td>(-6, 10)</td>
<td>(3, 1)</td>
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<tr>
<td>(-2, 7)</td>
<td>(4, 1)</td>
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<tr>
<td>(2, 1)</td>
<td>(1, 1)</td>
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</tbody>
</table>

**Legend**
- ✓: Accepted
- ✗: Rejected
Low PG Ranking after PAV20h-Aging from BBR

- Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken

(Elwardany et al, C&BM 2020)
BBR & Corrected 4mm-DSR $\Delta T_c$ Ranking after PAV40h

- Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, special binders.

(Elwardany et al., C&BM 2020)
BBR & ABCD $\Delta T_f$ Ranking after PAV40h

- Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Visbroken.

![Graph showing $\Delta T_f$ ranking for various binders](image-url)

(Elwardany et al., C&BM 2020)
BBR & ABCD $\Delta T_f$ Ranking after PAV40h

- Unmodified, Polymer-modified, ReOB-modified, SDA, PPA-modified, Biophalt, Oxidized, Airblown, Special binders.

7% SBS

(Elwardany et al., C&BM 2020)
\[ \Delta T_c \& \Delta T_f \text{ Ranking Field validation} \]

\[ \Delta T_c, (Tc(S) - Tc(m)), PAV-40h (°C) \]

FAA/AI study - Block cracking

Cumulative Transverse Cracking (m)

Year

2006 2007 2008 2009 2010 2011 2012

MN 1-2
MN 1-3
MN 1-4
MN 1-5

REOB
Terpolymer
MN 1-2
MN 1-3
MN 1-4
MN 1-5

GSE
WC
WTX

MTO S1
MTO S4
Hypothesis: Two Thermally-Induced Damage Mechanisms

- Mix Restraint (External)
- Mastic Restraint (Internal)

Evidence for Unrestraint Specimens

- Acoustic Emissions Results (Behnia et al., 2018)
- FEA & Mix-BBR(Sliver) Results (Elwardany et al., AAPT 2019)
Factors affecting ABCD - $T_{cr}$

- Coeff of Thermal Contraction controls volumetric change rate
- Binder LVE properties $G^*$ and $\delta$
  - Ability to relax stresses
  - Thermal stress developed under given cooling conditions
- Binder Strength
- Parameters function of glass transition temperature $T_g$
  - $T_g$ : transition region and not a single temperature
  - Complex binders usually have a wider $T_g$ region

(Elwardany et al.; C&BM 2020)
Tg influence on BBR Tc and ABCD Tcr

- Tg (H) and Tc(S) correlation: better for unmodified, impacted by aging level - Confirms other works (Lesueur, Olard, Bahia)
- Tg and Tcr: lower correlations, shows PMA features
NCHRP 9-60 Binder Mapping

- PAV20 aged binders
- PMA’s and Non PMA’s
Correlations between $\Delta T_c$ and CII after PAV40h

- Unmodified, Polymer-modified, ReOB-modified, SDA,
  PPA-modified, Biophalt, Oxidized, Airblown, Special binders

$$y = -60.91x^2 + 37.11x - 5.40$$

$R^2 = 0.64$

$\Delta T_c = (T_c(S) - T_c(m))$

Colloidal Instability Index (PAV40h)

Classical CII= $\frac{(\text{Sat}+\text{Asph})}{(\text{Arom}+\text{Res})}$

(Elwardany et al., C&BM 2020)
• SAR-AD maltene subfractions effect on DSC Tg(H)
• Continuous trend evolution from Saturates (negative slope) to highly Aromatics and Resins (positive slope)
• No trend with asphaltenes: no direct effect on Tg
**Tg(H) and Tc(S) and Maltenes**

- Relationship between Tg(H) or Tc(S) with MII
- **New composition balance index:** Maltene Instability Index MII: \((\text{Sat}+\text{Aro1})/(\text{Aro2}+\text{Aro3}+\text{Res})\)
\( \Delta T_c \) and wax

- **Positive \( \Delta T_c \)**
  - \( \Delta T_c \) vs. Crystallizable fraction
  - Graph showing data points for various samples.
  - High wax (CF)

- **Waxy crudes stand out in mapping**
- **... and \( \Delta T_c \)**
Relaxation and Molecular Weight Distribution

- $\Delta T_c$ from BBR vs. binder polydispersity from GPC
- $\Delta T_c$ is more complex than either $T_c$, and relates on GPC/SEC polydispersity index or molecular associations – captures PMA’s singular features
Summary

• Thermal stress mechanisms
  • Internal and external - Macro and micro scales
  • Influence of the glass transition

• Formulation
  • Crude oil origin and refinery process
  • Chemical composition
  • Balance – maltenes, asphaltenes and waxes (CF)
  • Additives / polymers interactions with the base

• Aging, both chemical (oxidative) and physical

• Testing
  • Importance of glass transition and equi-stiffness temperature on defining testing conditions – Ref. temperature needed
  • Power and limitations of rheological parameters
  • Usefulness of failure, particularly for PMA’s
  • Combination proposed for future specifications
<table>
<thead>
<tr>
<th>Wax from asphalts</th>
<th>REOB</th>
<th>Air blowing</th>
<th>Thermal Conversion visbreaking</th>
<th>Polymers Physical blends</th>
<th>Crosslinked SBS or reacted Terpolymers</th>
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<tr>
<td>CII</td>
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<td>PI (GPC)</td>
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<td>Oxidation</td>
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<td>PH</td>
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<td>PG Low</td>
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<td>Tc(S)</td>
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<td>ΔTc</td>
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<td>Tcr (ABCD)</td>
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<td>ΔTf</td>
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<td>Failure Modulus (DTT)</td>
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What kills asphalt?
Poor formulation and poor testing…

Neither one is simple, but progress is possible!
Thank You!

Questions?

Contact: jplanche@uwyo.edu
Findings and Recommendations
From
NCHRP Project 9-61

Short- and Long-Term Binder
Aging Methods to Accurately
Reflect Aging in Asphalt Mixtures

Ramon Bonaquist, P.E.
Advanced Asphalt Technologies, LLC
NCHRP Project 9-61

- Completed December 2020
  - NCHRP Report 967
- Research Team
  - Advanced Asphalt Technologies, LLC
    - Ramon Bonaquist - PI
  - Western Research Institute
    - Jeramie Adams - Co-PI
- Consultants
  - Dave Anderson
  - Gayle King
  - Erick Sharp
Today’s Outline

• Objectives
• Short-Term Conditioning
  – Approach
  – Findings
  – Recommendations
• Long-Term Conditioning
  – Approach
  – Findings
  – Recommendations
Objectives

• Evaluate laboratory conditioning procedures
  – AASHTO T 240, AASHTO R 28 and alternatives

• Recommend improvements
  – New procedure
  – Modifications to existing procedures

• Calibrate the improved procedures to accurately simulate aging
  – Mixture production, transport, and placement
  – Service life of the pavement
Short-Term Conditioning

• Concerns with AASHTO T 240
  – Uniformity of the film and how well it is renewed is viscosity dependent
  – Some modified binders tend to crawl out of the bottle

• Alternatives Evaluated
  – AASHTO T 240
  – AASHTO T 240 with preheated containers
  – Modifications to AASHTO T 240 made in the U.K. Ageing Profile Test
  – Static Thin Film Test (12.5 g binder in PAV pan)
Short-Term Evaluation

• Compare binder conditioning procedures to binder recovered from short-term oven conditioned mixtures
  – NCHRP 9-52 recommendations
  – Designed as a paired difference experiment
  – HMA and WMA temperatures
  – Eight Binders

<table>
<thead>
<tr>
<th>Neat PG 52-34</th>
<th>SBS PG 64-34</th>
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</thead>
<tbody>
<tr>
<td>Terpolymer PG 64-34</td>
<td>SBS PG 76-28</td>
</tr>
<tr>
<td>Neat PG 64-22</td>
<td>PG 64-22 with 3 % SBR Latex</td>
</tr>
<tr>
<td>SBS PG 76-22</td>
<td>SBS 82-22</td>
</tr>
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</table>
Binder Loss Survey

• Maine DOT
• 33 Agencies responded
  – 10,500 annual tests
• Binder loss occurred in about 4 % of samples
  – 15 Agencies list only modified binders as susceptible
  – 7 Agencies list only neat binders as susceptible
  – 2 Agencies list both modified and neat binders as susceptible
Major Short-Term Conditioning Findings

• For HMA Conditions
  – No significant difference in aging index for any of the short-term binder conditioning procedures and short-term oven aging of mixtures
  – No viscosity effect identified for AASHTO T 240 or any of the alternatives
  – Binder leakage in AASHTO T 240 occurs in about 4 % of samples

• For WMA Conditions
  – Mixing screw procedures are needed when the viscosity of the binder at the conditioning temperature exceeds about 0.55 Pa·s
Short-Term Conditioning Recommendations

• Keep AASTHO T 240
  – Further investigate procedure/training to reduce instances of binder loss

• Consider Static Thin Film If 12.5 g PAV Adopted
  – Eliminates binder transfer between short- and long-term conditioning
  – Condition binder using a small positive pressure to eliminate elevation effect
    • Project 20-07/Task 400, Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder
Long-Term Conditioning

• Concerns with AASHTO R 28
  – Conditioning is not severe enough
  – Service life that is simulated is not well defined

• Alternatives Evaluated
  – PAV film thickness
  – PAV temperature
  – PAV conditioning time
What is Target Age for Long-Term?

Length of Transverse Cracks, m

Pavement Age, yrs

AR
CA
MS
NM
NC
MO
NY
OH
WI

Transverse Cracking in SPS 8 Sections
Long-Term Evaluation

• Response Surface Experiment
  – Varied temperature, film thickness, and conditioning time
  – Compare lab conditioned recovered binder from ARC AZ and MN sites
  – Master curve parameters and FTIR data

• Calibration Experiment
  – 26 Pavement Sections from LTPP
  – Cores and Original Binder
  – Age: 8 to 19 yrs
  – Wide range of climates
Major Long-Term Response Surface Findings

- Smooth evolution of aging in PAV
- PAV reproduces field aging
- Higher temperature, thinner films, and/or longer conditioning times needed to simulate near surface aging
- 40 hr, 50 mm thickness and 20 hr, 12.5 mm thickness approximately equal
Long-Term Calibration Experiment

• Calibration Experiment
  – 12.5 g Mass
  – 20 hr Conditioning Time
  – Varied PAV Conditioning Temperature To Match Recovered Binder Properties
  – Statistical Model to Account for
    • Temperature
    • Age
    • Air Voids
    • Binder Temperature Aging Sensitivity
    • Depth
PAV Conditioning Temperature Model

Predicted Equivalent PAV Temperature °C

Best Fit Measured Equivalent PAV Temperature, °C
12.5 g, 20 hr PAV Temperatures to Simulate 10 years of In-Service Aging in Top 1 Inch

<table>
<thead>
<tr>
<th>Average 98 % Reliability High and Low Pavement Temperature</th>
<th>Calculated PAV Temperature °C</th>
<th>Recommended Temperature °C</th>
<th>% of LTPPBind 3.1 Stations</th>
<th>PG Grade Based on Environment</th>
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<td>-6(^1)</td>
<td>84.4</td>
<td>85</td>
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<td>0(^1)</td>
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<td>33(^1)</td>
<td>115.0</td>
<td>115</td>
<td>1</td>
<td>PG 76-10</td>
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</table>

\(^1\) Outside range of data used in calibration
Major Long-Term Conditioning Findings

• Feasible to simulate approximately 10 years of near surface, in-service aging using the PAV
  – 12.5 g conditioned for 20 hours
  – 50 g conditioned for 40 hours
  – Temperatures between 85 and 115 C depending on climate
  – Pressure of 2.1 MPa

• Residue from 12.5 g PAV conditioning is significantly more aged than standard PAV residue
  – Need to adjust performance grading criteria
Major Long-Term Conditioning Findings (Continued)

• 12.5 g PAV conditioning requires greater attention to detail
  – Thicker pans to reduce warpage
  – Tighter tolerance on levelness
Long-Term Conditioning Recommendations

• Current Performance Grading
  – No change

• Conditioning for Adoption of $\Delta T_c$ Criterion
  – Single 20 hr PAV run
  – Use 2 50 g pans for low temperature/intermediate grading
  – Use 8 12.5 g for $\Delta T_c$ evaluation using 40 hour $\Delta T_c$ criterion

• Conditioning for Revised Performance Grading
  – Static thin film conditioning for short-term conditioning
  – 12.5 g PAV for long-term
Questions/Discussion

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aatt@erols.com
Other TRB events for you

• **July 16:** Review of Federal Highway Administration Infrastructure R&D - Expert Task Group on Pavements

• **August 10:** National Conference on Transportation Asset Management

• **August 25:** Best Practices for Unsurfaced Road Evaluation and Rating

https://www.nationalacademies.org/trb/events
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