Outline

- Introduction
- Materials
- Binder rheology
- Strain capacity, failure envelope
- Mixture vs binder performance
- Delta Tc, GRP, DENT, extended BBR
- Summary, conclusions
NCHRP 9-59 Objective

The primary objective of NCHRP 9-59 is to develop a test or tests that will help to effectively and efficiently control the properties of asphalt binders that contribute to the fatigue resistance of asphalt mixtures.
Problem

Bill Ahearn, Pamela Marks, Simon Hesp

Hesp et al., Proceedings CTAA, 2009

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

Hwy 41 North of Kaladar (1999)
What is causing these failures?

- Problem binders
  - Excessive brittleness
  - Poor healing
  - Misleading BBR grading
- Delta $T_c$, $R$-value, GRP and DENT are all indicators of the same problem
Over last month…

- Further progress made in data analysis since TAI meeting in Savannah
- Slight change in assumed failure envelope significantly improved results
- May be a few more changes as final report is compiled and reviewed…
Binders included in NCHRP 9-59

- NCHRP 9-59, 8 polymer modified, 8 non-polymer modified
- 2 REOB, 2 oxidized, 1 PPA
- RTFOT + 40 hour PAV
- SHRP binders, RTFOT aging
- ALF, MNRoad, Westrack binder, miscellaneous aging
Binder Tests

- DSR / master curve
- DSR / linear amplitude sweep (LAS)
- Double-edge notched tension (DENT)
- Various tests from previous research
Mixture tests

- Flexural fatigue
- Uniaxial fatigue
- Healing
- Loose mix aging, 95 C for 5 days
- Various tests from previous research
Binder rheologic type and R value
Some notes on R-value

Polymer modified binders and heavily aged non-modified binders are rheologically complex.

R can be calculated from a DSR point measurement as long as $|G^*|$ is about 10 MPa or higher:

$$R = \log(2) \frac{\log(|G^*|/1 \times 10^9)}{\log(1 - \delta/90)}$$
Asphalt Binder Failure Envelope

\[ N_f = \left[ \frac{FSC \times (VBE/100)}{\varepsilon_t} \right]^{2.08 (90/\delta)} \]

- **From binder tests**
- **Heukelom**
- **SHRP DENT**
- **ALF DENT**
- **NCHRP 9-59 DENT**
- **Direct tension**

Failure Strain or FSC, %

Stiffness/3 or G*, Pa
Fatigue/fracture performance ratio (FFPR)

\[
FFPR = \frac{\text{measured FSC}}{\text{average FSC}}
\]

Graph showing the relationship between Failure Strain or FSC and Stiffness/3 or \(G^*\), Pa for different FFPR values of 0.5, 1.0, and 2.0.
More on FFPR

- FFPR is an indicator of inherent fracture and fatigue resistance.

- FFPR $>> 1$ indicate good fatigue performance, FFPR $<< 1$ indicate poor performance.

- For the binder studied in NCHRP 9-59, FFPR values ranged from about 0.4 to 2.
GFTAB model

\[ N_f^\wedge = \left( \frac{FFPR_i \times FSC^* \times (VBE/100)}{\varepsilon_t} \right)^{k_1(90/\delta)} \]

FFPR represents the overall strain tolerance of each binder. FSC is the typical failure strain at any given \(|G^*|\). K1 was found to be 2.08.
Results of GFTAB model

\[ R^2 = 90\% \]
Is GFTAB for real?

$FSC^* = 2.9 \times 10^6 |G^*|^{-0.79}$

*Failure Strain or FSC, %

*Stiffness/3 or $G^*$, Pa
SHRP AAD-1: Fatigue exponents at different temps

- $y = -4.96x - 11.96$
- $y = -3.42x - 5.69$
- $y = -4.99x - 11.79$
- $y = -3.78x - 7.25$

log strain, m/m
SHRP AAD-1: Fatigue exponent vs. phase angle

\[ y = 2.21x \]
\[ R^2 = 0.85 \]

\[ \text{Exp} = 2.08 \times 90/\text{phase} \]
Mixture Fatigue FFPR and Binder R-value

\[ R^2 = 80\% \]

- **SHRP (non-modified)**
- **BBF non-modified**
- **BBF polymer modified**
- **Uniaxial non-modified**
- **Uniaxial polymer modified**
ENT/Extension FFPR and Binder R-value

- \( R^2 = 85\% \)
- \( R^2 = 92\% \)

- SHRP (non-modified)
- NCHRP 9-59 non-modified
- NCHRP 9-59 polymer-modified
Mixture fatigue FFPR vs DENT/Extension FFPR

\[ R^2 = 61\% \]
Mixture fatigue FFPR vs LAS FFPR

R^2 = 66%

- SHRP (non-modified)
- BBF non-modified
- BBF polymer modified
- Uniaxial non-modified
- Uniaxial polymer modified
DENT extension vs $G^*$

- $R^2 = 98\%$
- $R^2 = 73\%$
- $R^2 = 56\%$

- $R < 2.2$
- $2.2 < R < 3.0$
- $R > 3.0$
- Polymer modified
NPFS 776: TSRST Strength and R-value

![Graph showing the relationship between TSRST Strength and BBR R-value with R² values of 16% and 27%. The graph includes data points for Lab mixes, Polymer modified, MNRoad/field, and MNRoad/modified.]
Pavement fatigue life and R-value

Simple LEA analysis with constant sub-base/sub-grade properties, 100-mm pavement
What about $\Delta T_c$? Glover-Rowe Parameter? DENT test? Extended BBR/physical hardening?
\[ \Delta T_c \text{ and } R \text{-value} \]

\[ \Delta T_c \text{ and } R \text{-value are directly related, and both indicate rheologic type and strain tolerance} \]
Of all rheological parameters examined, GRP has the best correlation to DENT extension.
Modulus, R-value and FSC
GRP, R-value and FSC

![Graph showing the relationship between GRP and FSC for different R-values (1.5, 2.5, 3.5). The graph plots FSC in percentage against GRP in kPa. Each R-value has a corresponding line on the graph.]
Extended BBR/physical hardening

Data from Kanabar, 2010

Graph showing the relationship between m-Hardening, Deg. C and Delta Tc, C with R² values of 71%, 76%, and 25% for different sets of data.
Extended BBR/physical hardening

- Physical hardening increases with increasing $\Delta T_c / R$-value
- For high $\Delta T_c/R$ the BBR will overestimate m-value
- Not only are these binders brittle, their BBR grades are lower than they should be…

Can we adjust $T_c$ for physical hardening using $R$?
Adhesive healing

\[ N_f \left[ \frac{(FSC/\varepsilon_t) \times (VBE/100)}{2.08(90/\delta)} \right] \]

- Continuous loading
- Pulse loading
- Net damage
- Absolute healing
Adhesive Healing

R² = 71%

R² = 38%

Phase Angle (from R), degrees

Absolute Healing

Non-modified
Polymer-modified

National Center for Asphalt Technology
NCAT
Auburn University
Adhesive healing

- Absolute healing increases with increasing phase angle.
- Since phase angle at a given modulus decreases with increasing R, binders with high R values will show less healing.
- Maximum net damage at 10 to 20 MPa, increases with increasing R.
Rheologic type can be specified in several ways

- **R-value**
  - Calculated from DSR, $G^*$ apx. 10 Mpa
  - Calculated from BBR
- **DSR minimum phase angle at $G^* = 10$ MPa for example**
  - BBR, maximum $S$ at $m 0.3$, for example
  - BBR, maximum $\Delta T_c$
Polymer-modified binders

- High R-values appear to be as bad or worse for the performance of polymer-modified binders as for non-modified ones
- Probably need similar control of R for all binders
- Level of modification should be controlled primarily through high temperature spec
Summary

- Binders with high R-values are a “triple whammy”
  - Increased brittleness
  - Decreased adhesive healing
  - Errors in BBR grading

- Need to control rheologic type—ΔT_c, R-value or some related parameter—to eliminate these problems

(might want a minimum R too)
Remaining work

- Draft final report is being compiled
- Completion of validation testing
- Related work being done as part of NCHRP 9-60 (binder manufacture/pavement performance/specifications) and NCHRP 9-61 (binder aging)
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