Outline

- Objectives
- Problem
- Theoretical concepts
- Tests
- Materials
- Analysis results
- Remaining work
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.
Presentation Objective

- Describe project objectives and important concepts used in testing and analysis
- Provide summary of results to date
- Describe remaining efforts
Problem

Bill Ahearn, Pamela Marks, Simon Hesp

Hesp et al., Proceedings CTAA, 2009
Theoretical concepts
General Failure Theory for Asphalt Binder

\[ N_f = \left( \frac{FSC}{\varepsilon_{\text{binder}}} \right)^{Ko(90/\delta)} \]

\[ N_f = \left\{ \frac{FSC}{\left[ \varepsilon_{\text{mix}} / (VBE/100) \right]} \right\}^{Ko(90/\delta)} \]

\[ D = \sum_{i=1}^{n} N_i \left[ \frac{(\varepsilon_{\text{mix}})_i}{(VBE/100)} \right]^{Ko(90/\delta)} \]

\[ FSC = D^{\delta/(90 \times Ko)} \]

FSC = fatigue strain capacity

Phase angle \( \delta \) is for the binder, not the mix...
Typical Failure Envelope

- ARC Fatigue
- 9-25 Fatigue
- Direct Tension
- Fit
- Heukelom

Parameters:
- DT Stiffness/3 or $G^*$, Pa
- FSC, %

Log-log scale with magnitudes from $1.00 \times 10^{-1}$ to $1.00 \times 10^{10}$. Points and lines illustrate the relationship between stiffness and failure.
Fatigue/Fracture Performance Ratio, FFPR

\[ FFPR = \frac{\text{Measured FSC or } \varepsilon^*}{\text{Typical FSC or } \varepsilon^*} \]

FFPR is simply the ratio of observed to expected failure strain (based upon data for a range of typical binders). Values significantly above 1 are good, below 1 are bad.
Test methods
Dynamic Shear Rheometer

Master curve for PG 76-22
Simplified DENT Test

- Standard ductility batch
- Molds/specimens same as for force-ductility but with double 7.5-mm notch
- 50 mm/min
- Temperature 5 to 25°C
DENT Test Results

- **Force, N**
- **Extension, mm**

- Initial stiffness
- Total energy to failure
- Ext. to Max. load
- Ext. to 20% of Max. load
FFPR for DENT Energy to Failure

![Graph showing Total Energy to Failure vs. Specimen Stiffness at 3 Seconds, with data points for Typical, ALF Blown, ALF SBS LG, ALF Terpolymer, NCHRP 9-59, and Fit/Typical.]
Typical LAS test

![Graph showing typical LAS test results with time (s) and concentration (C) on the axes. The graph includes a fit line and data points for 300 s, 600 s, and 900 s.]
LAS FFPR

- Use GFTAB analysis
- Failure envelope from analysis of 9-59 uniaxial fatigue data
- Calibration factor to account for shear loading and non-constant stresses and strains
- Results in FSC value from which FFPR is calculated
NCHRP 9-59 Mixture Testing

- Uniaxial fatigue (SVECD)
  - Two temperatures
  - Three replicates

- (Texas overlay test)
  - 20°C
  - Three replicates

- Bending beam fatigue
NCHRP 9-59: Laboratory Aging

- Binders: RTFOT + 40 hour PAV
- Mixture: Standard short term aging followed by loose mix aging at 95°C for 5 days.
- Based on data available at the start of the project, which was very limited
Materials
### NCHRP 9-59 Binders

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<tr>
<th>Grade</th>
<th>Modifier/Additive</th>
<th>Expected Performance</th>
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<tbody>
<tr>
<td>PG 88-22</td>
<td>SBS</td>
<td>good</td>
</tr>
<tr>
<td>PG 76-28</td>
<td>SBS</td>
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<tr>
<td>PG 76-22</td>
<td>SBS/PPA</td>
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<tr>
<td>PG 64-28</td>
<td>SBS</td>
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<tr>
<td>PG 70-22</td>
<td>SBR</td>
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<tr>
<td>PG 76-22E</td>
<td>SBS</td>
<td>good</td>
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<tr>
<td>PG 58-28</td>
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<td>moderate</td>
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<tr>
<td>PG 64-22</td>
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<th>Grade</th>
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<tr>
<td>PG 70-22</td>
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<td>PG 58-28</td>
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<td>PG 70-22</td>
<td>PPA</td>
<td>poor</td>
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*All binder aged in 40 hour PAV at 100°C*
NCHRP 9-59 Mixture Design

- 9.5 mm nominal maximum size
- Blend of granite, limestone and sand
- 6.0 % binder content
- Designed at 4.0 % air voids at 80 gyrations
- Compacted to 7.0 % air voids for most tests
Analysis and Results
General Method of Analysis

- Model fatigue response
- Include different strain tolerance values (FF{R) for each binder
- Compare these FFPR values to those calculated from binder tests
- Run model using measured binder FFPR values to see if model improves significantly
Flexural Fatigue Model

\[ \log N_f = K_0 + K_1 \log E^* + K_2 \log \left( \frac{\varepsilon}{\text{FFPR}_i} \right) + K_3 \log VBE \]

\text{FFPR}_i \text{ is different for each binder—the values determined from mix fatigue can then be compared to those determined from binder tests.}
Flexural Fatigue Analysis

Predicted Nf vs. Observed Cycles to Failure

Experimental +/- 2s precision

<table>
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<tr>
<th>R-squared</th>
<th>Value</th>
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<td>DENT Extension</td>
<td>43</td>
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<tr>
<td>DENT TEF</td>
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<td>DENT EML</td>
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<td>R-Value</td>
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<tr>
<td>LAS</td>
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FFPR, Flexural Fatigue vs. DENT Extension

\[ R^2 = 43\% \]
Uniaxial Fatigue Analysis

Predicted Nf vs. Observed Cycles to Failure

Experimental \(+/- 2s\) precision (from BBF)

<table>
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<th>R-squared</th>
<th>DENT Extension</th>
<th>DENT TEF</th>
<th>DENT EML</th>
<th>R -Value</th>
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<td>46</td>
<td>58</td>
<td>59</td>
<td>71</td>
<td>81</td>
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Mix Uniaxial FFPR vs FFPR from DENT Energy to Failure

\[ R^2 = 58\% \]
Mix Uniaxial FFPR vs FFPR from Binder LAS

\[ R^2 = 81\% \]
Mix Uniaxial FFPR vs Binder R-Value

\[ R^2 = 83\% \]
LAS FFPR vs Binder R Value

\[ R^2 = 66\% \]
ALF Fatigue Experiment and DENT Test Data

![Graph showing ALF Cycles to First Crack vs. DENT FFPR from TEF with an R² value of 95%](image-url)
ALF Fatigue and FFPR from LAS Test

\[ R^2 = 1\% \]
Healing experiment

- The healing experiment conducted in NCHRP 9-59 shows that at phase angles below about 40 degrees, there is little healing; at phase above about 70 degrees, healing is nearly complete.

- We have found several studies where there are good correlations between field performance and phase angle supporting this observation.
In conclusion…
Preliminary Findings

- Substantial evidence suggests DENT test is a reasonably good predictor of fatigue and fracture performance.
- Conflicting evidence on effectiveness of LAS test.
- Phase angle appears to relate well to adhesive healing, which in turn appears to be a significant factor in field performance.
Remaining work

- Complete uniaxial testing
- Refine analysis and select final test methods
- Finalize validation binders and perform validation testing
- Draft and Final Reports in 2018
Acknowledgements

- NCHRP
- The Project Panel
- Industry suppliers
- Nam Tran and his associates at NCAT
- My associates at AAT, including Ray, Don, and Bob