Performance Modeling of a Highly Modified Asphalt Pavement

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Richard Willis, NAPA

Northeast Asphalt User Producer Group Meeting
July 18, 2017
Outline

- What is highly modified asphalt?
- NCAT test track section performance
- AASHTOWare™ Pavement ME Design modeling
- FLEXPave™ software
- FLEXPave modeling
- Conclusions and where we go from here
What Is Highly Modified Asphalt?

Highly Modified Asphalt is exactly what it says, asphalt with double the normal amount of SBS polymer.
This gives a much denser polymer network with up to 10X rutting and fatigue cracking resistance.
National Center for Asphalt Technology Test Track

- 5 trucks, 16 h/day, 5 days/week
- Axle load: 18 kip
- Speed: 45 mph
Track cycle of 10 million ESALs simulates the design lifetime of damage in 2+ years

ESAL = Equivalent Single Axle Load = 1 pass of 18 kip axle

Highly Modified Asphalt (HiMA) project started in 2009 cycle
Part of Performance Group study—6 sections including control
Continued in 2012 cycle
Total 20 million ESALs
Control (S9) and HiMA (N7) Section Designs

Section S9 - Control
178 mm Standard Hot Mix
- 32 mm (PG 76-22; 9.5 mm NMAS; 80 Gyrations)
- 70 mm (PG 76-22; 19 mm NMAS; 80 Gyrations)
- 76 mm (PG 67-22; 19 mm NMAS; 80 Gyrations)

Section N7
145 mm Highly Modified Hot Mix
- 32 mm (7.5% SBS; 9.5 mm NMAS)
- 57 mm (7.5% SBS; 19 mm NMAS; 80 Gyrations)
- 57 mm (7.5% SBS; 19 mm NMAS; 80 Gyrations)

Dense Graded Crushed Aggregate Base
- $M_r = 85$ MPa
- $n = 0.40$

Test Track Soil
- $M_r = 200$ MPa
- $n = 0.45$

Lift thicknesses limited by 3:1 thickness:NMAS requirement

150 mm

7 in

5\(\frac{3}{4}\) in

Courtesy Prof. David Timm, Auburn U.

KRATON
Crack Maps at 17 Million ESALs

3/14 Rutting

S9  6.0 mm

2/14 Crack Maps

Lane - 9%  Left wheel path - 12%  Right wheel path - 21%

N7  1.6 mm

Lane - 0%  Left wheel path - 0%  Right wheel path - 0%
Rutting over 20 Million ESALs
N7 Crack Map at 20 Million ESALs

S9 resurfaced at 17 million ESALs

N7 cracking is superficial top-down
AASHTOWare™ Pavement ME Design

- Traditional layered elastic model
- Comprehensive input data
- Fatigue cracking model
  \[ N_{f-HMA} = k_{f1}(C)(C_H)b_{f1}(\varepsilon_t)^{k_f2}b_{f2}(E_{HMA})^{k_f3} \]
- Permanent deformation model
  \[ D_{p(HMA)} = \varepsilon_{p(HMA)}h_{HMA} = b_{r1}k_z\varepsilon_{r(HMA)}10^{kr1}\eta^{kr2}T^{kr3} \]
Fatigue Global Calibration Parameters

\[ y = k_{f3} \left( \frac{1}{\varepsilon_0} \right)^{k_{12}} \]

\[ k_{f3} = \text{modulus coefficient} \]
# Fatigue Calibration Factors for Section N7

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Rutting Global Calibration Parameters

- $k_{r1}$ is the y-axis intercept
- $k_{r2}$ is the x versus y slope
- $k_{r3}$ is the $k_{r1}$ versus temperature slope
### Rutting Calibration Factors for Section N7

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Predicted AC Bottom-Up Cracking

- 50% Reliability
- Specified Reliability

Bottom-Up Cracking (%)

Measurement Dates

Predicted Rutting
### Predicted damage summary

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<td>Bottom-Up Cracking, % Area</td>
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### Measured damage summary

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<td>Bottom-Up Cracking, % Area</td>
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Asphalt Mixture Performance Tester
AMPT Cracking Test Methods

- **Modulus**
  - Axial compression dynamic modulus test (AASHTO T 378)
  - Dynamic modulus mastercurve and time-temperature shift function

- **Cracking Resistance**
  - AMPT cyclic fatigue test (AASHTO TP 107)
  - C vs. S (damage characteristic curve)
  - Energy-based failure criterion
S-VECD Model for Cracking

These characteristic relationships remain the same under different modes of loading, different temperatures, different stress/strain amplitudes, and different loading histories.
Specimen Geometry

110 mm
38 mm
100 mm

2 gyratory specimens needed

E* Tests
Fatigue Tests
FlexPAVE™ 1.0

- Three dimensional layered viscoelastic analysis for moving loads and thermal stresses
- Fatigue performance analysis based on Viscoelastic Continuum Damage (VECD) Model
- Rutting performance analysis based on the shift model
- Support for multiple axle and multiple wheel loading
- Integrated with EICM software to capture temperature variation for thermal stress analysis and material properties
- Integrated GUI that includes pre and post processors
General Information
EICM in FlexPAVE™

Temperature Profile Input
- EICM
- EICM Text File
- Isothermal

EICM Database Temperature
- State: AL
- Year: 2014
- Day: 0
- City: DECatur
- Month: Aug

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Material Properties

General Information
- Structure Name: Flexible 3-Layer Pavement
- Pavement/Lane Width (m): 3.65

Layer Properties
- Layer: AC
- Thickness (cm): 10
- Material Type: Asphalt Concrete
- Specific Gravity (optional): 2.5
- Expansion Co. (1/C): 0.00005

Strength/Modulus
- Poisson's Ratio: 0.3000
- E_filtered (KPa): 9.7369e+04
- Ref. Temp. (C): 5
- Shift Factor a1: 6.9619e-04
- Shift Factor a2: -0.1620
- Shift Factor a3: 0.7928

Import Damage Data
Import Rutting Data

Please note that FlexPAVE 1.0 uses the power function with the C11 and C12 coefficients to define damage characteristic curve instead of an exponential function.
Damage Contour
Field Validation
Validation Sections

59 asphalt mixtures, including WMA and RAP mixtures, from 55 pavement sections
FlexPAVE™ Simulation

NCAT Test Track 2009 Performance Group
FlexPAVE™ Simulation

NCAT Test Track 2009 Section N7
FlexPAVE™ Simulation

NCAT Test Track 2009 Section N7 Expanded Scale
NCAT Test Track Prediction

% Cracking Measured vs % Damage Predicted

- R
- RW
- C
- AW
- FW
- O
Cracking Performance Simulation by FlexPAVE™

- **FHWA-ALF SBS**
  - 95°C
  - 21 Days
  - 52 Hrs

- **SHRP AAD-1**
  - 8.9 Days
  - 16.8 Hrs

- **SHRP AAG-1**
  - 19 Days
  - 37.6 Hrs
Effect of Aging on Cracking

- Short-Term Aged
- Loose Mix, 95°C, 8.9 Days
- Loose Mix, 135°C, 16.8 Hr
NCHRP 09-54 Aging Procedure

- Loose mixture aging in an oven at 95°C
- Use the climate aging index (CAI) map for laboratory aging durations for specific pavement depth and age of interest in the field
NCHRP 9-54 Aging Map

Required Oven Aging Duration at 95°C to Match 8 Years of Field Aging at 20 mm Below Pavement Surface (Days)
Conclusions

- NCAT section N7 developed fine surface cracking late in its life, but forensic analysis showed that the cracking was minor top down cracking not impacting the structural integrity of the pavement.
- Highly modified asphalt may be useful in perpetual pavement design.
- Demonstrated performance up to 20 million ESALs shows that the thickness of pavement structures may be reduced while retaining or even improving long term performance.
Conclusions

- AASHTO M332 specifications (plus elastic recovery) have been effective to specify HiMA binders for commercial applications.
- Standardized test methods in increasingly common use are adequate to characterize HiMA mixtures for the purpose of pavement design.
- The current Pavement ME Design protocol is suited to designing perpetual pavements with highly modified asphalts. Relative global calibration factor adjustment with Level 1 design gives performance predictions that agree well with actual field performance relative to known structures.
Conclusions

- Both AASHTOWare Pavement ME Design™ and FlexPAVE™ are effective design tools.
- ME Design currently lacks a validated model for top-down cracking.
- FlexPAVE currently lacks a built-in aging model and so required aged material properties.
- We will be doing follow up modeling with both to compare!
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