Optimized or Balanced Mix Design

• Crack Resistant
• Rut Resistant
• Resistant to Moisture Damage
Balanced Mix Design: ETG Definition

• Asphalt mix design using *performance tests* on appropriately *conditioned specimens* that address *multiple modes of distress* taking into consideration mix aging, traffic, climate and location within the pavement structure

Performance Pendulum
(Shane Buchanan, Oldcastle)
Disk-Shaped Compact Tension (DCT) Test

- ASTM D7313-13
- Loading Rate:
  - Crack Mouth Opening Displacement
  - CMOD Rate = 1.0 mm/min
- Measurements:
  - CMOD
  - Load
Semi-Circular Bend (SCB) Test

• Multiple variants exist
  • Early work in Europe
  • Simultaneous cold (Marasteanu et al. – MN) and intermediate temperature (Mohamed et al. – LA) versions
  • Recent work from Al-Qadi et al. (IL) → AASHTO TP 105

• AASHTO TP 105 (I-FIT)
  • Line load control, loading rate = 50 mm/min
  • Test temperature = 25 deg. C

• Measurements:
  • Displacement
  • Load

• Outcomes
  • Fracture Energy
  • Flexibility Index (FI)
Fracture Parameters

Fracture work: Area under Load-Displacement curve

Fracture Energy, $G_f$: Energy required to create unit fracture surface

$G_f = \text{Fracture Work, } S_f$

Fracture Area

Flexibility Index, $FI$: $FI = \frac{G_f}{m}$
Choosing A Fatigue Test for Long Life Asphalt Pavement (LLAP)

Mansour Solaimanian, Ph.D., P.E.
Pennsylvania State University
August 2nd, 2017

Scott Milander
Pezhouhan Kheiry
Xuan Chen
Saman Barzegari
Ilker Boz
Today's Talk

- A Review of Asphalt Concrete Fatigue Tests
- Semi-Circular Beam (SCB) Test
- PSU SCB Study and Preliminary Results
- Next Steps
Today’s Talk

• A Review of Asphalt Concrete Fatigue Tests
• Semi-Circular Beam (SCB) Test
• PSU SCB Study and Preliminary Results
• Next Steps
Lab Scale Tests

Monotonic Tests
- Indirect Tensile Strength
- Semi-Circular Beam
- Disk-Shaped Compact Tensile

Cyclic Tests
- Four Point Bending Beam
- Indirect Tensile
- Uniaxial Push-Pull
- Texas Overlay

Picture Curtesy: IPC Global, Umass, Penn State
Lab Scale Tests (Cyclic Tests)

Texas Overlay Tester

Fatigue/Cantilever Trapezoid

Bending Beam
Model Scale Accelerated Tests
• Third Scale Model Mobil Load Simulator (MMLS3)
Test Tracks and Full Scale Tests

Penn State Track

NCAT Track
Picture Curtesy: NCAT

...and ALF, HVS, MLS, ....
Today’s Talk

• A Review of Asphalt Concrete Fatigue Tests
• Semi-Circular Beam (SCB) Test
• PSU SCB Study and Preliminary Results
• Next Steps
Background on SCB

• Early Work on Rocks (Chong and Kuruppu, 1984)
• Introducing SCB for Asphalt Testing (Molenaar, 2000 & 2002)
• Further Research (Mohammad et al., 2004) - LA
• Further Research – IFIT (Alqadi et al., 2015) - IL
• Implementation in Specs (Mohammad et al., LTRC, 2016)
SCB Test Setup

Specimen Thickness: 50 mm
Notch Depth: 15 mm
Notch Width: 1.5 mm
Parameters Used For Evaluation

Fracture Energy

\[ G_f = \frac{W_f}{B \cdot L} \]

- **B**: Specimen Thickness
- **L**: Ligament Length

Flexibility Index

\[ FI = A \times \frac{G_f}{\text{abs}(m)} \]

- **A**: Constant

Stiffness Index

Slope @ 50% Peak Load in Pre-Peak Curve
Advantages of SCB Test

• Specimen Easily Prepared Using SGC or Field Cores
• Four Specimens from One Compacted Mix
• Easy to Perform and Simple to Analyze
• Possible To Perform Test Using Marshall-Type Stability Tester

• Good Correlation to Field Performance Has Been Reported. (Limited Data so far)?
Current Issues

• In the SCB test, do we know the answer to these?

  • What test temperature?
  • How fast to test?
  • What is good versus poor performance?
  • What pass/fail criteria?
  • Test short-term aged or long-term aged mix?
  • Test variability and how to reduce variability?
Today’s Talk

- A Review of Asphalt Concrete Fatigue Tests
- Semi-Circular Beam (SCB) Test
- PSU SCB Study and Preliminary Results
- Next Steps
Study Objectives

• Effect of Test Temperature
• Effect of Loading Rate Range
• Effect of Aging (short term vs long term)
• Effect of Binder Content and Binder Stiffness
• Effect of Voids

Use data to establish Temperature – Loading Rate Master Curve and Propose the Final SCB Test Protocol
Test Temperature

I-FIT Protocol: Fixed Temperature for All Mixes, i.e. 25°C

Proposed Protocol: Using Effective Temperature Concept

NCHRP 704: A Performance-Related Specification for HMA

\[
T_{\text{eff}} = -13.995 - 2.332(F_{\text{req}})^{0.5} + 1.006(\text{MAAT}) \\
+ 0.876(\sigma \text{MMAT}) - 1.186(\text{wind}) \\
+ 0.549(\text{sunshine}) + 0.071(\text{rain})
\]

Freq: Loading Frequency, Hz;
MAAT: Mean Annual Air Temperature, °F;
\sigma \text{MAAT}: Standard Deviation of the Mean Monthly Air Temperature;
Rain: Annual Cumulative Rainfall Depth, inches;
Sunshine: Mean Annual Percentage Sunshine, %; and
Wind: Mean Annual Wind Speed, Mph.

Harrisburgh is around 18°C
Test Loading Rate

Current Protocol:
• 50 mm/min (too fast, not enough data points, higher COV)
• 0.5 mm/min (too slow, affected by creep)

Proposed Protocol based on our results so far:
• Using loading rate between 5 to 20 mm/min will minimize the effect of creep, and provide a reasonable range for FI for long term aged mix.
• A set of tests (3 replicates) can be conducted within 5 minutes
**Specimen Preparation**

- SGC Specimen or Field Cores
- Cut to Ensure Minimum AV Gradient
- Obtain Density
- Condition Specimens at Test Temperature
- Conduct Test

**It Takes 3 days from Mixing to Obtain Results**
Specimens After Cutting Ready for Testing

Specimens Before (L) / After (R) Testing
Typical Load vs Displacement Curves
3 Replicates, PG 58-28, 25°C

Load (N) vs Displacement (mm) graph showing different loading rates:
- 50 mm/min
- 25 mm/min
- 5 mm/min
- 1 mm/min
Temperature/Loading Rate Effects

Fracture Energy Comparison

Tested @ 25 °C

Tested @ 18 °C
Temperature/Loading Rate Effects

Flexibility Index Comparison

- Tested @ 25 °C
- Tested @ 18 °C

Flexibility Index

- Virgin Agg+PG58+7AV
- Virgin Agg+PG58+4AV
- Virgin Agg+PG58+7AV+5.9BC
- Virgin Agg+PG76+7AV
- Virgin Agg+PG58+7AV @ 18C
- Virgin Agg+PG58+4AV @ 18C
- Virgin Agg+PG58+7AV+5.9BC @ 18C
- Virgin Agg+PG76+7AV @ 18C
Aging Effect

Flexibility Index Comparison, all at 18°C

- 1 mm/min
- 5 mm/min
- 20 mm/min
- 50 mm/min

**Short Term Aged**
- Virgin Agg+PG58+7AV @ 18C
- Virgin Agg+PG58+4AV @ 18C
- Virgin Agg+PG58+7AV+5.9BC @ 18C
- Virgin Agg+PG58+7AV @ 18C LTOA
- Virgin Agg+PG58+4AV @ 18C LTOA
- Virgin Agg+PG58+7AV+5.9BC @ 18C LTOA
- Virgin Agg+PG76+7AV @ 18C LTOA

**Long Term Aged**
Correlate Stiffness Indices of Aged Mixes

**Stiffness Index Comparison**

\[ y = 1.3827x + 1846.5 \]

\[ R^2 = 0.8427 \]
Correlating Facture Energy of Aged Mixes

Fracture Energy Comparison

\[ y = 0.6063x + 811.61 \]

\[ R^2 = 0.8137 \]
Correlating Fl of Aged Mixes

Flexibility Index Comparison

- 1 mm/min
- 5 mm/min
- 20 mm/min
- 50 mm/min

Line of Equality
Temperature/Loading Rate Sweep in SCB

Flexibility Index
Long Term Aged Material

Faster Loading

Temperature (°C)

Flexibility Index

1 mm/min
5 mm/min
20 mm/min
50 mm/min
Effect of Binder Content

Typical Load vs Displacement Curve
STOA, PG64-22, 7% AV

Load (N)
Displacement (mm)

Post Peak Slope

- 4.7% BC
- 5.2% BC
- 5.7% BC
- 6.2% BC
Effect of Binder Content

7% Air Void

Flexibility Index

Binder Content (%)
Effect of Binder Content

4% Air Void

Flexibility Index

Binder Content (%)

- PG58-28
- PG64-22
- PG76-22
Effect of Binder Grade (Stiffness)

Typical Load vs. Displacement Curve
STOA, 7% AV, 5.2% BC

- PG58-28
- PG64-22
- PG76-22
Effect of Binder Grade (Stiffness)

7% Air Void

Flexibility Index

Binder High Temperature Grade

- 4.7% BC
- 5.2% BC
- 5.7% BC
- 6.2% BC
Effect of Binder Grade (Stiffness)

4% Air Void

Flexibility Index

Binder High Temperature Grade

0 5 10 15 20 25 30 35

52 58 64 70 76 82

4.7% BC 5.2% BC 5.7% BC 6.2% BC
Effect of Binder Grade (Stiffness)

10% Air Void

Flexibility Index vs. Binder High Temperature Grade

- 4.7% BC
- 5.2% BC
- 5.7% BC
- 6.2% BC
Effect of Air Void

Typical Load vs. Displacement Curve
STOA, PG64-22, 5.2% BC
Effect of Air Void

5.2% Binder Content

Flexibility Index vs. Air Void (%)

- PG58-28
- PG64-22
- PG76-22
The Effect of Air Void Reported by UIUC

Source: Maxwell 2016
The Effect of Air Void Reported by UIUC

Source: Maxwell 2016
Where do we go from here?

- Effect of Modifiers
- Effect of RAP/RAS
- Effect of Crumb Rubber
- Plant vs Lab Mixes
- Cataloging PA Mixes
- Correlation with Field Performance
PAPA Proposed Crack Performance Testing

- Virgin vs. 15% RAP mix
- Design Binder vs. +0.5% AC
- Lab mix vs. Production mix
- Short-term vs. long-term aging
- 16 cells in matrix
- Baseline for existing mixes
Thank you!