Semi-Circular Bending Beam Test: Effect of Loading and Mix Parameters

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Outline

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

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

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

Picture Courtesy: 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

...and ALF, HVS, MLS, ....

Penn State Track

NCAT Track
Picture Curtesy: NCAT
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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 Apply on Rocks (Initial Application)

Photo Source: Lim et al. 1984
SCB Test Applied to Rocks

SCB Testing of Granite Rock

Photo Source: Dynamic Behavior of Materials, Vol.1
SCB Test Applied to Rocks

Compression-Induced Fracture Surfaces and Failure Mechanism

Photo Source: Advances in Materials Science and Engineering Vol. 2014, Article 814504
SCB Test Setup

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

![Graph showing load versus displacement with labeled parameters: Slope @ 50% Peak Load, Peak Load ($P_{\text{max}}$), Slope @ Inflation Point (m), Work of Fracture ($W_f$), Critical Displacement.]

**Fracture Energy**

$$G_f = \frac{W_f}{B \cdot L}$$

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

**Flexibility Index**

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

*A*: Constant

**Stiffness Index**

Slope @ 50% Peak Load in Pre-Peak Curve
Louisiana SCB Method (J Integral Concept)

Notch Depth: 25.4 mm

Notch Depth: 31.8 mm

Notch Depth: 38.0 mm

Strain Energy to Failure

Plot Source: Mohammad et al. 2012
**Louisiana SCB Method (J Integral Concept)**

\[
J_c = - \left( \frac{1}{b} \right) \frac{dU}{da} = \left( \frac{U_1}{b_1} - \frac{U_2}{b_2} \right) \frac{1}{a_2 - a_1}
\]

Where:

- \( J_c \) = Critical strain energy release rate, KJ/m²;
- \( b \) = Specimen thickness, m;
- \( a \) = Notch depth, m; and
- \( U \) = Strain energy to failure, kN-m or KJ.

**Plot Source:** Elseifi et al. 2012

**thickness:** 50 mm

**multiple-notch depths (25.4/31.8/38 mm)**

\( J_c \) : slope of the notch depth vs. strain energy plot
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??
Current Issues

• What Test Parameters to Use?
  • What test temperature?
  • How fast to test?
  • What pass/fail criteria?
  • Sensitivity to Mix Parameters
  • Short-term aged or long-term aged mix?
• Test repeatability and reproducibility?
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INVESTIGATE

• 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
**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

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

*Harrisburgh is around 18°C*

**Freq:** Loading Frequency, Hz;
**MAAT:** Mean Annual Air Temperature, °F;
**σMAAT:** 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.
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)

Findings:
• 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.
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)

- 50 mm/min
- 25 mm/min
- 5 mm/min
- 1 mm/min
Temperature/Loading Rate Effects

Fracture Energy Comparison

Fracture Energy (J/m^2)

Tested @ 25 °C

Tested @ 18 °C

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

1 mm/min  5 mm/min  20 mm/min  50 mm/min
Temperature/Loading Rate Effects

Flexibility Index Comparison

- **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**

Tested @ 25 °C

Tested @ 18 °C

Flexibility Index

Temperature/Loading Rate Effects
Stiffness Indices of Aged Mixes

\[ y = 1.3827x + 1846.5 \]

\[ R^2 = 0.84 \]
Facture Energy of Aged Mixes

Fracture Energy

\[ y = 0.6063x + 811.61 \]

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

Flexibility Index

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

Long Term Aged Flexibility Index

Short Term Aged Flexibility Index
Temperature/Loading Rate Sweep in SCB

Flexibility Index
Long Term Aged

Faster Loading

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

STOA, PG64-22, 7% AV

Post Peak Slope

Effect of Binder Content

Load (N) vs. Displacement (mm) for different binder contents: 4.7% BC, 5.2% BC, 5.7% BC, and 6.2% BC.
Effect of Binder Content

7% Air Void

Flexibility Index vs. Binder Content (%) for different binder types (PG58-28, PG64-22, PG76-22).
Effect of Binder Content

4% Air Void

Flexibility Index vs Binder Content (%)

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

STOA, 7% AV, 5.2% BC

![Graph showing the effect of binder grade on load and displacement. The graph compares STOA, 7% AV, 5.2% BC for PG58-28, PG64-22, and 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 Air Void

Typical Load vs. Displacement Curve
STOA, PG64-22, 5.2% BC

Effect of Air Void

2% AV
4% AV
7% AV
Effect of Air Void

5.2% Binder Content

Flexibility Index vs. Air Void (%) for PG58-28, PG64-22, and PG76-22.
The Effect of Air Void Reported by UIUC

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

Source: Maxwell 2016
CRM Mixes – Peak Load (LTOA)
CRM Mixes – Fracture Energy (LTOA)

Fracture Energy (J/m²)

- PG64+22
- PG58-28+10% CRM
CRM Mixes – Flexibility Index (LTOA)

- PG64+22
- PG58-28+10% CRM
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• Higher loading rate ➞ Lower FI
• Higher temperature ➞ Higher FI
• Higher Binder Content ➞ Higher FI
• Higher Air Void ➞ Higher FI?
• Higher Aging ➞ Lower FI
• Increase in Binder Stiffness (Grade)?
• CRM+PG 58 higher FI compared with PG 64
Thank you!

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