Moving Towards Performance Based Testing
Semi-Circular Bend Test

Pennsylvania Asphalt Pavement Association
Regional Technical Meetings
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Outline

• Background on Semi-Circular Bend (SCB) Test

• PennDOT/Industry Initiative on Performance Testing

• Review of Results
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 Applied to Rocks

SCB Testing of Granite Rock

Photo Source: Dynamic Behavior of Materials, Vol.1
**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
Test Loading Rate

Current Protocols:
• 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 mixes.
Specimens After Cutting Ready for Testing (4” Thick Test Specimens)

Specimens Before (L) / After (R) Testing
Affect of Strain Rate

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
Industry SCB Testing: How Did It Start?

- Move to Performance Testing
- Initiated by Asphalt Pavement Quality Improvement Committee and PAPA
- Industry Expressing Interest in Participating
Purpose of the Effort

- Promote transition to Performance Testing
- Investigate Performance of PA Mixes in SCB
- Develop a *Baseline* Database of SCB Test Results
- Evaluate Sensitivity of the PA Mixes to the Test
- Evaluate Impacts of Mix Changes on Improved Crack Resistance
- Evaluate Test Protocols
- **Evaluate Correlation with Field Performance**
Mix Criteria and Variables

- Air Void: 5.5% (Final SCB Specimen)
- Design Binder Content (and +0.5%)
- Virgin Mixes & Mixes with 15% RAP at Design BC and at 0.5% Higher Binder Content
- Mixes at higher RAP Contents
- NMAS: 4.75, 9.5mm, 12.5mm, 19mm, 25mm
Lab vs Plant and Aging Effect

Lab Prepared Mix
- Short Term Oven Aged (2hr @ 275F)
- Long Term Oven Aged (5 days @ 185F)

Plant Prepared Mix
- Short Term Aged
- Long Term Aged

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## Progress to Date

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QUANTITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Producers</td>
<td>11</td>
</tr>
<tr>
<td>No. of Plugs</td>
<td>73</td>
</tr>
<tr>
<td>No. of Plant Mixes</td>
<td>20</td>
</tr>
<tr>
<td>No. of Lab Mixes</td>
<td>53</td>
</tr>
<tr>
<td>No. of Binder Grades</td>
<td>2 PG 64-22 &amp; PG 76-22</td>
</tr>
<tr>
<td>No. of NMAS</td>
<td>4 (4.75, 9.5, 19.25mm)</td>
</tr>
<tr>
<td>No. of RAP Levels</td>
<td>5 (0, 10, 15, 20, 25, 30)</td>
</tr>
<tr>
<td>No. of SCB Tests Completed</td>
<td>252</td>
</tr>
</tbody>
</table>
What Do We Do with the Plugs?

NECEPT Staff Enters Following Into Database:

• Identification Code
• Source (JMF’s for All Mixes)
• Date of Compaction
• Date of Receipt at NECEPT
• Lab vs Plant Mix
• Aging Condition
• Air Void
Processing/Testing Specimens

- Photos Taken
- Specific Gravity Measurement
- Cut into 4 Specimens
- Specific Gravity Measurement
- Conduct SCB Test
Specimen Preparation

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

Higher AV
Waiting for More Specimens

• Continue Receiving Material
• Continue Cataloging/Testing Materials
• Continue Analysis

PLEASE:
• Label Materials Properly
• Ship/Transport Safely
• Include Mix Information/JMF/Compaction Date
A LOOK AT THE RESULTS

PLEASE NOTE:

“This is just a simple presentation of results. No In-Depth Analysis Has Been Conducted Yet.”
Industry SCB Test Results

Results from Specimens Prepared with High Quality, COV of AV < 5%

Results of test of 4 specimens from one plug
Industry SCB Test Results

Results from Specimens Prepared with High Quality, COV of AV < 5%

Results of test of 4 specimens from one plug
Industry SCB Test Results

Results from Specimens Prepared with Low Quality, COV of AV > 10%

Results of test of 4 specimens from one plug. *Investigate and/or discard results?*
Industry SCB Test Results

Overall Data Range and Distribution: Air Void (After Cutting – Individual Tests)

Short Term Oven Aging (STOA), Average: 5.04%

Long Term Oven Aging (LTOA), Average: 5.36%
Industry SCB Test Results

Overall Data Range and Distribution: Fracture Energy (Individual Tests)
Industry SCB Test Results

Overall Data Range and Distribution: Flexibility Index (Individual Tests)

STOA

LTOA

Short Term Age Slightly Higher
Industry SCB Test Results

Overall Data Range and Distribution: Peak Load (Individual Tests)

**STOA**

- Peak Load, N

**LTOA**

- Peak Load, N

Long Term Age Slightly Higher
Industry SCB Test Results

Reported vs. NECEPT Measured Air Void Comparison

- Slightly underreported measured air voids
Industry SCB Test Results (Avg. of 4 Test Specimens)

Source 01: Plant Produced

- LTOA
- 9.5mm
- PG64-22
- 5.6%BC
- 15%RAP
Industry SCB Test Results

Source 02: Plant Produced
- STOA
- 9.5mm
- PG64-22
- 5.9%BC
- 0/15%RAP

Flexibility Index

Air Void: 7.6%
0% RAP

Air Void: 7.5%
15% RAP

Note – Voids High Data Going Wrong Way????
Industry SCB Test Results

Source 03: Plant Produced
- STOA/LTOA
- 9.5mm
- PG64-22

5.6/6.1%BC
15%RAP

NOTE – Question Higher BC & Lower Result
Industry SCB Test Results

Source 04: Plant Produced/Lab Produced

- LTOA
- 9.5mm
- PG64-22
- 5.5%BC
- 0/15/25%RAP

### Flexibility Index

<table>
<thead>
<tr>
<th>Source</th>
<th>0%RAP</th>
<th>15%RAP</th>
<th>25%RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab Produced</td>
<td>AV: 5.0%</td>
<td>AV: 4.7%</td>
<td>AV: 5.3%</td>
</tr>
<tr>
<td>Plant Produced</td>
<td>AV: 5.1%</td>
<td>AV: 5.3%</td>
<td>AV: 5.0%</td>
</tr>
</tbody>
</table>

Questionable Labeling
Industry SCB Test Results

Source 05: Lab Produced
- STOA
- 9.5mm
- PG64-22/PG76-22

- 5.9/6.4/6.9%BC
- 0/15%RAP

<table>
<thead>
<tr>
<th>Specimen 1</th>
<th>Specimen 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC: 5.9%</td>
<td>BC: 6.9%</td>
</tr>
<tr>
<td>AV: 4.7%</td>
<td>AV: 4.7%</td>
</tr>
</tbody>
</table>

PG64-22 + 15%RAP

BC: 6.4%
AV: 4.5%

PG76-22 + 0%RAP

BC: 6.9%
AV: 5.3%
Industry SCB Test Results

Source 05: Lab Produced
- STOA
- 4.75mm
- PG64-22

Flexibility Index

0%RAP
Specimen 1
AV: 5.0%

0%RAP
Specimen 2
AV: 5.0%

15%RAP
AV: 4.7%
Industry SCB Test Results

Source 05: Plant Produced
Lab Produced

- STOA
- 25mm
- PG64-22

<table>
<thead>
<tr>
<th>Flexibility Index</th>
<th>AV: 5.0%</th>
<th>AV: 4.7%</th>
<th>AV: 4.9%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Produced</td>
<td>0% RAP</td>
<td>30% RAP</td>
<td>30% RAP</td>
</tr>
<tr>
<td>Lab Produced</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Industry SCB Test Results

Source 06: Lab Produced
- STOA/LTOA
- 9.5mm
- PG64-22

AV: 5.3%
AV: 5.9%
AV: 5.8%
AV: 5.9%

BC: 4.7%
BC: 5.2%
BC: 5.4%
BC: 5.9%

NOTE – Plant Higher Than Lab Results
Industry SCB Test Results

Source 06: Plant Produced

- STOA/LTOA
- 9.5mm
- PG64-22

- 4.8/5.4/5.5/5.9%BC
- 15%RAP

NOTE – Right Direction, Increased Binder – Short Term Higher
Industry SCB Test Results

Source 07: Lab Produced

- STOA/LTOA
- 9.5mm
- PG64-22

<table>
<thead>
<tr>
<th>Flexibility Index</th>
<th>STOA</th>
<th>LTOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC: 6.0% 15%RAP</td>
<td>AV: 5.2%</td>
<td>AV: 5.2%</td>
</tr>
<tr>
<td>BC: 5.8% 0%RAP</td>
<td>AV: 5.3%</td>
<td>AV: 5.2%</td>
</tr>
<tr>
<td>5.8/6.0% BC</td>
<td>0/15% RAP</td>
<td></td>
</tr>
</tbody>
</table>
Industry SCB Test Results

Source 08: Lab Produced
- STOA
- 9.5mm
- PG64-22
- 6.4/6.8%BC
- 10/15%RAP

NOTE – What is the Difference Between Specimen 1 & 2?
## Industry SCB Test Results

**Source 08: Lab Produced**  
- **STOA**  
- **19mm**  
- **PG64-22**  
- **4.7/5.0%BC**  
- **15%RAP**

<table>
<thead>
<tr>
<th>Flexibility Index</th>
<th>Specimen 1</th>
<th>Specimen 2</th>
<th>Specimen 3</th>
<th>Specimen 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV</td>
<td>4.4%</td>
<td>3.9%</td>
<td>3.5%</td>
<td>3.5%</td>
</tr>
</tbody>
</table>
Industry SCB Test Results

Source 09: Lab Produced
- STOA/LTOA
- 9.5mm
- PG64-22/PG76-22

NOTE – WHY is PG 76-22 Performing Poorer?
Industry SCB Test Results

Source 10: Lab Produced
- STOA
- 9.5mm
- PG64-22/PG76-22

- 5.9/6.0%BC
- 15/20%RAP

<table>
<thead>
<tr>
<th>Flexibility Index</th>
<th>PG64-22</th>
<th>PG76-22</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC:5.9% 20%RAP</td>
<td>AV: 5.6%</td>
<td>AV: 5.4%</td>
</tr>
<tr>
<td>BC:5.9% 15%RAP</td>
<td>AV: 5.5%</td>
<td></td>
</tr>
<tr>
<td>BC:6.0% 15%RAP</td>
<td></td>
<td>AV: 5.4%</td>
</tr>
</tbody>
</table>
What’s Next?

• Scrutinize the Data to draw supported conclusions

• Look at the Effect of Post Peak Slope on FI

• Obtain Virgin Asphalt Source Data

• Look at Effect of Aggregate Hardness
Summary & Questions
Thank You!

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Industry SCB Test Results

Source 02: Plant Produced

- STOA
- 9.5mm
- PG64-22
- 5.9%BC
- 0/15%RAP

Fracture Energy:
- 0% RAP
- 15% RAP

Flexibility Index:
- 0% RAP
- 15% RAP

Peak Load:
- 0% RAP
- 15% RAP
Industry SCB Test Results

**Source 03:** Plant Produced

- **STOA/LTOA**
- **9.5mm**
- **PG64-22**
- **5.6/6.1%BC**
- **15%RAP**
Industry SCB Test Results

Source 04: Plant Produced/Lab Produced

- LTOA
- 9.5mm
- PG64-22
- 5.5%BC
- 0/15/25%RAP
Industry SCB Test Results

Source 05: Lab Produced

- STOA
- 9.5mm
- PG64-22/PG76-22
- 5.9/6.4/6.9%BC
- 0/15%RAP
Industry SCB Test Results

Source 05: Lab Produced

- STOA
- 4.75mm
- PG64-22
- 6.8%BC
- 0/15%RAP
Industry SCB Test Results

**Source 05:** Plant Produced/Lab Produced

- **STOA**
- **25mm**
- **PG64-22**
- **4.6%BC**
- **0/30%RAP**

![Fracture Energy](image)

![Flexibility Index](image)

![Peak Load](image)
## Industry SCB Test Results

**Source 06:** Plant Produced

<table>
<thead>
<tr>
<th>Fracture Energy</th>
<th>Flexibility Index</th>
<th>Peak Load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STOA</strong></td>
<td><strong>LTOA</strong></td>
<td><strong>STOA</strong></td>
</tr>
<tr>
<td>4.8%BC</td>
<td>5.5%BC</td>
<td>4.8%BC</td>
</tr>
<tr>
<td>5.4%BC</td>
<td>5.7%BC</td>
<td>5.4%BC</td>
</tr>
<tr>
<td>5.5%BC</td>
<td>5.4%BC</td>
<td>5.5%BC</td>
</tr>
<tr>
<td>5.9%BC</td>
<td>5.2%BC</td>
<td>5.9%BC</td>
</tr>
</tbody>
</table>

- STOA/LTOA
- 9.5mm
- PG64-22
- 4.8/5.4/5.5/5.9%BC
- 15%RAP
Industry SCB Test Results

**Source 06:** Lab Produced

- **STOA/LTOA**
- 9.5mm
- PG64-22
- 4.7/5.2/5.4/5.9%BC
- 15%RAP
Industry SCB Test Results

**Source 07:** Lab Produced

- **STOA/LTOA**
- **9.5mm**
- **PG64-22**
- **5.8/6.0%BC**
- **0/15%RAP**
Industry SCB Test Results

Source 08: Lab Produced

- STOA
- 9.5mm
- PG64-22
- 6.4/6.8%BC
- 10/15%RAP
Industry SCB Test Results

Source 08: Lab Produced

- STOA
- 19mm
- PG64-22
- 4.7/5.0%BC
- 15%RAP
Industry SCB Test Results

Source 09: Lab Produced

- STOA/LTOA
- 9.5mm
- PG64-22/PG76-22
- 5.6%BC
- 15/20%RAP
Industry SCB Test Results

**Source 10: Lab Produced**

- **STOA**
- **9.5mm**
- **PG64-22/PG76-22**
- **5.9/6.0%BC**
- **15/20%RAP**