Industry/PennDOT Initiative
On Performance Testing

PAPA/PennDOT Bus Tour
Educational Session
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Outline

• A Review of Semi-Circular Bend (SCB) Test
• PA Industry Initiative on SCB
• Results & Observations
• Next Steps
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• A Review of Semi-Circular Bend (SCB) Test
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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**
  \[ \text{FI} = A \times \frac{G_f}{\text{abs}(m)} \]
  
  - **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 or Core
• Easy to Perform and Simple to Analyze
• Possible To Perform Test Using Marshall-Type Stability Tester
Test Loading Rate and Temperature

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 mix.

• Test at 20°C to simulate average PA climate
Specimen Preparation

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

Specimen after Cutting and Ready for Testing

Test Sensitivity
- Strain Rate
- Temperature
- Sample Preparation (Voids)
- Sample Curing

Specimen before and after Testing
Typical Load vs Displacement Curves
3 Replicates, PG 58-28, 25°C

Lower strain Rate → lower peak & flatter post peak slope → same or higher F.I.
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How Did it Start?

• Move to Performance Testing for Mix Optimization

• Initiated by Asphalt Quality Improvement Committee and PAPA

• Industry Expressing Interest in Participating
Purpose of the Effort

• Impetus to Performance Testing

• Investigate Performance of PA Mixes in SCB

• Develop A Database of SCB Test Results

• Evaluate Sensitivity of the PA Mixes to the Test Variables

• Evaluate Correlation with Field Performance
Mix Criteria and Variables

• Air Void: 5.5% (Final SCB Specimen)

• Design Binder Content (and +0.5%)

• Mixes with various RAP higher contents

• Short/Long term aging effects

• Laboratory mixes and plant produced mixes

• NMAS: 4.75, 9.5mm, 19mm, 25mm
# Summary of SGC Plugs Tested (total of 85)

<table>
<thead>
<tr>
<th>Source</th>
<th>Mix Origin</th>
<th>Mix Condition</th>
<th>NMAS, mm</th>
<th>Binder Grade</th>
<th># of Binder Contents</th>
<th>RAP</th>
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<tbody>
<tr>
<td>01</td>
<td>Plant</td>
<td>Long</td>
<td>9.5</td>
<td>64-22</td>
<td>1</td>
<td>15</td>
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<tr>
<td>02</td>
<td>Plant/Lab</td>
<td>Short/Long</td>
<td>9.5</td>
<td>64-22</td>
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<td>9.5</td>
<td>64-22</td>
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<tr>
<td>04</td>
<td>Plant/Lab</td>
<td>Long</td>
<td>9.5</td>
<td>64-22</td>
<td>1</td>
<td>0</td>
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<tr>
<td>05</td>
<td>Plant/Lab</td>
<td>Short</td>
<td>4.75, 9.5, 25</td>
<td>64-22 76-22</td>
<td>4</td>
<td>0, 15, 30</td>
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<tr>
<td>06</td>
<td>Plant/Lab</td>
<td>Short/Long</td>
<td>9.5</td>
<td>64-22</td>
<td>6</td>
<td>15</td>
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<tr>
<td>07</td>
<td>Lab</td>
<td>Long</td>
<td>9.5, 19</td>
<td>64-22</td>
<td>2</td>
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<td>9.5</td>
<td>64-22 76-22</td>
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<td>10</td>
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<td>15, 20</td>
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<tr>
<td>11</td>
<td>Lab</td>
<td>Long</td>
<td>9.5</td>
<td>64-22</td>
<td>1</td>
<td>0, 15</td>
</tr>
</tbody>
</table>
Statistics

TOTAL NUMBER OF SGC PLUGS RECEIVED = 85

Number of Plugs in each Category

NMAS, mm

- 4.75: 4
- 9.5: 3
- 19: 3
- 25: 75

RAP Content, %

- 0: 19
- 10: 2
- 15: 2
- 20: 2
- 25: 52
- 30: 2
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Air Voids

Reported vs. NECEPT Measured Air Void Comparison

(SGC plugs as received)
Asphalt Content

Number of Plugs in each BC Category

Number of Plugs

<table>
<thead>
<tr>
<th>Binder Content, %</th>
<th>4.6</th>
<th>4.7</th>
<th>4.8</th>
<th>5.0</th>
<th>5.2</th>
<th>5.4</th>
<th>5.5</th>
<th>5.6</th>
<th>5.7</th>
<th>5.8</th>
<th>5.9</th>
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<td>2</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td></td>
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</tbody>
</table>
Air Void Distribution

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

<table>
<thead>
<tr>
<th>Air Void, %</th>
<th>STOA</th>
<th>LTOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
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<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STOA
- Target: 5 - 6%
- Average: 5.2%

LTOA
- Target: 5 - 6%
- Average: 5.4%
Peak Load Distribution

Overall Data Range and Distribution: Peak Load

STOA

Average: 3337 N

LTOA

Average: 4123.7 N
Flexibility Index Distribution

Overall Data Range and Distribution: Flexibility Index

STOA

Flexibility Index

Median 7

Average: 8.1

LTOA

Flexibility Index

Median 5 or 6

Average: 4.6
Post Peak Slope Distribution
General Observations (G.O.)

1. Higher AC Content $\rightarrow$ higher F.I.
2. Higher RAP content lower F.I.
3. Longer aging $\rightarrow$ lower F.I.
4. Plant mix has higher F.I. than lab mix
5. Higher voids $\rightarrow$ higher F.I.
6. SMA mix delivers high F.I.
7. Finer mix with high BC $\rightarrow$ higher F.I.
General Observations (G.O.)

1. Higher AC Content $\rightarrow$ higher F.I.
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7. Finer mix with high BC $\rightarrow$ higher F.I.
Producer F: Plant Mix

G.O. #1

Plant Mix

Flexibility Index

Binder Content, %

STOA: Short Term Oven Aging
LTOA: Long Term Oven Aging

JMF = 5.9%
Post Min $P_{be}$

JMF = 5.2%
Pre Min $P_{be}$
Producer F: Lab Mix

STOA: Short Term Oven Aging
LTOA: Long Term Oven Aging

Plant: Lab
1:0.5
Producer H-1

STOA: Short Term Oven Aging
LTOA: Long Term Oven Aging

Binder Content, %

Flexibility Index

NMAS=9.5
NMAS=4.75
NMAS=25
PG76-22
15%RAP
30%RAP, Plant
General Observations (G.O.)

1. Higher AC Content $\rightarrow$ higher F.I.
2. Higher RAP content lower F.I.
3. Longer aging $\rightarrow$ lower F.I.
4. Plant mix has higher F.I. than lab mix
5. Higher voids $\rightarrow$ higher F.I.
6. SMA mix delivers high F.I.
7. Finer mix with high BC $\rightarrow$ higher F.I.
Producer G-1

STOA: Short Term Oven Aging
LTOA: Long Term Oven Aging
PG64-22
PG76-22

1:0.67
STOA:LTOA

1:0.67-0.76
15%:20%RAP
Producer G-2

STOA: Short Term Oven Aging
LTOA: Long Term Oven Aging

PG64-22
PG76-22

1:0.15-0.25
STOA:LTOA

1:0.33-0.67
15%:20%RAP
G.O. #2

Producer H-3

All Specimens were STOA

Diagram:
- Flexibility Index on the y-axis
- RAP Content, % on the x-axis
- Three data points for different NMAS values:
  - NMAS=9.5
  - NMAS=4.75
  - NMAS=25

Note: All specimens were STOA.
G.O. #2

All Producers

Flexibility Index vs. Stiffness Index, Newtons/mm

STOA-With RAP  STOA-No RAP
G.O. #2

All Producers

Stiffness Index, Newtons/mm

- Post Peak Slope
- STOA-With RAP
- STOA-No RAP
G.O. #2

All Producers

Stiffness Index, Newtons/mm

Post Peak Slope

LTOA-With RAP
LTOA-No RAP
General Observations (G.O.)

1. Higher AC Content $\rightarrow$ higher F.I.
2. Higher RAP content lower F.I.
3. Longer aging $\rightarrow$ lower F.I.
4. Plant mix has higher F.I. than lab mix
5. Higher voids $\rightarrow$ higher F.I.
6. SMA mix delivers high F.I.
7. Finer mix with high BC $\rightarrow$ higher F.I.
G.O. #3

Producer L-1

Flexibility Index vs. Binder Content, %

- **STOA-0%RAP**
- **STOA-15%RAP**
- **LTOA-0%RAP**
- **LTOA-15%RAP**

**1:0.5**
STOA:LTOA

**1:0.55**
0%:15%RAP
G.O. #3

**Producer I**

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

\[
y = 0.2694x + 0.9484 \\
R^2 = 0.6801
\]
### G.O. #3

**Producer F: Plant Produced**

- STOA/LTOA
- 9.5mm
- PG64-22

<table>
<thead>
<tr>
<th>Flexibility Index</th>
<th>STOA</th>
<th>LTOA</th>
<th>Binding Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC 4.8%</td>
<td>5.5%</td>
<td>AV: 5.7%</td>
<td>5.5%</td>
</tr>
<tr>
<td>BC 5.4%</td>
<td>AV: 5.7%</td>
<td>5.4%</td>
<td></td>
</tr>
<tr>
<td>BC 5.5%</td>
<td>AV: 5.4%</td>
<td>5.2%</td>
<td></td>
</tr>
<tr>
<td>BC 5.9%</td>
<td>AV: 5.7%</td>
<td>6.0%</td>
<td></td>
</tr>
</tbody>
</table>

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

**STOA vs LTOA ✓**

**Binder Content ✓**
G.O. #3

All Producers
General Observations (G.O.)

1. Higher AC Content $\rightarrow$ higher F.I.
2. Higher RAP content lower F.I.
3. Longer aging $\rightarrow$ lower F.I.
4. Plant mix has higher F.I. than lab mix
5. Higher voids $\rightarrow$ higher F.I.
6. SMA mix delivers high F.I.
7. Finer mix with high BC $\rightarrow$ higher F.I.
Producer F

G.O. #4

STOA: Short Term Oven Aging
LTOA: Long Term Oven Aging

JMF = 5.9%
Post Min $P_{be}$

JMF = 5.2%
Pre Min $P_{be}$
Producer F (Continued)

G.O. #4

Lab Mix

Binder Content, %

Flexibility Index

STOA: Short Term Oven Aging
LTOA: Long Term Oven Aging

Plant:Lab
1:0.5
G.O. #4

Producer E

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

![Diagram showing Flexibility Index vs. RAP Content, % with data points from Plant and Lab and a comparison question: Lab ✓ Plant?](image-url)
General Observations (G.O.)

1. Higher AC Content $\rightarrow$ higher F.I.
2. Higher RAP content lower F.I.
3. Longer aging $\rightarrow$ lower F.I.
4. Plant mix has higher F.I. than lab mix
5. Higher voids $\rightarrow$ higher F.I.
6. SMA mix delivers high F.I.
7. Finer mix with high BC $\rightarrow$ higher F.I.
G.O. #5

All Producers

Specimen Air Void, %

Peak Load, Newtons

1 2 3 4 5 6 7 8 9

0 1,000 2,000 3,000 4,000 5,000 6,000 7,000
General Observations (G.O.)

1. Higher AC Content $\rightarrow$ higher F.I.
2. Higher RAP content lower F.I.
3. Longer aging $\rightarrow$ lower F.I.
4. Plant mix has higher F.I. than lab mix
5. Higher voids $\rightarrow$ higher F.I.
6. SMA mix delivers high F.I.
7. Finer mix with high BC $\rightarrow$ higher F.I.
Producer H: Lab Produced

• STOA
• 9.5mm
• PG64-22/PG76-22

What effect do we see?
• Binder Content
• RAP
• Polymer

<table>
<thead>
<tr>
<th>Flexibility Index</th>
<th>Specimen 1</th>
<th>Specimen 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV: 4.7%</td>
<td>BC: 6.9%</td>
<td>BC: 6.9%</td>
</tr>
<tr>
<td>AV: 4.5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG64-22 + 15%RAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BC: 5.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AV: 4.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG76-22 + 0%RAP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BC: 6.9% Specimen 1
BC: 6.9% Specimen 2

5.9/6.4/6.9%BC
0/15%RAP
General Observations (G.O.)

1. Higher AC Content → higher F.I.
2. Higher RAP content lower F.I.
3. Longer aging → lower F.I.
4. Plant mix has higher F.I. than lab mix
5. Higher voids → higher F.I.
6. SMA mix delivers high F.I.
7. Finer mix with high BC → higher F.I.
G.O. #7

Producer H: Lab Produced

- STOA
- 4.75mm
- PG64-22
- 6.8%BC
- 0/15%RAP

Flexibility Index

<table>
<thead>
<tr>
<th>Specimen</th>
<th>0%RAP</th>
<th>15%RAP (6.1% Virgin Binder)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen 1</td>
<td>AV: 5.0%</td>
<td></td>
</tr>
<tr>
<td>Specimen 2</td>
<td>AV: 5.0%</td>
<td>AV: 4.7%</td>
</tr>
</tbody>
</table>
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Where could we go next?

1. Gather information from producers on details of aging protocol and specimen preparation
2. More SCB testing to fill in some of the gaps.
3. Test mix(es) with proven good long term performance.
4. Test to determine long term effects of rejuvenators.
5. Track mix performance in the field to verify lab predictions.
Questions??  Thank you!!

To contact ........................................

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Safe, Smooth, Sustainable, Long Lasting Pavements!