Industry/PennDOT Initiative
On Performance Testing

AN UPDATE
January 22, 2019
Outline

• Testing Modes
• A Review of Semi-Circular Bend (SCB) Test
• PA Industry Initiative on SCB
• Results & Observations
• Next Steps
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• Testing Modes
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LABORATORY PERFORMANCE TESTS
Modes of Testing
Loading Modes

- Uniaxial Compression
- Uniaxial Direct Tension
- Indirect Tension
- Triaxial Compression
- Shear
- Flexure
Laboratory Tests on Asphalt Concrete

- Uniaxial Tension
- Uniaxial Compression
- Cyclic Uniaxial Tension/Compression
Laboratory Tests on Asphalt Concrete

Flexural Beam Test

3-Point Bending Test

4-Point Bending Test
Laboratory Tests on Asphalt Concrete

Triaxial Test

Indirect Tensile Test
Laboratory Tests on Asphalt Concrete

European Standard Test
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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**

- **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
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
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
- 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
Lower strain Rate $\rightarrow$ lower peak & flatter post peak slope $\rightarrow$ 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>
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<td>15</td>
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<td>64-22</td>
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<td>64-22</td>
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<td>Short</td>
<td>4.75, 9.5, 25</td>
<td>64-22 76-22</td>
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<td>9.5</td>
<td>64-22</td>
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<tr>
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<td>64-22 76-22</td>
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<td>10</td>
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<td>9.5</td>
<td>64-22 76-22</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
- 9.5
- 19
- 25

75

RAP Content, %
- 0
- 10
- 15
- 20
- 25
- 30

0
19
52
2
2
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
Air Void Distribution

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

**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 → 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.
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. #1

Producer F: Plant Mix

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

JMF = 5.9%
Post Min P_{be}
JMF = 5.2%
Pre Min P_{be}
G.O. #1

Producer F: Lab Mix

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

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

Producer H-1

![Graph showing the relationship between Binder Content (%) and Flexibility Index. The graph includes data points for NMAS=9.5, NMAS=4.75, NMAS=25, 15%RAP, and 30%RAP, Plant. The binder content ranges from 4.0 to 7.0%, and the flexibility index ranges from 0 to 30%.](image)
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. #2

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

**G.O. #2**

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

- **PG64-22**:  
- **PG76-22**:  

**Overlap with PG64-22**

- **1:0.15-0.25**: STOA:LTOA  
- **1:0.33-0.67**: 15%:20%RAP

Graph showing flexibility index versus RAP content for different aging conditions and PG grades.
G.O. #2

Producer H-3

All Specimens were STOA

Flexibility Index vs. RAP Content, %

- NMAS=9.5
- NMAS=4.75
- NMAS=25
G.O. #2

All Producers
G.O. #2

All Producers

Stiffness Index, Newtons/mm

Flexibility Index

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

All Producers

Stiffness Index, Newtons/mm

Post Peak Slope

-18
-16
-14
-12
-10
-8
-6
-4
-2
0

STOA-With RAP

STOA-No RAP
G.O. #2

All Producers

Stiffness Index, Newtons/mm

Post Peak Slope

-45
-40
-35
-30
-25
-20
-15
-10
-5
0
500
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000

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

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

All Producers

Flexibility Index vs. Stiffness Index, Newtons/mm

- STOA
- LTOA
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. #4

Producer F

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

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

JMF = 5.2%
Pre Min $P_{be}$
G.O. #4

Producer F (Continued)

Lab Mix

Flexibility Index

Binder Content, %

Lab: 1:0.5

STOA: Short Term Oven Aging
LTOA: Long Term Oven Aging
G.O. #4

Producer E

- LTOA
- 9.5mm
- PG64-22

5.5%BC
0/15/25%RA P

Flexibility Index vs. RAP Content, %

Lab ✓ Plant?
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. #5

All Producers

Specimen Air Void, %

Flexibility Index

target
G.O. #5
All Producers
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.
Producer H: Lab Produced

- STOA
- 9.5mm
- PG64-22/PG76-22

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

Flexibility Index

<table>
<thead>
<tr>
<th>Flexibility Index</th>
<th>PG64-22 + 15%RAP</th>
<th>PG76-22 + 0%RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>AV: 4.7%</td>
<td>AV: 5.3%</td>
</tr>
<tr>
<td>10</td>
<td>BC: 5.9%</td>
<td>BC: 6.9% Specimen 1</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>BC: 6.4% Specimen 2</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Binder Content:
- 5.9/6.4/6.9%BC
- 0/15%RAP

5.9/6.4/6.9% BC

Producer H: Lab Produced
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. #7

Producer H: Lab Produced

- STOA
- 4.75mm
- PG64-22

- 6.8%BC
- 0/15%RAP

Flexibility Index

0%RAP
Specimen 1
AV: 5.0%

0%RAP
Specimen 2
AV: 5.0%

15%RAP
(6.1% Virgin Binder)
AV: 4.7%
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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.
To contact ........................................

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Committed To:
Safe, Smooth, Sustainable, Long Lasting Pavements!