SMA – High Performance for a Demanding Public

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Hershey, PA
Stone Matrix Asphalt (SMA)

- Gap graded aggregate blends with cubical shaped aggregate
- Mastic of polymer-modified asphalt binder, mineral filler and fibers
- When produced and placed correctly, known for outstanding performance
“SMA is a simple idea. Find a hard, durable, quality stone, fracture it into roughly cubical shape and of a size consistent with the proposed layer thickness, and then glue the stones together with a durable, moisture-resistant mortar of just the right quantity to give stone-to-stone contact among the coarse aggregate particles. For the asphalt technologist, the trick is getting the various parameters right.”
A Quick “More Recent” SMA History in NJ
A “More Recent” History of SMA in NJ

- Prior to 2005, SMA use was limited in NJ
  - Rt 78 E, MP 28.58 to 30.8 – 9.5 mm NMAS SMA
  - Rt 1 N & S, MP 11.3 to 11.8 – 12.5 mm NMAS SMA
- In 2005, NJDOT advertised project for I295 (9.5 mm SMA)
  - To help industry, Rutgers organized an SMA & OGFC Workshop
  - Larry Michaels (MDSHA)
  - Randy West and Don Watson (NCAT)
  - Jeff Graf (Maryland Paving)
A “More Recent” History of SMA in NJ

- Next SMA project did not come until 2007
- Rt 30 E & W, MP 13.2 to 13.9
  - 12.5 mm NMAS
  - Composite pavement overlay
  - 8 years before overlay
- Rt 278 E & W, MP 0.0 to 0.9
  - 9.5 mm NMAS
  - Flexible pavement
  - PMS showed good performance for 9 years
- 2 projects in 2007 and 2008
- After 2008, 8+ SMA projects per year
NJDOT SMA Specifications
NJDOT SMA Specifications

- NJDOT SMA specifications generally follow AASHTO M325 recommendations
  - 4% air voids @ Ndesign = 75 gyrations
  - Polymer modified PG64E-22 (PG76-22)
  - 0.3 to 0.4% cellulose fibers; 0.4 to 0.6% mineral fibers

<table>
<thead>
<tr>
<th>Property</th>
<th>Production Control Tolerances</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids</td>
<td>±1%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Voids in Mineral Aggregate (VMA)</td>
<td>–</td>
<td>17.0% minimum</td>
</tr>
<tr>
<td>VCAmix</td>
<td>–</td>
<td>Less than VCAdry</td>
</tr>
<tr>
<td>Draindown @ production temperature</td>
<td>–</td>
<td>0.30% maximum</td>
</tr>
<tr>
<td>Asphalt Binder Content (AASHTO T 308)¹</td>
<td>±0.40%</td>
<td>6% minimum</td>
</tr>
<tr>
<td>Tensile Strength Ratio (AASHTO T 283)</td>
<td>–</td>
<td>80% minimum</td>
</tr>
</tbody>
</table>

¹. Asphalt binder content may not be lower than the minimum after the production tolerance is applied.
NJDOT SMA Specifications

- NJDOT SMA specifications generally follow AASHTO M325 recommendations

<table>
<thead>
<tr>
<th>Production Control Tolerances from JMF</th>
<th>Sieve Size</th>
<th>19 mm % Passing</th>
<th>12.5 mm % Passing</th>
<th>9.5 mm % Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>1&quot;</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>±2%</td>
<td>3/4&quot;</td>
<td>90-100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>±5%</td>
<td>1/2&quot;</td>
<td>50-88</td>
<td>90-100</td>
<td>100</td>
</tr>
<tr>
<td>±5%</td>
<td>3/8&quot;</td>
<td>25-60</td>
<td>50-80</td>
<td>70-95</td>
</tr>
<tr>
<td>±3%</td>
<td>No. 4</td>
<td>20-28</td>
<td>20-35</td>
<td>30-50</td>
</tr>
<tr>
<td>±2%</td>
<td>No. 8</td>
<td>16-24</td>
<td>16-24</td>
<td>20-30</td>
</tr>
<tr>
<td>±4%</td>
<td>No. 16</td>
<td>–</td>
<td>–</td>
<td>0-21</td>
</tr>
<tr>
<td>±3%</td>
<td>No. 30</td>
<td>–</td>
<td>–</td>
<td>0-18</td>
</tr>
<tr>
<td>±3%</td>
<td>No. 50</td>
<td>–</td>
<td>–</td>
<td>0-15</td>
</tr>
<tr>
<td>±2%</td>
<td>No. 200</td>
<td>8.0-11.0</td>
<td>8.0-11.0</td>
<td>8.0-12.0</td>
</tr>
</tbody>
</table>

Coarse Aggregate Fraction
- Portion Retained on No. 4 Sieve

Minimum Lift Thickness
- 2 inches

Portion retained on No. 4 Sieve
- 1 1/2 inch

Portion retained on No. 8 Sieve
- 1 inch
SMA Laboratory Performance
SMA Laboratory Performance – Stiffness and Permanent Deformation

- Dynamic modulus and some permanent deformation tests may show some SMA mixes to be “softer” than HMA
  - SMA higher effective asphalt content than HMA
    - Thicker film thickness
  - No RAP allowed (for NJ)
  - E* (small strain stiffness) strongly a function of binder stiffness & effective binder volume
- Aggregate skeleton (stone-on-stone) difficult to mobilize without properly applied confinement
Mixture Stiffness – Dynamic Modulus

- Asphalt mixture stiffness properties determined using Asphalt Mixture Performance Tester (AMPT)
- Test method determines the material stiffness properties at different test temperatures and loading frequencies
- Results provide a “master stiffness curve” used in pavement design procedures
Dynamic Modulus Comparisons (NJ Mixtures)
AMPT Flow Number strongly related to binder stiffness properties and asphalt content

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Flow Number (cycles)</th>
<th>AC Content (%)</th>
<th>High Temp PG</th>
<th>Jnr</th>
<th>% Rec</th>
</tr>
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<tbody>
<tr>
<td>12.5M76 #1</td>
<td>1022</td>
<td>5.32</td>
<td>88.7</td>
<td>0.056</td>
<td>69.7</td>
</tr>
<tr>
<td>12.5M76 #2</td>
<td>4263</td>
<td>5.19</td>
<td>92.6</td>
<td>0.03</td>
<td>76.5</td>
</tr>
<tr>
<td>SMA #1</td>
<td>613</td>
<td>5.98</td>
<td>81.8</td>
<td>0.15</td>
<td>69.1</td>
</tr>
<tr>
<td>SMA #2</td>
<td>522</td>
<td>6.14</td>
<td>81.2</td>
<td>0.23</td>
<td>55.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic Level</th>
<th>Minimum Flow Number Cycles</th>
<th>General Rut Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Million ESALs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 3</td>
<td>---</td>
<td>Poor to Fair</td>
</tr>
<tr>
<td>3 to &lt; 10</td>
<td>200</td>
<td>Good</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td>320</td>
<td>Very Good</td>
</tr>
<tr>
<td>≥ 30</td>
<td>580</td>
<td>Excellent</td>
</tr>
</tbody>
</table>
SMA High Temperature Lab Performance (PA Mixes)

- Loaded wheel test procedures (APA and Hamburg) will also show similar trends to $E^*$ and Flow Number
  - Example:
    - Same aggregate source
    - Same asphalt binder source
Although SMA mixtures achieve excellent permanent deformation performance in the field, they may not show as well as some HMA in the lab:

- SMA aggregate skeleton difficult to mobilize without applying proper confining pressure
- SMA stiffness will appear “softer”
  - Higher effective asphalt content (higher film thickness)
  - Typically no RAP in SMA
  - PAVEMENT-ME?
SMA Laboratory Performance – Cracking Performance

- In contrast to the permanent deformation, due to higher effective AC, SMA mixtures typically outperform dense graded HMA in laboratory fatigue tests
- Examples from
  - Overlay Tester
  - Flexural Beam Fatigue
  - SCB Flexibility Index
- Sample size: 6” long by 3” wide by 1.5” high
- Loading: Continuously triangular displacement 5 sec loading and 5 sec unloading
- Definition of failure
  - Discontinuity in Load vs Displacement curve
Semi-circular Bend (SCB) Test

- Uses 3-point bending on a semi-circular asphalt sample
- Can use same equipment at AASHTO T283 (50 mm/min)
- Notch cut to initiate cracking
- Test evaluates the energy required to fracture the specimen and propagate a crack at the notch
  - Work of Fracture
- Additional analysis was used to calculate the Flexibility Index (FI)
  - Post peak response
Fatigue Cracking – SCB FI and Overlay Tester Averages (n > 10)

OVERLAY TESTER

SCB FLEXIBILITY INDEX

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Average Overlay Tester (cycles)</th>
<th>Average SCB Flexibility Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>92</td>
<td>4.4</td>
</tr>
<tr>
<td>SMA</td>
<td>729</td>
<td>16.2</td>
</tr>
</tbody>
</table>

Error bars represent standard deviation for all mixes tested – not test variability.
- Conducted at different test temperatures and displacements

![Overlay Tester Fatigue Life vs Temperature and GAP](image)
Flexural Beam Fatigue (MDSHA Mixes)

\[ N_{f,50\%} = k_1 \left( \frac{1}{\varepsilon_t} \right)^{k_2} \left( \frac{1}{E_0} \right)^{k_3} \]
In general, SMA obtains excellent laboratory performance

- May show to be “softer” than HMA at high temperatures due to higher effective asphalt contents and no RAP
  - Lower high temperature stiffness/more permanent deformation in AMPT and loaded wheel testers
  - Difficult to mobilize stone-on-stone rutting resistance without applied confining pressure

- SMA far superior in fatigue cracking resistance than HMA
  - Fatigue cracking resistance directly related to effective asphalt content
  - For NJ, RAP is not allowed in SMA
SMA Pavement Performance
Early SMA in United States - Maryland

  - Michael, Burke, and Schwartz
- 10 years of pavement performance starting in 1993
  - 86 different projects
  - > 1300 lane miles
  - > 80% interstates
  - 9.5, 12.5, and 19 mm NMAS
**Early SMA in United States - Maryland**

- **Excellent performance**
  - Rutting: 0.04 inches/yr (average)
  - Roughness (IRI): 3.2 in/mile per year (average)
Rutgers worked with MDSHA to evaluate performance of different HMA mixes for composite pavements

- Asphalt mixture performance shown earlier
- Utilized PMS to assess impact of surface course mix type on reflective cracking
  - Two separate roadways where both SMA (Gap Graded) and dense graded HMA placed
Cracking rate of SMA (Gap-Graded) was 5 to 8 times lower than HMA!
SMA Field Performance - NJ

- NJDOT PMS was mined to extract the SMA performance since 2007.
  - Surface Distress Index (SDI) used to monitor “life” of the pavement
  - SDI < 2.4 trigger for pavement rehabilitation
- Approximately 100 SMA pavement sections were evaluated
  - Minimum of 3 years of performance
  - 9.5 mm and 12.5 mm NMAS
  - Flexible and composite pavement overlays
  - Performance compared to mill 2”/pave 2” HMA
SMA Field Performance – NJ Flexible Pavements

9.5mm SMA - Asphalt Pavement

12.5mm SMA - HMA Pavement
SMA Field Performance – NJ Composite Pavements

9.5mm SMA - PCC Pavement

12.5mm SMA - PCC Pavement
Flexible Pavements
- Pavement distress curves indicate SMA should outperform HMA by 10+ years for flexible pavements

Composite Pavements
- Pavement distress curves indicate SMA should outperform HMA by 7+ years for composite pavements
- NJDOT also includes a Bituminous Rich Intermediate Course (BRIC) to provide even greater life expectancy
SMA vs Dense Graded – NCAT Study

- 13 state agencies provided PMS data
- Predicted service life using each individual state agency’s procedures
- SMA had average of 31.4% (3.9 years) increase in predicted service life over dense graded HMA
NCHRP 1-47 indicated distress predictions highly sensitive to $E^*$ (except thermal cracking)

The PAVEMENT-ME dependency on $E^*$ may make SMA look “soft”

- Higher permanent strains for rutting
- Potentially higher deflections = higher tensile strains

Before use, should look at calibrating models for HMA and SMA separately

NCAT Report 18-03 attempted to use lab tests
Thank you for your time!
Questions?

BE CAREFUL WHEN YOU ONLY READ CONCLUSIONS...

Reference: The Anscombe's quartet, 1973

Designed by @YLMSportScience

THESSE FOUR DATASETS HAVE IDENTICAL MEANS, VARIANCES & CORRELATION COEFFICIENTS

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