Performance Summary of NJ’s SMA

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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 I-295 (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>VCAmax</td>
<td>–</td>
<td>Less than VCA_{dry}</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>

<table>
<thead>
<tr>
<th>Coarse Aggregate Fraction Portion Retained on No. 4 Sieve</th>
<th>Portion Retained on No. 4 Sieve</th>
<th>Portion retained on No. 8 Sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Lift Thickness 2 inches</td>
<td>1 1/2 inch</td>
<td>1 inch</td>
</tr>
</tbody>
</table>
SMA Laboratory Performance
SMA Laboratory Performance – Stiffness and Permanent Deformation

- Dynamic modulus and some permanent deformation tests will show SMA “softer” than HMA
  - SMA higher effective asphalt content than HMA
    - Thicker film thickness
  - No RAP allowed
  - $E^*$ (small strain stiffness) strongly a function of binder stiffness
- Aggregate skeleton (stone-on-stone) difficult to mobilize without properly applied confinement
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

![Diagram showing dynamic modulus comparison across different loading frequencies for SMA #1, SMA #2, 12.5M76 #1, and 12.5M76 #2]
SMA High Temperature Lab Performance

- 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>
</thead>
<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>
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<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 Million ESALs</th>
<th>Minimum Flow Number Cycles</th>
<th>General Rut Resistance</th>
</tr>
</thead>
<tbody>
<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>
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, may not show as well as some HMA

- SMA aggregate skeleton difficult to mobilize without applying proper confining pressure
- SMA stiffness will appear “softer”
  - Higher effective asphalt content (higher film thickness)
  - No RAP in SMA
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
“High Performing” asphalt mixtures in NJ generally have Overlay Tester > 600 cycles
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
“High Performing” asphalt mixtures in NJ generally have SCB Flexibility Index > 15 cycles
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
SMA Field Performance
SMA Field Performance

- NJDOT PMS was mined to extract the SMA performance since 2007.
  - Surface Distress Index (SDI) used to monitor “life” of the pavement
  - SDA < 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 – Flexible Pavement

9.5mm SMA - Asphalt Pavement

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

9.5mm SMA - PCC Pavement

12.5mm SMA - PCC Pavement
SMA Field Performance Summary

- 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
Fiberless SMA
To help reduce the potential of draindown, polymer-modified asphalt (PMA) and fibers used with SMA and OGFC

- PMA results in better adhesion to aggregate at higher temps than Neat binders (generally higher viscosity)
- Fibers increase stiffness of mastic by increasing surface area
Issues with Fibers

- Cost – fibers and rental equipment
- Fibers need to be separated or “fluffed” prior to addition or clumping can occur
- Metering required and should have “sight glass” to ensure fibers flowing
- Fibers must be included in ignition oven correction factor determination
  - Impossible to separate AC and Fiber changes during production from ignition oven testing
Fiberless SMA Concept

- The inclusion of fibers used to increase the viscosity of the mastic (binder, fines, fibers)
  - Increased mastic viscosity will stick to aggregate better and resist draindown
- Utilizing an asphalt binder with higher viscosity can help increase mastic viscosity
  - As temperature decreases, binder viscosity increases
- Reduction in mixture temp will create compaction issues
  - Must couple mixture temp reduction with WMA additive
  - WMA technology that does not influence binder viscosity
Fiberless SMA “Mixture Design”

- **General methodology**
  - Utilize existing SMA design as your starting point (i.e. – asphalt content, aggregate blend)
  - Determine Draindown (AASHTO T305) and compacted air voids after reducing mixture temperature
    - Example: 325, 300, 280, 255°F
    - Compare draindown and compacted air voids
  - Examine mixing process to ensure coating is taking place
  - Make slight mixture adjustments if necessary
Design Example

- Determine Optimal Temperature for WMA-SMA
  - 12.5 mm NMAS SMA
  - 6.5% Asphalt Content
    - PG76-22
  - 0.2% Cellulose Fibers
  - 0.04% Draindown at Design

<table>
<thead>
<tr>
<th>Screen</th>
<th>% Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>2&quot;</td>
<td>50.00</td>
</tr>
<tr>
<td>1 ½&quot;</td>
<td>37.50</td>
</tr>
<tr>
<td>1&quot;</td>
<td>25.00</td>
</tr>
<tr>
<td>¾&quot;</td>
<td>19.00</td>
</tr>
<tr>
<td>½&quot;</td>
<td>12.50</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>9.50</td>
</tr>
<tr>
<td>#4</td>
<td>4.75</td>
</tr>
<tr>
<td>#8</td>
<td>2.36</td>
</tr>
<tr>
<td>#16</td>
<td>1.18</td>
</tr>
<tr>
<td>#30</td>
<td>0.600</td>
</tr>
<tr>
<td>#50</td>
<td>0.300</td>
</tr>
<tr>
<td>#100</td>
<td>0.150</td>
</tr>
<tr>
<td>#200</td>
<td>0.075</td>
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</table>
Compacted Air Voids vs Draindown
Final Result
- Optimal temp range for mixture between 265 and 255°F.
- In that range:
  - Air voids slightly above 4%
  - Draindown around 0.2 to 0.25% (specification is 0.3%)
  - Dust to Effective Binder below allowable

Final Recommendation
- Maintain asphalt content and increase dust content
  - Increase dust will help close up air voids and reduce draindown
- Received phone call from contractor saying project went great and they are planning to bid all future SMA projects the same way
Project #1 – New Jersey

- First project to look at fiberless SMA with WMA
- Location: Rt 1 in New Jersey
- 12.5mm SMA
  - 6.4% AC content
  - PG76-22
  - 0.3% cellulose fibers

<table>
<thead>
<tr>
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</tr>
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<tbody>
<tr>
<td>2”</td>
<td>50.00</td>
</tr>
<tr>
<td>1 ½”</td>
<td>37.50</td>
</tr>
<tr>
<td>1”</td>
<td>25.00</td>
</tr>
<tr>
<td>¾”</td>
<td>19.00</td>
</tr>
<tr>
<td>½”</td>
<td>12.50</td>
</tr>
<tr>
<td>3/8”</td>
<td>9.50</td>
</tr>
<tr>
<td>#4</td>
<td>4.75</td>
</tr>
<tr>
<td>#8</td>
<td>2.36</td>
</tr>
<tr>
<td>#200</td>
<td>0.075</td>
</tr>
</tbody>
</table>

1st Project – Supplier did own assessment of compacted air voids
# Project #1 – New Jersey

<table>
<thead>
<tr>
<th>Mixture ID</th>
<th>Temperature (F)</th>
<th>Percent Draindown</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mixing</td>
<td>Testing</td>
</tr>
<tr>
<td>Normal SMA</td>
<td>325</td>
<td>325</td>
</tr>
<tr>
<td>WMA SMA #1 (No Fibers)</td>
<td>325</td>
<td>325</td>
</tr>
<tr>
<td>WMA SMA #2 (No Fibers)</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>WMA SMA #3 (No Fibers)</td>
<td>255</td>
<td>255</td>
</tr>
</tbody>
</table>
Field Core Density
- Normal SMA Density = 5.13% air voids
  - Produced over 315°F
- WMA SMA Density = 5.12% air voids
  - Produced under 280°F
Dynamic Modulus – Mixture Stiffness

![Graph showing dynamic modulus vs. loading frequency for SMA Normal Production and SMA WMA with No Fibers.]
Hamburg Stripping Potential

Loading Cycles (n)

Vertical Deformation (mm)

○ SMA - Normal Production
△ SMA - WMA & No Fibers

Cycles to 12.5mm Rutting = > 20,000 cycles
## Overlay Tester – Cracking Potential

### SMA - WMA with No Fibers

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Temp (F)</th>
<th>Displacement (inches)</th>
<th>Fatigue Life (cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1</td>
<td>77 F</td>
<td></td>
<td>10,472</td>
</tr>
<tr>
<td># 2</td>
<td>77 F</td>
<td>0.025&quot;</td>
<td>27,855</td>
</tr>
<tr>
<td># 3</td>
<td>77 F</td>
<td></td>
<td>16,255</td>
</tr>
</tbody>
</table>

Average (Trimmed Mean) = 18,194

### SMA - Normal Production

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Temp (F)</th>
<th>Displacement (inches)</th>
<th>Fatigue Life (cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1</td>
<td>77 F</td>
<td></td>
<td>2,126</td>
</tr>
<tr>
<td># 2</td>
<td>77 F</td>
<td>0.025&quot;</td>
<td>2,425</td>
</tr>
<tr>
<td># 3</td>
<td>77 F</td>
<td></td>
<td>1,458</td>
</tr>
</tbody>
</table>

Average (Trimmed Mean) = 2,003
Project #1 – New Jersey
Project #1 – New Jersey
For initial pilot, reduction in production temp successfully reduced draindown when fibers eliminated
- Produced @ 275 to 285°F
- Laydown @ 270 to 280°F
Field densities of with and without fibers statistically equal
Mixture performance looked good
- Lower production temps not aging binder as normal
  - Stiffness slightly lower
  - Large increase in fatigue resistance (higher effective AC?)

One Complaint!
Thank you for your time! Questions?

BE CAREFUL WHEN YOU ONLY READ CONCLUSIONS...

Reference: The Anscombe's quartet, 1973

Designed by @YLMSportScience

These four datasets have identical means, variances & correlation coefficients.