Performance and Life-Cycle Cost Benefits of Stone Matrix Asphalt

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Acknowledgements

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Presentation Outline

• Background
• Research Objective
• Market Analysis
• Performance Analysis
• Life-cycle Cost Analysis (LCCA) Case Studies
• Conclusions
Background

• SMA: durable and rut-resistant gap-graded asphalt mix
  o Stone-on-stone contact to offer strength
  o Rich mortar binder to provide durability
• First introduced into the United States in early 1990s
• Commonly used as a premium asphalt mix to enhance field performance and extend life span of asphalt pavements and overlays
• Generally more expensive than dense-graded mixes containing polymer-modified asphalt binders
• Higher cost offset by the increase in life expectancy
Laboratory Evaluation of SMA mixes

• Comparing the test results of SMA versus a control dense-graded mix, not necessarily using polymer modified asphalt binder
• Better rutting resistance due to stone-on-stone aggregate structure
• Better resistance to moisture damage due to thicker asphalt film between aggregate particles
• No consistent trends on stiffness and cracking resistance comparisons
• Reduced susceptibility to oxidative aging
Field Evaluation of SMA Pavements

• NCHRP Project D9-8, Performance of SMA Mixes in the United States
  o 85 SMA pavement sections
  o 2 to 6 years old
  o Outstanding rutting and cracking performance
• Similar performance benefits reported by other studies
• Functional benefits
  o Improved visibility
  o Reduced splash and spray
  o Increased friction resistance
  o Noise reduction
Research Objective

• Quantify and compare the performance and life-cycle cost benefits of SMA versus polymer-modified Superpave dense-graded mixes used on similar trafficked highways
Market Analysis

- Survey of state asphalt pavement associations (SAPAs) identified at least 18 states that use SMA on a routine basis
Market Analysis

• Follow-up survey of SHAs
• Survey questions
  • Mix selection policy
  • Mix design specification
  • Bid item numbers
  • Cost and tonnage from 2011 to 2015
  • Field performance data
Mix Selection Policy

- 6 Written Document
- 10 Engineer Decision

Mix Design Method

- 2 AASHTO R 46
- 9 State Methods
- 5 AASHTO R 35

2011-2015 Tonnage

- 68,000 Tons: Highest tonnage
  1. Maryland
  2. Alabama
  3. Utah

- 1,872,000 Tons
**Weighted Bid Price (2011-2015)**

- SMA consistently more expensive than dense-graded mixes
- Difference in weighted bid price varied from $6 to $31 per ton
- SMA higher bid price possibly due to
  - Higher asphalt contents
  - Requirement for more cubical and durable aggregates
  - Inclusion of fibers as stabilizers
  - No/reduced use of RAP and RAS
  - Reduced plant versatility
Performance Analysis

• To compare the long-term field performance of SMA versus comparable Superpave dense-graded mixes
  o Equivalent roadway category
  o Equivalent pavement type

• Pavement management system (PMS) data of 407 SMA and 807 Superpave pavement sections
  o 2 states evaluate individual pavement distresses (rutting, cracking, etc.)
  o 7 states use composite condition indexes (distress index, surface rating, etc.)
Performance Analysis

- Network-level analysis approach
- S-shaped logistic performance prediction model used in most cases
Example: Michigan DOT Data

• Conduct distress survey by videotaping pavement surface
• Assign distress points based on distress type, extent, and severity
• Calculate distress index (DI) by combining all distress points
  o A “snapshot” of pavement distress condition
  o DI = 0: distress-free condition
  o DI = 50: remaining service life of zero
  o DI develops following a logistic growth model
Example: Michigan DOT Data

**SMA:** 22 years

- **Measured DI**
- **Fitted DI**

Maximum Threshold: 50

- 23 projects
- 87 data points

**Superpave:** 21 years

- **Measured DI**
- **Fitted DI**

Maximum Threshold: 50

- 90 projects
- 325 data points

Pavement Age (years)

Distress Index
Example: Virginia DOT Data

• Conduct distress survey using an Automated Road Analyzer (ARAN)
• Determine load related distress rating (LDR) and non-load related distress rating (NDR) based on distress type, extent, and severity
• Calculate critical conditioning index (CCI) as Min. (LDR, NDR)
  o A “snapshot” of overall pavement condition
  o CCI = 100: distress-free condition
  o CCI = 0: completely failed condition
  o CCI = 60: remaining service life of zero
  o CCI develops following a s-shaped logistic performance model
Example: Virginia DOT Data

SMA: 19 years

- Measured CCI
- Fitted CCI

44 projects
291 data points

Minimum Threshold: 60
19.0 years

Superpave: 14 years

- Measured CCI
- Fitted CCI

56 projects
245 data points

Minimum Threshold: 60
14.4 years
### Summary – Flexible Pavements

<table>
<thead>
<tr>
<th>Highway Agency</th>
<th>Performance Measure</th>
<th>Predicted Service Life (Years)</th>
<th>SMA Life Extension (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>SMA</td>
<td>Superpave</td>
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<tr>
<td>Alabama DOT</td>
<td>Pavement Condition Rating</td>
<td>16.2</td>
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<td>Rutting</td>
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<tr>
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<td>Maryland SHA (Principal Arterial)</td>
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<tr>
<td>Minnesota DOT</td>
<td>Ride Quality Index</td>
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<td>11.3*</td>
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<tr>
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<td>Surface Rating</td>
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<td>Virginia DOT</td>
<td>Critical Condition Index</td>
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<td>14.4</td>
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</table>

*Note: * PMS data from a limited number of pavement sections
# Summary – Composite Pavements

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<thead>
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<th>Highway Agency</th>
<th>Performance Measure</th>
<th>Predicted Service Life (Years)</th>
<th>SMA</th>
<th>Superpave</th>
<th>SMA Extension Life (Years)</th>
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<td>12.8</td>
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Note: * PMS data from a limited number of pavement sections
LCCA Case Studies

• To determine if the higher cost of SMA can be justified by the improved performance and extended service life

• Net present value (NPV)/equal uniform annual cost (EUAC) approach
  o Cost information from Market Analysis
  o Performance information from Performance Analysis
  o Assumption of 2-inch thick asphalt overlay
  o Analysis period selected using SMA’s service life
  o Discount rate selected using agency’s current practice
  o Routine maintenance costs and user costs not considered
NPV/EUAC Approach

- Present value of the first overlay cost ($PV_0$)
- Future value of the replacement overlay cost ($FV$)
- Salvage value at the end of the analysis period ($SV$)
- Discount rate ($r$)

\[
NPV = PV_0 + \sum FV_i \left[ \frac{1}{(1+r)^{n_i}} \right] + SV \left[ \frac{1}{(1+r)^{n_s}} \right]
\]

\[
EUAC = NPV \left[ \frac{r(1+r)^{n_s}}{(1+r)^{n_s} - 1} \right]
\]
Virginia DOT – Deterministic Approach

• SMA: $114/ton, 23 years service life
• Superpave: $89/ton, 13 years service life

Alternative 1: SMA

\[
P_{0} = 78,990 \quad \text{Year 0} \quad \text{Year 23} \quad SV = 0
\]

\[
P_{SV} = 0 \quad r = 4.0\%
\]

\[
\text{NPV} = 78,990 + 0 = 78,990
\]

Alternative 2: Superpave Mixture

\[
P_{0} = 62,134 \quad FV = 62,134 \quad SV = (14,339) \quad \text{Year 0} \quad \text{Year 13} \quad \text{Year 23}
\]

\[
P_{SV} = 37,316 \quad r = 4.0\%
\]

\[
P_{SV} = 5,818 \quad \text{Year 0} \quad \text{Year 13} \quad \text{Year 23}
\]

\[
\text{NPV} = 62,134 + 37,316 - 5,818 = 93,632
\]
Virginia DOT – Probabilistic Approach

- $PV_0$, $FV$, and $r$ following normal distributions
- NPV probability distribution curves generated based on 1,000 Monte Carlo simulations

Less than 1% probability that SMA is not as cost-effective as the comparable Superpave mix
No consistent conclusions for comparing the life-cycle cost benefits of SMA versus comparable Superpave mix.
Conclusions

• Currently 18 SHAs use SMA on a routine basis
• SMA was $6 to $31/ton more expensive than Superpave mixes with polymer modified asphalt binders
• SMA generally had equivalent or better performance than Superpave mixes on similar trafficked highways; in cases where SMA had better performance, the life extension varied from 1 to 13 years among the states and varied for different pavement types
• The cost effectiveness of SMA versus Superpave mixes depends on the relative level of significance from increased cost versus extended service life
Thank you!

Any questions?
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