Case Study: Long-term Performance of SMA Pavements in Washington State

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Outline

• Introduction
• Project Information
• Research Scope
• Results of SMA and HMA Comparison
  • Field Performance
  • Field Cores Mixture Properties
  • Extracted Binder Properties
• Conclusions and Future Study
Introduction

• SMA is widely used in northern and central Europe for over 25 years.

• In U.S., some studies in MD and GA showed: SMA performs well against rutting and roughness for periods exceeding 10 years.
  ✓ Stone to stone contact
  ✓ High asphalt content; Polymer modified binder

• National specifications: AASHTO R46, AASHTO M325

• State’s good experience is critical for successful implementation of SMA.

• WA’s experience (not so good at the beginning):
  ✓ 1999: SR 524 mix design construction issue
  ✓ 2000: I-90 inadequate control over mix production
Project Information

- Eastern Washington: dry-freeze
- I-90: from SR 21 to Ritzville; AADT- 38,300; paved in 2001
- SMA: 12.5-mm NMAS, PG 76-28
- HMA: 12.5-mm NMAS, PG 64-28
- Both on WB lanes, overlay thickness 63.5 mm
Research Objective

• Investigate the long-term performance of SMA pavement as compared to control HMA pavement

Field Performance

Material Property

• WSPMS
  - Pavement structural condition (PSC): cracking
  - Pavement rutting condition (PRC): rutting
  - Pavement profile condition (PCC): roughness
• Field inspection

Field cores
  - Mixtures testing
• Binder extraction
• Aggregate gradation
• Binder Recovery
  - Binder testing
# Material Characterization: Mixture

<table>
<thead>
<tr>
<th>Mixture Test</th>
<th>IDT Dynamic Modulus/Creep Compliance</th>
<th>Fatigue-IDT Fracture at Room Temp</th>
<th>Thermal Cracking-IDT Fracture at Low Temp</th>
<th>Studded Tire Wear Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Testing Conditions</strong></td>
<td>Temp.: -20, -10, 0, 10, 20, 30°C; Frequency: 20, 10, 5, 1, 0.1, 0.01 Hz Duration: 100 seconds</td>
<td>Temp.: 20°C Loading rate: 50.8 mm/min</td>
<td>Temp.: -10°C Loading rate: 2.54 mm/min</td>
<td>Temp.: room Temperature: 690 kPa Speed: 140 rpm Duration: 2 min</td>
</tr>
<tr>
<td><strong>Material Properties</strong></td>
<td>Dynamic modulus; Creep compliance</td>
<td>IDT strength; Fracture work density; Horizontal failure strain</td>
<td>IDT strength; Fracture work density</td>
<td>Mass loss</td>
</tr>
</tbody>
</table>
## Material Characterization: Asphalt Binder

<table>
<thead>
<tr>
<th>Binder Test</th>
<th>Performance Grading (PG)</th>
<th>Rutting: MSCR</th>
<th>Fatigue: Monotonic at Room Temp</th>
<th>Thermal Cracking: Monotonic at Low Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing Conditions</td>
<td>Different temp depending on the test (DSR, BBR)</td>
<td>Stress: 0.1, 3.2 kPa</td>
<td>Temp.: 20ºC</td>
<td>Temp.: 5ºC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Temp.:</td>
<td>Shear rate: 0.3 s⁻¹</td>
<td>Shear strain rate: 0.01 s⁻¹</td>
</tr>
<tr>
<td>Material Properties</td>
<td>PG; BBR stiffness; m-value</td>
<td>Jnr₀.₁, Jnr₃.₂; R₀.₁, R₃.₂</td>
<td>Maximum stress; Fracture energy; Failure strain</td>
<td>Maximum stress; Fracture energy; Failure strain</td>
</tr>
<tr>
<td>References/Standards</td>
<td>AASHTO MP1/T240/T313</td>
<td>AASHTO T350</td>
<td>Shen et al. 2017</td>
<td>Wu 2017; Shen et al. 2017</td>
</tr>
</tbody>
</table>

![Peak Stress (Strength)](image)

- **Shear Stress**
- **Fracture Energy**
- **Shear Failure Strain**
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Field Performance

SMA Performance

HMA Performance (Note: HMA was patched in 2008)

Field Inspection

<table>
<thead>
<tr>
<th>Section</th>
<th>Cracking</th>
<th>Rutting</th>
<th>Rut Depth, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>74</td>
<td>61</td>
<td>7.1</td>
</tr>
<tr>
<td>SMA</td>
<td>80</td>
<td>88</td>
<td>5.8</td>
</tr>
</tbody>
</table>
Overall, HMA E* 20% higher than SMA E*.

SMA is more flexible than HMA.
Creep Compliance

- Overall, HMA shows lower creep compliance than SMA.
- SMA gives a better ability to relax stress, and thus better thermal cracking resistance.
Studded Tire Wear Test Result

- No significant difference in mass loss
- Comparable wear resistance

<table>
<thead>
<tr>
<th></th>
<th>Average Mass Loss, g</th>
<th>Standard Deviation, g</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 HMA specimens</td>
<td>2.7</td>
<td>1.46</td>
<td>0.73 &gt; α=0.05</td>
</tr>
<tr>
<td>12 SMA specimens</td>
<td>3.3</td>
<td>0.75</td>
<td></td>
</tr>
</tbody>
</table>
### IDT Test Results

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Parameters</th>
<th>HMA</th>
<th>SMA</th>
<th>HMA – SMA, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°C</td>
<td>IDT Strength, kPa</td>
<td>2992.3</td>
<td>297.2</td>
<td>15.9</td>
</tr>
<tr>
<td></td>
<td>Fracture Work Density, kPa</td>
<td>148.9</td>
<td>24.8</td>
<td>-32.5</td>
</tr>
<tr>
<td></td>
<td>Horizontal Failure Strain</td>
<td>0.0060</td>
<td>0.0004</td>
<td>-37.5</td>
</tr>
<tr>
<td>-10°C</td>
<td>IDT Strength, kPa</td>
<td>4465.0</td>
<td>369.6</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Fracture Work Density, kPa</td>
<td>82.0</td>
<td>11.0</td>
<td>-31.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- SMA performs **better** than HMA for **bottom-up and top-down cracking resistance**, as well as **thermal cracking resistance**.
## Aggregate Gradation Test Result

### Graph
![Graph showing passing percentage against sieve size raised to 0.45 power (mm).](image)

### Table

<table>
<thead>
<tr>
<th>Material</th>
<th>In-place Measured Asphalt Content, %</th>
<th>Designed Asphalt Content, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMA</td>
<td>6.8</td>
<td>6.8</td>
</tr>
<tr>
<td>HMA</td>
<td>5.6</td>
<td>5.44</td>
</tr>
</tbody>
</table>
### Binder PG Test Results

<table>
<thead>
<tr>
<th></th>
<th>Original PG</th>
<th>Measured True PG</th>
<th>PG</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>64-28</td>
<td>73.3-24.4</td>
<td>70-22</td>
</tr>
<tr>
<td>SMA</td>
<td>76-28</td>
<td>81.8-29.3</td>
<td>76-28</td>
</tr>
</tbody>
</table>

- SMA shows better resistance to rutting.
- SMA slows down oxidation possibly due to a thicker asphalt film.

### Binder MSCR Test Results

- SMA binder shows better resistance to rutting.
**DSR Monotonic Fracture Test Result**

### 20°C

- **Shear Stress, kPa**
  - SMA: 1446
  - HMA: 1256
  - SMA – HMA, %: 15
- **Fracture Energy, kPa**
  - SMA: 10495
  - HMA: 1930
  - SMA – HMA, %: 444
- **Failure Strain**
  - SMA: 10
  - HMA: 2
  - SMA – HMA, %: 443

### 5°C

- **Shear Stress, kPa**
  - SMA: 2410
  - HMA: 4144
  - SMA – HMA, %: -42
- **Fracture Energy, kPa**
  - SMA: 5275
  - HMA: 5082
  - SMA – HMA, %: 4
- **Failure Strain**
  - SMA: 3
  - HMA: 1
  - SMA – HMA, %: 85
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Conclusions

• SMA pavement exhibited better long-term field performance than HMA control pavement.

• Field SMA field cores indicated:
  ✓ Lower $E^*$ and higher creep compliance
  ✓ Better resistance to rutting
  ✓ Comparable resistance to studded tire wear
  ✓ Better resistance to bottom-up and top-down fatigue cracking
  ✓ Better thermal cracking resistance

• Field-extracted SMA binder indicated:
  ✓ Slower oxidation rate due to a thicker film thickness
  ✓ Better rutting resistance
  ✓ Better fatigue and thermal cracking resistance
Future Study:
Balanced Mix Concept for SMA

Too Soft

Too Brittle

(Credit: Mr. David Lippert)
Balanced Mix Design Concept for SMA

Low Temperature Cracking

Fatigue/Block/Other Forms of Cracking

Permanent Deformation

-40°C -20°C 20°C 40°C

(Credit: Dr. Imad Al-Qadi)
SMA Pavement with Sustainability Considerations

- End-of-life
- Preservation, Maintenance, & Rehabilitation
- Use
- Construction
- Design
- Material Production

Environmental
Social
Economic
Future Study

• Include more case studies with varying traffic, environmental and other factors to draw relatively conclusive decisions.

• Further evaluation on the effects of aggregate gradation and binder PG on the difference performance.
Acknowledgements

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Citation

Thank You!
Any questions?

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