Thiopave Warm Mix Asphalt

Richard W. May
Shell Sulphur Solutions
Sulphur (Sulfur)

- Non-metallic element, S, atomic number 16
- Most elemental sulphur produced today is from natural gas and petroleum processing
- Primary use is in fertilizer production. Other uses include ore leaching, chemical processing
  - Primary Sulphur Producers: USA, Canada, former Soviet Union, West Asia
  - Primary Sulphur Consumers: USA, China
Sulphur-Extended Asphalt: Background

• Great deal of interest in 1970’s and early 1980’s
  – Energy crisis/ oil embargo disrupted asphalt binder (bitumen) supplies
  – Sulphur offered a practical means of extending the supply of bitumen

• Sulphur was incorporated directly into the bitumen

• Used mostly with conventional, dense-graded mixes. Other mixture types included:
  – “Sand-asphalt-sulfur” patching mixtures and bases
  – OGFC
Sulphur in Bitumen

Source: Performance Properties of Sulphur Extended Asphalt Mixtures with SEAM (Shell internal)
General Conclusions from Historic Research on SEA

• “Laboratory and theoretical studies indicate that the addition of sulphur to asphaltic pavements can produce better, more economic pavements.”
  – FHWA-RD-78-160

• “…the presence of 20 to 40 percent by weight of sulfur in the paving binder had no deleterious effect on the overall performance of SEA pavement…”
  – Field Evaluation of Sulfur-Extended Asphalt Pavements, TRR 1115
  – Corroborated in a laboratory study reported in November 1990 (FHWA-RD-90-110)

• Greatest concern with performance appeared to be with moisture sensitivity based on laboratory testing
Shell Thiopave – What is it?

• Shell Thiopave* is a patented asphalt mix additive based on sulphur technology.
• It replaces up to 25% of the bitumen in an asphalt mix.
• It is added to the asphalt mix as a solid pellet (<5 mm).
• It melts quickly in the mix to form part of the binder.
• An organic compaction agent is included separately as part of the Shell Thiopave system.

* Formerly known as SEAM
Pellets in SuperSacks or Bulk
Determination of mass percentage of total binder (Thiopave + Bitumen) to yield the same binder volume as in an existing asphalt mixture design:

\[ P_{bt} \times 100R \]

\[ \frac{100R - F_{Th}(R - G_{b})}{[100R - F_{Th}(R - G_{b})]} \]

Where:

- \( F_{Th} \) = Percentage of Shell Thiopave in total binder (typically 30-40%)
- \( R \) = Shell Thiopave to bitumen substitution ratio
  - \( = \frac{G_{Th}}{G_{b}} \) for equivalent binder volume
  - \( G_{Th} \) = Specific gravity of Shell Thiopave (2.06)
- \( P_{Th} \) = Percentage of Shell Thiopave by mass of mixture = \( P_{bt} \times F_{Th} \)
- \( P_{bm} \) = modified % bitumen by mass of mixture = \( P_{bt} - P_{Th} \)

>> Bureau of Mines, 1980
Example Calculation

Assume: \( P_b = 5.3\% \)
\( F_{Th} = 40\% \) (ie. 40% Shell Thiopave/ 60% Bitumen blend by mass)
\( G_{Th} = 2.06 \)
\( G_b = 1.03 \implies R = \frac{2.06}{1.03} = 2.00 \)

\[ P_{bt} \% = \frac{5.3 \times \frac{100}{100} (2.00)}{100(2.00) - (40)(2.00-1.03)} = 5.3 \times 1.24 \]

\[ = 6.6\% \]

\( \therefore P_{Th} = 2.6\%, P_b = 4.0\% \)
Thiopave is a WMA

At Sea-to-Sky:

- Conventional HMA mixed at 293-302°C
- Thiopave mixed at 275°C
- Thiopave behind screed at 248-257°C
- Thiopave finish rolling at +140°C
Sea-to-Sky
Fall 2008 Trials

- 2010 Winter Olympic Skiing
- October 26th – 904 tons
- November 13th – 1102 tons
- November 18th – 1213 tons
- All Base Mix with 30% Thiopave
- All 80/100 Pen (PG 64-28, 64-22)
## Lab-Compacted, Field-Produced AMPT Dynamic Modulus Results (Sea-to-Sky)

<table>
<thead>
<tr>
<th>Temperature (F)</th>
<th>Mixture E* (psi) - Control 80/100-pen Superpave Mix</th>
<th>Mixture E* (psi) – Thiopave Modified Superpave Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>10</td>
<td>2,281,366</td>
<td>2,542,282</td>
</tr>
<tr>
<td>40</td>
<td>853,287</td>
<td>1,250,260</td>
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<tr>
<td>70</td>
<td>149,018</td>
<td>270,353</td>
</tr>
<tr>
<td>100</td>
<td>34,624</td>
<td>52,012</td>
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<tr>
<td>130</td>
<td>21,692</td>
<td>27,890</td>
</tr>
</tbody>
</table>

**Temperature**

- **Mixture E* (psi) – Thiopave Modified Superpave Mix**

- **Mixture E* (psi) – Control 80/100-pen Superpave Mix**

**Shell Thiopave**

Technologies for Sulphur Enhanced Road Construction
Lab-Compacted, Field-Produced E* (Sea-to-Sky)

Temp: 40 F (4 C)

Dynamic Modulus (psi)

Control

Thiopave

Frequency

0
1
5
10
25

0.1
0.5
1
5
10
25

1,000,000
1,500,000
2,000,000
2,500,000

Dynamic Modulus (psi)
Lab-Compacted, Field-Produced E* (Sea-to-Sky)

Temp: 70 F (21 C)

Dynamic Modulus (psi)

- Control
- Thiopave

Frequency

Dynamic Modulus (psi)
Lab-Compacted, Field-Produced E* (Sea-to-Sky)

Temp: 100 F (38 C)

Dynamic Modulus (psi)

Frequency

Control
Thiopave

Shell
Thiopave
Technologies for Sulphur Enhanced Road Construction
Lab-Compacted, Field-Produced $E^*$ (Sea-to-Sky)

Temp: 130 F (54 C)

Dynamic Modulus (psi) vs. Frequency

- Control
- Thiopave

Shell

Thiopave

Technologies for Sulphur Enhanced Road Construction
Lab Mix Design Fatigue Curves (Sea-to-Sky)
Sea-to-Sky Field Mix - TSRST

Mean Fracture Temperatures:
Conventional: \(-21.1\) C (SD = 5.8 ; n = 12)
Thiopave Mix: \(-28.4\) C (SD = 1.7 ; n = 15)

80-100 Pen
PG 64-22
NCAT Test Sections

July 24, 2009
Traffic Began August 28, 2009
After 1\textsuperscript{st} million ESAL (11-5-09)
E* Master Curves (NCAT)

Source: NCAT
E* : 10 Hz – 21 C (NCAT)
Laboratory Fatigue Curves - Shell Mix Design

$y = 6.2054 \times 10^{18} x^{-5.2478 \times 10^0}$
$R^2 = 9.6271 \times 10^{-1}$

$y = 2.2094 \times 10^{14} x^{-3.5019 \times 10^0}$
$R^2 = 9.2739 \times 10^{-1}$

Cycles to Failure

Strain Level (microstrain)

- 0% SEAM 4% Design Air
- 30% SEAM 2% Design Air

Power (30% SEAM 2% Design Air)

Power (0% SEAM 4% Design Air)
### NCAT Lab Study

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Statistic</th>
<th>Fracture Stress (psi)</th>
<th>Fracture Temperature (°C)</th>
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</thead>
<tbody>
<tr>
<td>0% Sulfur 4% Design Air</td>
<td>Average</td>
<td>349.0</td>
<td>-20.5</td>
</tr>
<tr>
<td></td>
<td>COV</td>
<td>8.9</td>
<td>4.4</td>
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<td>30% Sulfur 3.5% Design Air</td>
<td>Average</td>
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<tr>
<td></td>
<td>COV</td>
<td>10.7</td>
<td>15.1</td>
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<td>40% Sulfur 3.5% Design Air</td>
<td>Average</td>
<td>429.7</td>
<td>-20.1</td>
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<tr>
<td></td>
<td>COV</td>
<td>12.4</td>
<td>11.1</td>
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<td>30% Sulfur 2% Design Air</td>
<td>Average</td>
<td>381</td>
<td>-21.9</td>
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<tr>
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<td>COV</td>
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<td>4.8</td>
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<tr>
<td>40% Sulfur 2% Design Air</td>
<td>Average</td>
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<tr>
<td></td>
<td>COV</td>
<td>12.2</td>
<td>8.1</td>
</tr>
</tbody>
</table>
15 miles in Western Missouri, US-71
AMPT Flow Number

TSRST Low Temp Cracking

US-71
Hamburg Wheel Tracking (LTRC)

Wearing Course Asphalt Mixture Containing Thiopave Additives
LWT Test Results, 50°C, Wet
Concerns & Solutions

• Emissions (H$_2$S & SO$_2$)— third party documentation at warm mix temps
• Dust – masks & goggles if very close
• Recycling – OK at warm mix temps
• Low Temp Brittleness or Cracking – no evidence of problem
• Moisture Susceptibility – need LAS or Lime with marginal mixes
Longview, TX – checking OEL, STEL
Longview, TX – checking milling op
Milling Head – checking OEL, STEL
Longview, TX – checking RAP Mix
Checking RAP emissions
Lime in a Batch Plant Experiment