Evaluation of Rheology and Engineering Properties of a Bridge Deck Thermoplastic Waterproofing Material

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- The team at Chase Construction
Water-proofing bridge decks

- Asphalt has been used on bridge decks for over 100 years with a view to providing water-proofing properties.
- Historically the materials have functioned well without the need for modification but as traffic volumes and loads increase modification has become the norm for high quality surfacing materials.
  - some examples of use
Asphalt Bridge Deck
Waterproofing
Tower Bridge, London
Constructed 1886 to 1894

Boorman, T.H., "Asphalts, Their Sources and Utilizations, Asphalt for Dustless Roads, Recent Improvements in Asphalt Industries," Comstock, New York, 1908
George Washington Bridge, NY
Opened to traffic in 1931

Asphalt Waterproofing used on steel upper deck and concrete lower deck

Rosphalt used on most heavily trafficked lanes in 2008
Traffic volume approx. 1,000,000 vehicles/week

Longest suspension bridge in world when opened!
Objectives for a performance material

- Performance
  - Skid resistance
  - Waterproofing
  - Smooth ride quality
  - Resistance to fatigue
  - Deformation resistance
  - Durability
  - Long life

- Attributes
  - Quick installation
  - Ease of application
  - Low cost compared to other materials
  - Use of conventional equipment
Why thermo-plastic modifiers

- Have structure at lower temperatures associated with deck temperatures during service that are similar to visco-elastic solid - no, or little deformation
- Polymers designed to enable processing by all conventional HMA plants and equipment
- Cost of installation low compared to alternate products
- Selection of products allows a very long fatigue life to be obtained, low stiffness and very flexible material
Thermo-plastic modifiers

- Asphalt is a thermo-visco-elastic-liquid material and as the material heats up it transitions to viscous behavior.
- At all temperatures it is a visco-elastic liquid.
- Lacks structure to prevent deformation – relies on aggregate for this.
Modified vs. unmodified binder response to loading

Typical unmodified binder response

Typical modified binder response
Complex modification

Asphalt binder behaves as a visco-elastic liquid at all temperatures. Thermo-plastic (visco-elastic solid) polymers provide structure at pavement temperatures while careful selection of plastic properties in system design allow for plastic flow at placement temperatures.
Hydraulic conductivity
The performance

- Hydraulic conductivity below $1 \times 10^{-7} \text{cm/sec}$ is achieved by careful attention to volumetric design.

- Asphalt materials are effectively “impermeable” when a correct volumetric design is performed.
Hydraulic conductivity

- Long been known that permeability (or conductivity) is related to mixture volumetrics (for example Goode and Lufsey, 1965).
- Below 3% air voids – impermeability is generally met. In some publications this critical value of air voids is given as a high as 8%, (Nijboer, 1952).
Hydraulic conductivity

- HC test ASTM D5084
- The test is difficult to perform – originally developed for soils
- Data from trials consistent with expectations
- HC < 1e-7 cm/sec = effective impermeability
Volumetric design and compaction
Volumetric design

- Need to consider optima at location where no further change in voids occurs
- Rosphalt changes voids to approximately 1% and increases volume of binder by over 5%
- Data in grey points represents historical database of various designs conducted over 20-year period for projects in USA (States – NY, NJ, KY, MA, IA, WI, OH, ME, IN, WV) and Canada (Provinces – ON, NB, NS).
Density development, field

Percent of Gmm vs. Roller Passes

Lay down

Roller Passes

10 ton roller

5 ton roller

1 2 3 4 5
Volumetrics and workability

- LT gets density more quickly
- Optima binder for Rosphalt process is point at which mastic skeleton is optimized
- Located at location where voids cease to reduce
- Density development on site consistent with laboratory work
Performance test

- Deformation
  - Binder
    - PG grade
    - Master curves
    - Jnr
  - Mixture
    - Wheel tracking, APA, Hamburg

- Fatigue and flexibility
  - Bending beam fatigue test
  - Bending stiffness

- Thermal cracking
  - PG binder
  - Mix – IDT analysis
PG tests

- Temperature spread increased from 93 to 112.6°C
- Binder changes from S to m controlled
Modified vs. unmodified binder response to loading

Typical unmodified binder response

Typical modified binder response
Test using the DSR applying a 1 sec creep stress followed by 9 sec recovery.
MSCR test performed in DSR

Applied Stress (A to B)

Load applied to upper plate

Asphalt

Fixed Plate

Recovery (B to C)

\[ J_{nr} = \frac{\gamma_u}{\tau} \]

\[
% \text{ recovery} = \frac{100 \times \gamma_r}{\gamma_p}
\]

\( \tau = \text{stress applied during tests} \)

\( \gamma_p = \text{peak strain} \)

\( \gamma_r = \text{recovered strain} \)

\( \gamma_u = \text{un-recovered strain} \)

Strain, %

time, seconds
\[ J_{nr} = \frac{\gamma_u}{\tau} \]

- \( \tau \) = applied stress during creep kPa
- \( \gamma_u \) = Avg. un-recovered strain
- \( J_{nr} \) = non-recoverable compliance
Why different stress levels

![Graph showing stress levels for different structures]

- Poor structure
- Good structure

3200 Pa
This binder shows no elastic recovery - binder behavior is viscous flow when loaded at 70°C

In test the stress level changes from 100 Pa to 3200 Pa after 10 loading cycles

Permanent deformation (strain after recovery period)
- 100 Pa $\rightarrow$ 543.1%
- 3200 Pa $\rightarrow$ 20,144%
Rosphalt, MSCR at 70°C

- With 5.5% PG64-22
- Rosphalt at 70°C demonstrates good elastic recovery at both stress levels in test
- Permanent deformation (strain after recovery period)
  - 100 Pa → 1.02%
  - 3200 Pa → 49.3%
- Very large difference in performance level compared to unmodified materials
Rosphalt LT, MSCR at 70°C

- With 5.5% PG64-22
- Rosphalt at 70°C demonstrates good elastic recovery at both stress levels in test
- Permanent deformation (strain after recovery period)
  - 100 Pa $\rightarrow$ 0.103%
  - 3200 Pa $\rightarrow$ 95.7%
- Very large difference in performance level compared to unmodified materials
Rosphalt LT, MSCR at 70°C

- With 6.5% PG64-22
- Permanent deformation (strain after recovery period)
  - 100 Pa → 0.793%
  - 3200 Pa → 374.0%
- Very large difference in performance level compared to unmodified materials
- Shows that a different % of base asphalt effects the performance level
Jnr vs. Elastic Recovery

The graph illustrates the relationship between Jnr (1/kPa) and Elastic Recovery (%). The x-axis represents Jnr, and the y-axis represents Elastic Recovery. Different data points and lines are color-coded to represent various categories and conditions, such as R50 Org 5.5%, 3200Pa, R50 NF 5.5%, 100Pa, and more. The graph also includes lines for Elastic/Non-Elastic and S-Grade Limit, H-Grade Limit, V-Grade Limit, and E-Grade Limit.
Jnr vs. Elastic Recovery

Elastic/Non-Elastic Line

- R50 Org 5.5%, 100Pa
- R50 NF 5.5%, 100Pa
- R50 NF 5.5%, 3200Pa
- R50 NF 6.5%, 100Pa
- R50 NF 6.5%, 3200Pa
- R50 + 3% @ 5.5%, 100Pa
- R50 + 3% @ 5.5%, 3200Pa
- Wax Study - 3200 Pa
- Wax Study - 100 Pa
- E-Grade Limit

Elastic Recovery, %

Jnr, 1/kPa
Comparative effect of modification on PG64-22 at two concentration levels

If the binder performance at 70°C is compared to an unmodified system the relative deformation performance is 0 to 2%

<table>
<thead>
<tr>
<th>Performance measure</th>
<th>Stress level</th>
<th>PG64-22</th>
<th>5.5% + Rosphalt LT</th>
<th>6.5% + Rosphalt LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jnr (non-recoverable creep compliance), 1/kPa</td>
<td>100 Pa</td>
<td>5.39</td>
<td>0.0002</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>3200 Pa</td>
<td>6.09</td>
<td>0.027</td>
<td>0.122</td>
</tr>
<tr>
<td>Elastic recovery, %</td>
<td>100 Pa</td>
<td>1</td>
<td>100</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>3200 Pa</td>
<td>0</td>
<td>75</td>
<td>59</td>
</tr>
<tr>
<td>Total permanent strain, %</td>
<td>100 Pa</td>
<td>543</td>
<td>0.103</td>
<td>0.793</td>
</tr>
<tr>
<td></td>
<td>3200 Pa</td>
<td>20,144</td>
<td>95.7</td>
<td>374</td>
</tr>
<tr>
<td>Percent of strain compared to unmodified PG64-22, %</td>
<td>100 Pa</td>
<td>100</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>3200 Pa</td>
<td>100</td>
<td>0.5</td>
<td>1.9</td>
</tr>
</tbody>
</table>

It should be noted that aggregate structure has changed so that a significant part of the stress is carried by the binder/fine aggregate mastic and consequently the final mix behavior will not completely represent this ratio.

Mix testing performed to assess final behavior of composite mixture.
Hamburg wheel tracking test

- Test conducted at 50°C

<table>
<thead>
<tr>
<th>Number of Passes</th>
<th>Rut Depth, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>5,000</td>
<td>3.9</td>
</tr>
<tr>
<td>10,000</td>
<td>4.1</td>
</tr>
<tr>
<td>15,000</td>
<td>5.3</td>
</tr>
<tr>
<td>20,000</td>
<td>6.2</td>
</tr>
</tbody>
</table>
APA wheel tracking test

- Test conducted at 64°C

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Results: Cores 4 +5</th>
</tr>
</thead>
<tbody>
<tr>
<td>APA Rut Resistance, mm</td>
<td>AASHTO TP 63: (Temp. = 64°C; Hose Pressure: 100 psi Load 100 lbs; Cycles 8,000)</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Fatigue
Fatigue cracking on bridges can be a considerable problem.

- Need flexible material
- Low stiffness
Fatigue and flexibility - understanding of needs

- Measurements of strains in deck with loaded truck tends to be less than 600 microstrain.
- Complex FE analysis studies performed in some locations.
- Most specifications in USA adopt 750 microstrain – seems reasonable compared to other analysis.
Fatigue testing

- Fatigue testing conducted by TAI
- Testing conducted on design and trial mixes
Rosphalt LT - trial data

Most specs are 750 microstrain.
Flexibility

- Rosphalt materials all have significantly lower stiffness, 20 C, 10 Hertz

<table>
<thead>
<tr>
<th>Average E*, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>KY Standard</td>
</tr>
<tr>
<td>Rosphalt</td>
</tr>
</tbody>
</table>
Low temperature cracking
Thermal cracking

- Thermal cracking is a significant problem for pavements in Canada and the northern USA
- Abatech is sole source supplier of software for calculation procedures in AASHTO PP42 and ASSHTO M320-Table 2
- Analysis can be performed with binder or mix data
Binder data

- Data is difficult to assess – but table 1 data gives different result to table 2
- Table 1 $\rightarrow$ -27, Table 2 $\rightarrow$ -33
- What is mix performance
University of Illinois developed tensile strength and stiffness data from Indirect Tensile Test. Stiffness data converted to master curve and used to compute thermal stress. Data combined with strength data to obtain critical cracking temperature.
Thermal stress analysis

- Thermal stress computations for low temperature cracking using Abatech software
Rosphalt LT mix low temperature performance = -36.5 to -38°C
Objectives for a performance material

Performance
- Skid resistance
- Waterproofing
- Smooth ride quality
- Resistance to fatigue
- Deformation resistance
- Durability
- Long life

Attributes
- Quick installation
- Ease of application
- Low cost compared to other materials
- Use of conventional equipment

Mix property verification is key to understanding of the performance.

Using mixture testing a performance window in excess of +70(E) to -34 can be obtained.
23,000 tons
installed in 15 days
no road closure

Thank you for your attention - Questions?