SBS Polymer Modified Base Course Mixtures for Heavy Duty Pavements

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Background

- Usually pm binders are used in wearing course to increase resistance to permanent deformation
- Experiences on e.g. Schiphol/ Amsterdam airport have shown that use of pm binders in base courses can be very beneficial.
Requirements for SBS Modifications to be used in Base Courses

• High stiffness for a large load-spreading capacity. This implies that a relatively hard base bitumen should be used and hence for modification. The viscosity of the PMB should be looked at carefully when selecting SBS grade and content.

• A hard bitumen generally contains less maltenes; this means that less “solvent” is available. This should also be considered when selecting the SBS grade and content.

• The PMB should give the asphalt mixture a high resistance to cracking and permanent deformation.
Mixtures Tested

- Stone asphalt concrete base course mixture
- Max grain size 22 mm
- Pen 40 bitumen used in reference mixture
- Binder content 4.6% by mass
- Void content 5%
- In pm mixtures same volume of pm binder was replacing reference binder
Test Program

- Stiffness testing using different set ups
- Monotonic tension and compression tests to determine failure envelopes
- Fatigue testing
4p Bending, ITT, Tension and Compression Tests for Stiffness Measurements
## Results Stiffness Tests at 20 °C

<table>
<thead>
<tr>
<th>Mixture</th>
<th>$4PBT, 8$Hz, fatigue (initial)</th>
<th>$4PBT, 8$Hz, at 50 μstrain</th>
<th>ITT, $8$Hz, loadlevel: $^1=800N$ $^2=1000N$</th>
<th>$E_t$ at 1 % / s</th>
<th>$E_c$ at 1 % / s</th>
</tr>
</thead>
<tbody>
<tr>
<td>599-40 (= 40)</td>
<td>8871</td>
<td>13368$^1$ 12513$^2$</td>
<td>11701</td>
<td></td>
<td>7028</td>
</tr>
<tr>
<td>604-41 (= 41)</td>
<td>10124</td>
<td>13991$^1$ 12630$^2$</td>
<td>14468</td>
<td></td>
<td>6161</td>
</tr>
<tr>
<td>602-42 (= 42)</td>
<td>10801</td>
<td>11329$^2$</td>
<td>12660</td>
<td></td>
<td>7714</td>
</tr>
<tr>
<td>45</td>
<td>8154</td>
<td>8502</td>
<td>10378$^2$</td>
<td>10046</td>
<td>4029</td>
</tr>
<tr>
<td>48</td>
<td>9940</td>
<td>9544</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tension Test
Tension Test Results at 5 °C

Mix 45: \( \sigma_t \) as a function of ax. and rad. strain at \( T=5°C \)
for different strain rates [\%/s]
Tensile Strength in relation to Strain Rate and Temperature

\[ f_t = a \left[ 1 - \frac{1}{1 + \left( \frac{\sigma \varepsilon}{T} \right)^{b+c}} \right]^{d} \]
Compression Test
Compression Test Results at 40 °C

Mix 45: $\sigma_c$ as a function of ax. and rad. strain at $T=40^\circ$C for different strainrates [%/s]

<table>
<thead>
<tr>
<th>Strain [%]</th>
<th>Stress [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.78</td>
</tr>
<tr>
<td>-1</td>
<td>0.95</td>
</tr>
<tr>
<td>-2</td>
<td>0.10</td>
</tr>
<tr>
<td>-3</td>
<td>0.01</td>
</tr>
</tbody>
</table>

![Graph showing stress vs. strain for different strain rates at 40°C](image-url)
Triaxial Test, Cohesion “C” and Angle of Internal Friction “ϕ”
General Case

• Failure envelope can also be generated by means of tension and compression tests.

• In generalized case, $\sigma$ is replaced by bulk stress $I_1$ and $\tau$ is replaced by deviator stress parameter $J_2$. 
Parameters used in the Failure Envelope Graphs

\[ I_1 = \sigma_1 + \sigma_2 + \sigma_3 \]

\[ J_2 = \frac{1}{2}(s_1^2 + s_2^2 + s_3^2) = \frac{1}{6}
\left[
(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2
\right] \]
When mat A and mat B have about same stiffness, then an almost similar point in $I_1 - J_2$ space will be obtained but mat B will perform much better.

Mixtures did not differ too much in terms of stiffness.
Failure Envelopes at 5 °C and Strain Rate of 0.01 % / s
Failure Envelopes at 40 °C and Strain Rate 0.01 % / s

\[ I_1 \text{ [N/mm}^2\text{]} \]

\[ \sqrt{J_2} \text{ [N/mm}^2\text{]} \]

DAC
concrete B45
40
41
42
43
45
SMA
PAC
Analyses

- Results were used as input for advanced elasto-visco-plastic models
- Models were incorporated in FEM code
- 9000 load repetitions were simulated
- 2 days computation time
Damage Development (Mat.47)

- N=1000
- N=5000
- N=9000

total damage
4 Point Bending Fatigue Test
Fatigue Test Results at 20 °C and 8 Hz

\[ y = 959.16x^{-0.1792} \]
\[ R^2 = 0.7354 \]

\[ y = 691.22x^{-0.1374} \]
\[ R^2 = 0.9208 \]

\[ y = 1978x^{-0.2577} \]
\[ R^2 = 0.8657 \]
Procedure to get Limit Strain Value = Endurance Limit

- From frequency and strain level used in fatigue test, strain rate can be calculated
- From strain rate and temperature, tensile strength can be calculated
- Applied stress during fatigue test is known
- Stress ratio $R = \frac{\sigma_t}{f_t}$ can be calculated
- Fatigue results can be expressed as $N_{f,50}$ vs $R$
- $R_{\text{limit}}$ can be determined
Fatigue Life in terms Stress Ratio

Loading cycles $N_{f,50}$

- $R_{initial}$
- $R_{limit}$

- 599-40
- 602-42
- 604-41

Prediction
Limit Tensile Strain

\[ \varepsilon_{\text{limit}} = \frac{R_{\text{limit}}}{S_{m,\text{initial}}} \cdot a \left[ 1 - \frac{1}{1 + \left[ 4 \cdot f \cdot \varepsilon_{\text{init}} \cdot 100 \cdot e^{\left( \frac{b+c}{T} \right)} \right]^d} \right] \]
Relationship between $R_{\text{limit}}$ and Mix Stiffness

$$y = 3 \times 10^{-5}x - 0.1289$$

$R^2 = 0.9592$

![Graph showing the relationship between $R_{\text{limit}}$ and $S_{m,\text{initial}}$ with data points and the regression line.](image-url)
**Endurance Limits at 8 Hz and 20 °C**

<table>
<thead>
<tr>
<th>Mixture</th>
<th>$S_{m,initial}$ (GPa)</th>
<th>$\varepsilon_{limit}$ ($10^{-6}$ m/ m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>599-40</td>
<td>8.9</td>
<td>50</td>
</tr>
<tr>
<td>602-42</td>
<td>10.8</td>
<td>80</td>
</tr>
<tr>
<td>604-41</td>
<td>10.1</td>
<td>75</td>
</tr>
</tbody>
</table>
Analyzed Pavement Structures

F = 50 kN; r = 150 mm

Variable thickness; Stiffness of mixtures 40, 41 and 42; \( \mu = 0.35 \)

E = 300 MPa; h = 300 mm; \( \mu = 0.35 \)

E = 100 MPa; \( \mu = 0.35 \)
Required Asphalt Thickness

tensile strain at bottom of asphalt layer [m/m]

diagram showing the relationship between tensile strain [m/m] and thickness asphalt layer [m] for different asphalt types, with specific values indicated for 42/194 and 41/211.
Conclusions

- Mixtures with excellent mechanistic properties can be produced using specially designed polymers.
- The fatigue behaviour of asphalt mixtures can be described by means of an endurance limit.
- The endurance limit can be estimated using a series of tension tests performed at different strain rates and temperatures and mix stiffness tests. Extensive fatigue testing seems not necessary.
- Modifying asphalt mixtures with specially designed polymers can result in a significant reduction of the asphalt layer thickness.
Thank you for your attention