Permanent Deformation Tests on conventional and polymer modified asphalt mixes

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1. Introduction

As we all know, the increase of heavy traffic in Europe in the next 20 years will be up to 20% to 30%. Permanent deformation is worldwide the main problem of asphalt pavements with heavy traffic. The critical conditions for the performance of bituminous mixes are generally associated with either high service temperatures (> 50 °C) or low service temperatures (< 5 °C). At high temperatures the problems are deformation and fatting-up and at low temperatures cracking and ravelling.

Permanent deformations in general are plastic deformations of the wearing and binder course, that means the upper 12 cm of an asphalt pavement.

Single or combined reasons for rutting can be:
- high service temperatures;
- slow speed;
- canalized traffic;
- high tyre pressure;
- tyre construction: twin tyre or supersingle tyre;
- stiffness of asphalt mixture;
- stiffness of asphalt binder;
- compaction degree of the asphalt layers.

The mechanical behaviour of asphalt mixes can be simply described by the Mohr-Coulomb-Law:

\[ J = c + F \tan \theta \]

Where
- \( J \) = shear stress (MPa)
- \( c \) = cohesion (MPa)
- \( F \) = normal stress (MPa)
- \( \theta \) = angle of friction (°)
This equation is theoretically only valid for unbounded and non-plastic materials under failure conditions. But it helps very much to understand the mechanical behaviour in the beginning of plastic deformations. The equation is graphically shown in figure 1.

Fig. 1: Mohr-Coulomb relationship
The angle of friction is determined by:
- particle texture (roughness);
- particle shape;
- particle size distribution;
- stage of compaction.

The contribution which can be given by the aggregates is limited: to achieve a high stiffness of the asphalt mixture you have to use crushed coarse aggregates with a good particle shape, crushed sand and a particle size distribution, which follows either the Fuller parabola or the Stone Mastic principle with a maximum particle size of 11 or 16 mm.

The cohesion is mainly determined by the stiffness and visco-elastic, viscoplastic behaviour of the binder. The use of normal straight-run bitumen does not increase the cohesion strongly. Only modified binders can help to avoid rutting of asphalt roads under heavy traffic, which will increase unlimited in the future.

The simplified description of the mechanical behaviour of asphalt mixes demonstrates very clearly, that the only possibility to raise the resistance against permanent deformation is the use of stiffer binders with a higher softening point, that means better high temperature behaviour without loss of low temperature properties.

The following table shows the effect of harder straight-run bitumens:

<table>
<thead>
<tr>
<th>Bitumen pen (1/10 mm)</th>
<th>Relative $S_{\text{bit}}$</th>
<th>Relative $S_{\text{mix}}$</th>
<th>Relative Deformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.2</td>
<td>0.67</td>
<td>1.5</td>
</tr>
<tr>
<td>60</td>
<td>0.6</td>
<td>0.88</td>
<td>1.1</td>
</tr>
<tr>
<td>50</td>
<td>1.0</td>
<td>1.00</td>
<td>1.0</td>
</tr>
<tr>
<td>40</td>
<td>1.3</td>
<td>1.07</td>
<td>0.94</td>
</tr>
<tr>
<td>30</td>
<td>3.0</td>
<td>1.32</td>
<td>0.75</td>
</tr>
</tbody>
</table>

$S_{\text{bit}}$ = stiffness of the bitumen
$S_{\text{mix}}$ = stiffness of the asphalt mixture

Table 1: relation between penetration and relative deformation
To reduce the permanent deformation by 25% you have to use a 30 pen bitumen. The reduction is not very satisfying! More over there is a reasonable risk of low temperature cracking in winter time.

Figure 2 shows the relation between relative deformation and Penetration-index PI: the effect of the penetration-index is higher than the effect of the penetration itself. That shows that you have to use binders with low temperature susceptibility (positive PI), to increase the resistance against permanent deformation!

![Fig. 2: relative deformation as a function of penetration index](image)

One way to reach this goal by using harder bitumens without risk of temperature cracking, is the use of polymer modified binders on the basis of SBS-polymers with a high softening point and a low breaking point.

Now I would like to show you the results of laboratory tests and the practical application of modified binders and asphalt mixtures with extreme high resistance against permanent deformation.
2. Binder characteristics

Table 2 shows the characteristics of the investigated binders:

<table>
<thead>
<tr>
<th>Binder</th>
<th>Pen 1/10 mm</th>
<th>Softening point /°C</th>
<th>Breaking point /°C</th>
<th>Elastic recovery</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>B65</td>
<td>58</td>
<td>49.5</td>
<td>-15</td>
<td>18</td>
<td>-1</td>
</tr>
<tr>
<td>PmB 65</td>
<td>63</td>
<td>53</td>
<td>-19</td>
<td>84</td>
<td>0</td>
</tr>
<tr>
<td>PmB 45</td>
<td>47</td>
<td>58</td>
<td>-15</td>
<td>81.5</td>
<td>+0.5</td>
</tr>
<tr>
<td>SFB5-50</td>
<td>52</td>
<td>93</td>
<td>-22.5</td>
<td>90</td>
<td>+5.7</td>
</tr>
</tbody>
</table>

PmB: polymer modified binders according to the German standard, polymer content appr. 3-5%
SFB5-50: Sealoflex binder with high polymer content

Table 2: binder characteristics

The values of table 2 indicate that via the use of SFB5-50 a very high resistance against permanent deformation must be expected.

3. Asphalt mixture characteristics

We tested two different mixtures in the laboratory:
- Binder course asphalt 0/22 mm.
- Stone Mastic Asphalt 0/11 mm for the surface course.

Tables 3 and 4 show the mixture characteristics:

<table>
<thead>
<tr>
<th>Binder course 0/22</th>
<th>Binder-cont. (M.-%)</th>
<th>&gt; 2 mm (M.-%)</th>
<th>Void cont. (V.-%)</th>
<th>Marshall-stability (kN)</th>
<th>Voids filled with bit. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B 65</td>
<td>4.2</td>
<td>75.0</td>
<td>6.0</td>
<td>11.0</td>
<td>62.5</td>
</tr>
<tr>
<td>PmB 45</td>
<td>4.2</td>
<td>75.0</td>
<td>6.4</td>
<td>10.8</td>
<td>61.0</td>
</tr>
<tr>
<td>SFB5-50</td>
<td>4.8</td>
<td>75.0</td>
<td>6.4</td>
<td>14.1</td>
<td>64.0</td>
</tr>
</tbody>
</table>

Table 3: binder course characteristics
<table>
<thead>
<tr>
<th></th>
<th>Stone Mastic 0/11</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B65</td>
</tr>
<tr>
<td>Binder-cont. (M.-%)</td>
<td>6.5</td>
</tr>
<tr>
<td>&gt; 2 mm (M.-%)</td>
<td>75.2</td>
</tr>
<tr>
<td>Void cont. (V.-%)</td>
<td>3.7</td>
</tr>
<tr>
<td>Marshall-stability (kN)</td>
<td>7.6</td>
</tr>
<tr>
<td>Voids filled with bit. (%)</td>
<td>80.5</td>
</tr>
</tbody>
</table>

**Table 4: stone mastic characteristics**

The particle size distribution of both mixtures (see figures 3 and 4) are in accordance with the German specifications for asphalt courses for heavy loaded pavements.

![Fig. 3: particle size distribution binder course 0/22](image-url)
Fig. 4: particle size distribution Stone Mastic Asphalt 0/11

Tables 3 and 4 showed the different behaviour of mixtures with the highly polymerised binder SFB5-50: to achieve the same void content conditions, you need a higher binder content.

During the mix design with the Marshall procedure we observed that a higher binder content does not result into a lower void content. The reason for this phenomenon is the high elasticity of the binder: after compaction the test specimens grew up due to elastic behaviour which results in a higher void content. We tested the resistance against permanent deformation with the wheel tracking test according to the German standards.

The Wheel tracking test (see figure 5) was originally developed in Great Britain. The Esso Oil company brought this test device to Hamburg, where the test procedure was improved. Now it is a high-tech device. A rolling steel wheel passes 20,000 times in 6 hours over the asphalt specimen (plate of 30 x 36 cm). The loading time per cycle is 0.1 sec. During the test the rut depth is monitored continuously as an average of 25 measurements within 100 mm test length in the middle of the plate. The test is run in a waterbath by 40° C or 50° C. The specimens are prepared in a compaction machine, a so-called plate compactor, developed in the USA during the SHRP-programme.

In the meantime, the Hamburg device is standardized in Germany and will also be standardized in Europe. In the USA the Hamburg device is very often being used.
We studied the influence of the:
- different binder systems;
- test temperature and
- compaction degree.

Temperature: figure 6 shows the great influence of the temperature on rutting. A normal bitumen pen 65 shows more than 4 times higher rut depth, if the temperatures raises from 40° C to 50° C. The SFB5-50 shows only an increase of the rut depth of 1.5 times.
Fig. 6: stone mastic asphalt 0/11 mm, rut depth after 20,000 passes in relation to the test temperature

Compaction degree: with lower compaction degree permanent deformation occurs over proportionally (see figure 7). For the binder SFB5-50 you can observe that the compaction degree has a significant lower influence. That means that this binder forgives some mistakes during laying and compacting of the asphalt layer.

Fig. 7: stone mastic asphalt 0/11 mm, rut depth after 20,000 passes in relation to the compaction degree
Tables 5 and 6 show a comparison of the wheel tracking and dynamic creep test results.

<table>
<thead>
<tr>
<th></th>
<th>SMA 0/11</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B65</td>
<td>PmB65</td>
<td>PmB45</td>
<td>SFB5-50</td>
</tr>
<tr>
<td>Rutting depth [mm]</td>
<td>3.1</td>
<td>2.1</td>
<td>1.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Deformation [%]</td>
<td>74.1</td>
<td>1.1</td>
<td>0.9</td>
<td>0.6</td>
</tr>
</tbody>
</table>

1 wheel tracking test: T = 40°C, after 20,000 wheel passes
2 dynamic creep test: T = 40°C, after 20,000 load cycles

Table 5: permanent deformation of stone mastic asphalt 0/11

<table>
<thead>
<tr>
<th></th>
<th>Binder course 0/22</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B65</td>
<td>PmB65</td>
<td>SFB5-50</td>
</tr>
<tr>
<td>Rut depth [mm]</td>
<td>11.4</td>
<td>4.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Deformation [%]</td>
<td>75.2</td>
<td>1.0</td>
<td>0.4</td>
</tr>
</tbody>
</table>

1 wheel tracking test: T = 50°C, after 20,000 wheel passes
2 dynamic creep test: T = 40°C, after 20,000 load cycles

Table 6: permanent deformation of binder course 0/22

The highway authority of Hamburg introduced the following specifications for asphalt mixes with high resistance against permanent deformation, tested with the wheel tracking test:
### Table 7: specification for SMA and binder course for roads class SV (≥ 3200 lorries/day) and class I (1800- to 3200 lorries/day)

<table>
<thead>
<tr>
<th>Material</th>
<th>T = 40°C</th>
<th>T = 50°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone Mastic asphalt 0/11 or 0/8</td>
<td>≤ 2.5</td>
<td>≤ 3.5</td>
</tr>
<tr>
<td>Binder course 0/22 or 0/16</td>
<td>-</td>
<td>≤ 3.5</td>
</tr>
</tbody>
</table>

Test roads with these materials have been found to have rut depths less than 4 mm after 12 to 14 years service life without any other damages.

#### 4. Practical application of Sealoflex SFB5-50 in Germany

The first application of Sealoflex SFB5-50 in Germany was in November 1997 in Hamburg, one of the most important container-harbours of Europe. The handling of the containers needs large areas, where the containers are stored, often 4 containers on top of each other. So called Van-carriers transport the containers; they have eight wheels, each one with a wheel load up to 125 kN. By comparison: heavy road-trucks have a maximum wheel load of roughly 60 kN! The Van-carriers produced strong rutting and damage of the toplayer of asphalt pavement structures after a short time. Concrete structures were also not usefull due to the bad underground conditions.

After a very comprehensive study by our laboratory of the whole container parking place, we recommended for a new area of 30,000 m² a modified asphalt structure.

Following our advises, the authority of the HHLA - Hamburg Hafen- und Lagerhausgesellschaft- decided to use Sealoflex SFB5-50 for two asphalt layers (10 cm wearing course 0/22 mm, 6 cm Stone Mastic asphalt 0/16 mm). The structure thickness is some 25% thinner than a normal structure with straight-run bitumen.

Up till now there is no damage, no rutting or cracks. Only under the feets of the containers we can observe light permanent deformations of less than 4-8 mm. Under such extreme loads - pressure stress approximately 30 MPa - deformations in asphalt structures can not be prevented. Other areas with straight-run bitumen pen 65 or pen 45 show deformations of up to 30 mm in the same time. Laying and compaction of the modified asphalt was no problem.
Even at low air temperatures of +5 °C a compaction degree of > 97% could be ensured by using a heavy static roller. It is remarkable that the surface structure of the top layer shows no wearing after one year service life: the aggregates are still coated and there is no loss of single aggregates as at other asphalt layers. The very good experience with this material caused the HHLA to build an other area of 36,000 m² in 1998.

5. Final conclusions

The binder Sealoflex SFB5-50 has an extremely good high and low temperature behaviour, combined with a very good fatigue behaviour.

The following special applications can be recommended:
- heavy loaded pavements;
- airport pavements;
- Gußasphalt for bridge layers;
- SAMI: stress absorbing interlayers;
- thin asphalt layers for crack prevention;
- open graded asphalt (porous asphalt).