Pre-bituminised S&P grids for asphalt pavement
S&P Carbophalt®
S&P Glasphalt®
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1. Introduction

Over the past decades traffic intensity has grown continuously. In addition, the wheel loads acting on our road surfaces have also increased. Consequently, intense road maintenance measures are required. Replacement and repair cycles are becoming shorter and shorter. Maintenance and renewal works on roads hinder the traffic flow. For this reason, a durable road surface should be provided in the course of repair operations in order to minimise future maintenance.

Since 1996 pre-bituminised S&P grids have been successfully used for increasing the durability of asphalt surfaces. The S&P grids reduce fatigue cracks as well as thermal cracking. The S&P carbon fibre grids S&P Carbophalt additionally increase the structure value of the bituminous pavement. The carbon fibre grid S&P Carbophalt has a structure value equal to that of an asphalt layer measuring 3 – 4 cm in thickness. This establishes interesting rehabilitation options for inner-city areas. For example, an existing old pavement can be cut-milled to a depth of 3 cm and repaired with the carbon fibre grid as well as a new pavement layer of 3 cm. The structure value of the reinforced pavement layer corresponds to a 6 – 7 cm thick layer of non-reinforced asphalt. When milling to a depth of 3 cm the kerb and edge areas are not affected. Because the existing, old level is maintained after the repair job, shafts do not have to be raised. Carbon fibre reinforced thin layers are therefore cost-efficient alternatives for repairing bituminous pavement layers.

Specific maintenance measures are to be implemented in the course of the repair job to prevent damage in future. To avoid plastic deformation of pavement layers, the bitumen type in new layers can be varied. One expedient reinforcing technique is the use of a pavement layer that is resistant to rut formation. Tension members (grid interlayers) are used to prevent structural deformation, fatigue cracks and reflection cracks on existing pavement layers. Accounting for the various mechanisms at play in bituminous pavement layers (Graphic 1), replacement of such pavement layers should be based on appropriate repair concepts.

Grafic 1: Mechanisms acting inside asphalt pavement ⇒ repair technique

- Strain
  ⇒ reinforcement in lengthwise or crosswise direction

- Vertical shear
  ⇒ For example in existing concrete slabs that undergo bituminous resurfacing of the pavement layer, local stabilisation of the concrete slab is carried out by means of PU injection.

- Horizontal shear
  ⇒ Force-locked bonding of old cracks
Grafic 1 clearly indicates that the asphalt reinforcement should be combined with other repair techniques.

2. Different types of asphalt pavement interlayers

A distinction is to be made between SAMI (Stress Absorbing Membran Interlayer) sealings and grid interlayers. The two systems are often used in combination.

SAMI sealings  ⇒ Stresses are absorbed and dissipated thanks to the soft interlayer

Two possibilities are available
- SAMI non-woven
- SAMI surface dressing

Grid interlayers  ⇒ Stresses are absorbed and transferred by the reinforcement

Conventional grid interlayers are made of different fibre-rovings that form a grid structure. The grid is bitumen-friendly or SBR-coated and partially covered with an adhesive on the bottom side. With conventional grid interlayers of this kind the required layer bonding can only be achieved at the construction site when the mesh opening of the grid is at least 15 - 20 mm and an additional SAMI surface dressing is provided on the grid interlayer.

S&P grids are pre-bituminised to stabilise the grid structure during transport to the site. When unrolling the grid and laying of the asphalt mixture the grid structure dissolves under the high temperatures. The carbon fibre or glass fibre strands are now arranged displacement free. Large grains in the mixture ideally integrate with the existing pavement layer during compaction through the displacement of the fibre strands. The fibre strands that can also be displaced in lengthwise direction adjust to the uneven surface of the existing pavement layer. Thanks to the S&P technique “Opening of the junction bonding under the influence of heat“ a layer bonding of the reinforced asphalt layer according to Leutner >12 kN resp. 15 kN (150 mm test core) is achieved.

Reinforcing grid / non-woven interlayers

In compound products a non-woven is laid in addition to the reinforcing grid. The reinforcing grid can basically be combined with different non-woven variants:

- **Hot-melt non-woven** (grammage 20 – 80 g/m²)
  The hot-melt non-woven is removed during the laying process under the influence of heat. In the compound product, the hot-melt non-woven acts as an application aid for the asphalt reinforcement grid.

- **Covering non-woven** (grammage 20 – 80 g/m²)
  The covering non-woven is used as an auxiliary means during the laying procedure. The ability of the non-woven to absorb bitumen is too low to ensure a SAMI function. In the compound product, the covering non-woven acts as an application aid for the asphalt reinforcement grid.
• **SAMI non-woven** (grammage 90 - 140 g/m²)
  The bitumen absorption of a SAMI non-woven is 0.8 - 1.3 kg/m² (effective bitumen quantity). The non-woven impregnated with bitumen acts as a stress-reducing intermediate layer.

Practice has shown that the required layer bonding according to the Leutner method is frequently not achieved with these combination products. This situation is pointed out in various publications. Because an asphalt grid can only develop its full potential with satisfactory bonding, compound products of this kind are no longer used in several countries.

For asphalt overlays on old concrete roads both a SAMI sealing and a reinforcing grid are required. In such cases it is recommended to combine an asphalt reinforcing grid with a SAMI surface dressing. The required layer bonding according to Leutner can be achieved with this combination.

### 3. Fibre-rovings for asphalt pavement interlayers

There are different fibre-rovings available for the production of asphalt interlayers. *Table 1* gives a list of possible fibre-rovings.

<table>
<thead>
<tr>
<th>Fibre type</th>
<th>E-modulus (N/mm²)</th>
<th>Elongation at break (%)</th>
<th>Milling off the overlying layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (C-fibre)</td>
<td>≥ 240'000</td>
<td>1.75</td>
<td>is possible</td>
</tr>
<tr>
<td>Aramid (A-fibre)</td>
<td>~ 120'000</td>
<td>2.5</td>
<td>can be problematic</td>
</tr>
<tr>
<td>Glass (G-fibre)</td>
<td>≥ 73'000</td>
<td>≤ 4.5</td>
<td>is possible</td>
</tr>
<tr>
<td>Polyester (PES-fibre)</td>
<td>~ 15'000</td>
<td>~ 12.0</td>
<td>can be problematic</td>
</tr>
<tr>
<td>Steel (comparison)</td>
<td>210'000</td>
<td>&gt; 5.0</td>
<td>can be problematic</td>
</tr>
</tbody>
</table>

*Table 1*

Table 1 shows that carbon fibre and glass fibre are well-suited to incorporating into asphalt reinforcement as well as to subsequently being milled off. Both fibre-rovings feature a low elongation at break and thus deliver a high reinforcing effect. While milling the carbon or glass fibre-reinforced asphalt, fibre-roving lengths of max. 1 to 8 cm in length will emerge. Recycling or reusing the bituminous mixtures is therefore not compromised by the addition of these fibres.
In the prebituminised S&P asphalt grids the fibre-rovings are optimised to meet the requirement profiles (*Table 2*).

<table>
<thead>
<tr>
<th>Name of the Product</th>
<th>Fibre-roving (longitudinal)</th>
<th>Fibre-roving (transverse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S&amp;P Carbophalt G</td>
<td>Glass (G)-Fibre</td>
<td>Carbon (C)-Fibre</td>
</tr>
<tr>
<td>S&amp;P Glasphalt G</td>
<td>Glass (G)-Fibre</td>
<td>Glass (G)-Fibre</td>
</tr>
</tbody>
</table>

*Table 2*

For a realistic tensile strength comparison of different reinforced asphalt pavements it is essential to compare the tensile strength under identical elongation. The tensile strengths as a function of elongation given for prebituminised S&P grids can be taken from the technical data sheets.

The continuous quality assurance through the EMPA Dübendorf (Switzerland) confirm the recommended tensile forces.

### 4. Reinforced asphalt pavement as a composite material

RC (reinforced concrete) is the best known composite material in the construction industry. In reinforced concrete the rebar is applied in a matrix of concrete. *Table 3* compares the E-moduli of the components.

<table>
<thead>
<tr>
<th>E-modulus of matrix</th>
<th>E-modulus of tension member</th>
<th>Ratio between E-modulus of matrix &amp; tension member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>Steel</td>
<td>RC (reinforced concrete)</td>
</tr>
<tr>
<td>25 – 30 kN/mm²</td>
<td>205 kN/mm²</td>
<td>(~1 : 7)</td>
</tr>
</tbody>
</table>

*Table 3: Ratio between the E-moduli of the matrix and tension member in RC*

The E-modulus of a fibre grid is always lower than the theoretical E-modulus of the fibre. The grid configuration results in a less than ideal fibre arrangement. Accordingly, a reduction factor needs to be applied to the fibre's theoretical elasticity modulus for the comparison of reinforced asphalt pavement (*Table 4*).

**Recommended reduction factor = 1.5**

<table>
<thead>
<tr>
<th></th>
<th>E-modulus of fibre</th>
<th>E-modulus of fibre grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon fibre (C)</td>
<td>240 kN/mm²</td>
<td>160 kN/mm²</td>
</tr>
<tr>
<td>Glass fibre (G)</td>
<td>73 kN/mm²</td>
<td>49 kN/mm²</td>
</tr>
<tr>
<td>Polyester fibre (PES)</td>
<td>15 kN/mm²</td>
<td>10 kN/mm²</td>
</tr>
</tbody>
</table>

*Table 4: Reduced E-moduli of fibres*
Table 5 compares the relevant E-moduli of various fibre-reinforced pavement layers. The E-modulus of a bituminous pavement layer lies between 3 – 15 kN/mm², depending on the ambient temperature.

The reduced E-modulus can now be used to prepare a comparative table.

<table>
<thead>
<tr>
<th>E-modulus of matrix</th>
<th>E-modulus of fibre grid</th>
<th>E-modulus ratio between matrix &amp; fibre grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt covering (6 kN/mm²)</td>
<td>Carbon fibre grid (160 kN/mm²)</td>
<td>~ 1 : 26</td>
</tr>
<tr>
<td>Glass grid (49 kN/mm²)</td>
<td>Polyester grid (10 kN/mm²)</td>
<td>~ 1 : 8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~ 1 : 2</td>
</tr>
</tbody>
</table>

Table 5: Ratio between the E-moduli of the matrix and fibre grid in reinforced asphalt pavement

The table above clearly shows that the carbon-fibre and the glass-fibre grid is effective as tension reinforcement. Moreover, the carbon-fibre grid increases the asphalt layer’s resistance to cracks significantly. A flawless bond between layers is a prerequisite. The bond should be verified by taking a core sample. In comparison, polyester grid-reinforced asphalt pavements only show a small effectiveness.

5. Interlayer shear bond of reinforced bituminous pavement layers

A grid is only effective with a perfect interlayer shear bond with the matrix. The tensile forces from the grid are transferred to the upper and lower bituminous layer via the interlayer bond. In various EU directives and road construction standards respectively, a shear force > 12 kN respectively > 15 kN (Leutner method, Ø 150 mm test core) is required between the old and new bituminous layer (Image 1). In some countries it is not the shearing force that is tested, but rather the pull off strength. Graphic 2 shows the relationship of the shear force to the pull off strength.

The interlayer shear bond always has two components:

Interlayer shear bond = mechanical interlocking of the surfaces + adhesion provided by the bonding agent
With SAMI non-woven interlayers the non-woven material forms the substrate for the bonding agent. The SAMI non-woven interlay is applied as a relatively thick intermediate layer between the pavement layers. This prevents mechanical interlocking of the grains in the new mix with the old substrate (Graphic 3).

With the prebituminised S&P grids, on the other hand, there is no interlayer present. The fibre strands open under the influence of heat during the unrolling of the grid. Unrolling can therefore be carried out in road curves. The grid dissolves again at temperatures of 130 – 150°C during the installation of an asphalt overlay. The displacement-free S&P fibre strands of carbon or glass fibres give under the pressure of the grains of the mixture. During compaction the large grains penetrate through the S&P fibre strands and interlock with the substrate without hindrance (Graphic 4). The fibre strands of the S&P grid can also be displaced in longitudinal direction when compacting the mixture. They appropriately adapt to the uneven or cut milled surface of the substrate.

In the case of traditional asphalt grids the fixed grid structure prevents the penetration of large particles of the mixture. Accordingly, traditional grids tend to form waves when an overlay is applied. The required interlayer shear bond is only achieved with traditional grids when an additional SAMI surface dressing is applied. The pre-coated chippings (4 - 8 mm) of the SAMI surface dressing guarantees the interlocking and thus the mechanical bonding components. Table 6 shows that prebituminised S&P asphalt grids that are laid without additional SAMI surface dressing are a very interesting option from the financial point of view.

In the framework of the research project ASTRA 2011/011_OBF “Implementation of Asphalt Interlayers in the Maintenance Management of Bearing and Top Courses”, it was proven through the EMPA Dübendorf CH that the pre-bituminised S&P products Carbophalt G and Glaspalt G surpass the standardised shear forces for the layer bond. These results have also been confirmed on various completed projects.
SAMI surface dressing  | Traditional grid  | SAMI non-woven  
---|---|---
1.6 - 1.8 kg/m² polymer modified bitumen covered with 12 - 15 lt/m² bitumen coated chippings 4/8 mm  | of PP, PES, glass  | 120 - 140 g/m² polypropylene non-woven and 1.5 - 1.7 kg bitumen emulsion (70%)  
Costs ready-laid*: 8.50 – 9.50 CHF/m²  | Costs ready-laid*: 7.00 – 8.00 CHF/m²  | Costs ready-laid*: 3.50 – 4.50 CHF/m²  
**Interlayer bond:** o.k.  | **Interlayer bond:** insufficient  | **Interlayer bond:** reduced  

**Combination SAMI surface dressing + traditional grid**  
Costs ready-laid*: 15.50 – 17.50 CHF/m²  ⇒ Interlayer bond: o.k.  

**Combination SAMI non-woven + traditional grid**  
⇒ Interlayer bond: reduced  

Prebituminised S&P grid of glass fibre  
Costs ready-laid*: 11.50 – 13.50 CHF/m²  
(cost is lower than traditional grid and SAMI surface dressing)  
⇒ Interlayer bond: o.k.  

| **Table 6: Cost-benefit analysis different reinforcements**  
*country-specific  
Note: for a 10'000 m² project  
---|---|---

### 6. Tack coat underneath grid interlayer

On **hot summer days**, a special tack coat (polymer modified bituminous emulsion) with a higher softening point is needed under the prebituminised S&P grids. **Table 7** shows the technical characteristics of the emulsion.

<table>
<thead>
<tr>
<th><strong>Penetration index</strong> (EN12591)</th>
<th><strong>Softening point</strong> (SN EN 1427)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.2</td>
<td>&gt; 53 °C</td>
</tr>
</tbody>
</table>

**Table 7: Technical data emulsion**

A tack coat fulfilling the specifications in **Table 7** is suitable for high daytime temperatures. Before being applied to large areas the bituminous emulsion should ideally be heated to a temperature of 50 – 60 °C. **Calls for tenders should on all accounts specify technical data for the tack coat.** The quantity of the required bituminous emulsion depends on the roughness of the substrate and of the emulsion type 250 – 300 g/m² emulsion. The quantity of bituminous emulsion required varies between 250 and 300 g/m² depending on the roughness of the substrate and the emulsion type. The upper limit value in combination with pre-bituminised asphalt reinforcement of 300 g/m² must not be exceeded. The asphalt reinforcement may only be laid out on dry (“broken”) emulsion. If the grid interlayer is applied to shaded areas or on **cool autumn days**, the problem of tack coat softening does not arise.
7. Research at EMPA Dübendorf CH  
“Impact of different pavement layers“

7.1 Load test at the four-point bending beam

At the EMPA CH research centre, bituminous pavement layers with different types of reinforcement were examined, using the four-point bending beam. This showed two typical break patterns.

Whereas in the asphalt layer without grid (Image 2) a crack developed in the middle of the reference sample, leading to a break, the C-fibre reinforced asphalt layer (Image 3) showed optimal stress redistribution and crack distribution.

The ultimate load (structure value) as well as the crack resistance of the reinforced pavement layer is significantly increased through the carbon fibre grid (Graphic 5).

[Image 2: Reference sample without grid]
[Image 3: Sample with S&P Carbophalt G 200 kN as interlayer]

Graphic 5: Impact of the carbon fibre grid
In graphic 6 a polyester grid was compared with the pre-bituminised S&P glass and carbon fibre grid. The polyester grid with a tensile elasticity modulus of ~10 kN/mm² bends during the test under the load and is thus not capable of absorbing tensile forces acting on the asphalt pavement. The pre-bituminised glass grid S&P Glasphalt G with a tensile elasticity modulus of ~49 kN/mm² absorbs tensile forces in the asphalt layer and is thus suitable for reducing cracks in the asphalt pavement. The ultimate load can be increased further with the carbon fibre grid S&P Carbophalt G. The carbon fibre grid with a tensile elasticity modulus of ~160 kN/mm² increases the structure value of the reinforced asphalt layer and substantially improves the resistance to cracks.

Graphic 6: Carbon fibre grid in comparison with other intermediate layers

A further test compared the influence of the temperature at -10°, 0° as well as at +10°C, on a non-reinforced layer and on a carbon-fibre reinforced asphalt layer.

Graphic 7/8 show that the carbon fibre grid S&P Carbophalt G considerably increases crack resistance as well as the ultimate load in all temperature ranges.

Graphic 7/8: Influence of temperature
A further test compared the influence of the load 1 mm/min, 5 mm/min as well as 10 mm/min on a non-reinforced asphalt layer and on a carbon-fibre reinforced asphalt pavement layer.

**Graphic 9/10** show that the carbon fibre grid *S&P Carbophalt G* considerably increases the ultimate load and crack resistance in all load ranges.

**7.2 Dynamic loading under effective wheel**

At the EMPA CH research centre two-layer carbon-fibre reinforced and non-reinforced pavements were compared under cyclic loading (**Graphic 11 / Table 8**). To simulate the deflection of the foundation the test specimens were applied to a rubber base and subjected to rolling over by 0.5 million wheel motions at a temperature of 25 °C.

**Graphic 11: Test arrangement dynamic cyclic load**
Test Specimen K1: Two-layer pavement without asphalt grid

Test Specimen K5: Two-layer pavement S&P Carbophalt placed at a depth of 4 cm (cut-milled sub-base)

Table 8: Overview Test Specimen

The test specimens (Table 8) were fitted with strain gauges on the bottom in longitudinal and transverse directions (Image 4). The results of the experimental tests were modelled by the EMPA CH using a finite element calculation. Modelling and experimental tests showed comparable results.

The expansion transverse to the wheel load on the bottom of the asphalt layer was reduced by 25 - 40 % (depending on the asphalt mix) as a result of the carbon fibre grid S&P Carbophalt G.

Image 5 and 6 show the compressive stress in front of and behind the wheel load, when being rolled over, as well as the tensile forces under the wheel load. In the carbon-fibre pavement specimen the forces are fed into the grid and absorbed by it. The asphalt layer thus experiences reduced stress.
Graphic 12 shows the maximum deflection of the different test specimens in comparison with the load cycles. It makes apparent that the measured deflection is significantly smaller in dry or wet applied (mounted) asphalt layers reinforced with S&P carbon fibre reinforcement.

8. Deflection measurements on C-fibre reinforced asphalt pavement layers

In autumn 2003, the load-bearing capacity of the Andermatt-Hospental main road in Switzerland was tested before and after installation of a 4 cm thick new asphalt overlay reinforced with S&P Carbophalt. Measurements were conducted with a Lacroix deflectograph at a rear axle load of 10 t.
Deflection measurements were carried out at 5.5 metre intervals over the entire route length of 2 x 1.9 km = 3.8 km. The measuring principle is illustrated in Grafic 13.

For evaluation of the results, the measured route was divided into homogeneous sections. These sections were mapped in a graph together with the related characteristic deflection parameters (dv, 1/100 mm) (Graphic 14).

In a number of sections, S&P Carbophalt G was installed as an intermediate layer under the new, 4 cm thick asphalt layer. The theoretically expected reduction in dv values resulting from reinforcement of a 4 cm thick overlay (without a grid interlayer) serves as a basis for rating the strengthening effect of the S&P carbon-fibre interlayer. The Lacroix table (Grafic 15) shows the measured strengthening effect of a 4 cm thick asphalt overlay and S&P carbon-fibre grid in the area of the road axis.
The effect of the carbon-fibre grid (S&P Carbophalt) is equivalent to that of a 3 - 4 cm thick new pavement layer. The definite influence of the S&P carbon-fibre grid on the load bearing capacity is verified.

These field tests and resulting measurements confirmed the effectiveness of S&P carbon fibre reinforcement as previously demonstrated by EMPA Dübendorf CH.

9. Investigations at NPC (Netherland Pavement Consultants)

“Asphalt reinforcement against fatigue cracks“

Fatigue cracks in the bituminous pavement layer occur as a result of stress exertion (wheel loads).

The type of fatigue crack depends on the tyre type and pressure. Crack propagation typically occurs from bottom to top (Graphic 16). New tyre types and high load cycles also lead to crack propagation in the reverse direction. Netherlands Pavement Consultants (NPC) conducted a series of tests to evaluate the resistance of grid interlayers to fatigue cracks under subjection to cyclic loading on the four-point-bending beam.

A two-layer pavement sample with a total thickness of 9 cm (3 cm + 6 cm) is loaded cyclically via a four-point bending beam with a span of 500 mm (Graphic 17). During the test, the ambient temperature is maintained at 5 °C. Cyclic loads (simulating vehicle wheel loads) are applied at a frequency of 29.3 Hz and controlled at the load of 50 – 4'500 N. The selected range simulates wheel loads occurring typically on roads. The bending of the test beam until breakage of the asphalt or until an irreversible sample deformation of 35 mm is ascertained as a function of the load cycles.

Formation of fatigue crack as a result of cyclic loading is recorded. The starting point of the fatigue crack is defined as a notch cut in the bottom of asphalt beam sample.

During the test, the non-reinforced, two-layer pavement sample was compared with various, reinforced pavement samples of the same thickness (Table 9). The grid or non-woven interlayers were installed between the two pavement layers according to the manufacturer’s specifications.
1 Reference sample
   Without interlayer
2 Non-woven
   Polypropylene, 140 g/m²
3 PES grid
   Polyester 60 kN/m (longitudinal and transverse)
4 Pre-bituminised
   S&P Glasphalt G
   Glass grid 120/120 kN/m (longitudinal and transverse)
5 Pre-bituminised
   S&P Carbophalt G
   Glass fibre, 120 kN/m (longitudinal)
   Carbon fibre, 200 kN/m (transverse)

Table 9: Overview of samples

Test results:
The tests were used to compare the retarding effect of the asphalt reinforcement on crack propagation (Graphic 18). Penetration of cracks through the new pavement layer ultimately leads to irreversible deformation or breakage of the pavement sample. The results accordingly provide information on the fatigue resistance of pavement under cyclic loads.

Graphic 18: Overview of test results

The pavement samples reinforced with S&P Carbophalt G exhibited extremely high resistance to crack propagation under cyclic loads.
10. Investigations at BRRC (Belgian Road Research Centre) „Asphalt reinforcement against thermal crack reflection“

Existing cracks in the old pavement layer reflect through the new asphalt layer because of the daily temperature fluctuations during winter months. With the S&P grids, existing cracks are covered before the new pavement layer is applied (Image 9).

![Image 9: Application of S&P Carbophalt G](image)

Various asphalt grids were tested by the Belgian Road Research Centre. Graphic 19 shows the test set-up. A new asphalt pavement of 7 cm thickness was applied to an old cracked pavement layer (cracking is simulated by milling). Various asphalt reinforcements were applied between the old and new asphalt layers. Crack opening as a result of temperature fluctuations was simulated with a liquid which freezes and thaws again. The results (graphic 20) show that with correct interlayer shear bonding of the placed S&P grids (S&P Glasphalt / S&P Carbophalt) crack reflection can be prevented.

![Graphic 19: Test set-up, Road Research Centre](image)

![Graphic 20: Test results, Road Research Centre](image)

The test set-up was modelled using the Lusas finite element program. Modelling of the unreinforced model confirmed that the stresses in the asphalt layer rose to 46.8 N/mm². However, asphalt can only take up a maximum stress of 3.5 N/mm². The cracking is correspondingly reflected in the non-reinforced asphalt layer on the surface. Modelling of the reinforced model (graphic 21) revealed that a slight detachment occurred at the boundary of the crack. This enabled the forces to be directed into the reinforcement.
In the reinforced model the stresses in the top asphalt were less than 3.5 N/mm². Thus the crack reflection can be stopped. The modelling shows that the stress in the new asphalt layer can be reduced by 25 – 40% at a test temperature of -10°C, based on the C-fibre reinforcement.

Graphic 21: Resulting stresses in the top asphalt in a model with six vertical cracks (crack length 0.06 m) because of the expansion of the water enclosed in the crack (existing asphalt)

11. Summary

The pre-bituminised carbon-fibre reinforcement reduces expansion in all the tested temperature and load ranges and thus reduces stress in the asphalt layer by approx. 30%. Carbon fibre grids as well as glass-fibre grids are used to reduce cracks in the asphalt layer. Both reinforcement grids increase durability. The carbon fibre grid additionally improves the structure value.

Graphic 22: Impact of wheel load on pavement layer destruction
Graphic 22 shows that the damage to the asphalt pavement increases in proportion to the wheel loading. The carbon-fibre grid reduces the stress peaks caused by wheel loads acting on the bituminous pavement layer. The destruction of the layer is thus reduced significantly. This is demonstrated by higher durability, prolonged replacement cycles as well as reduced maintenance. Thanks to reduced traffic congestion there are additional economic benefits. Taking all aspects into account the cost advantages delivered by reinforced asphalt pavement layers are relevant.

12. Reference literature

- Different Test reports EMPA, Dübendorf, Switzerland
- Inquiry report by Netherlands Pavement Consultants bv, NPC Nr. 018463
- Test report by Centre de recherches routières Bruxelles Belgique, EP 61530
- Test report by Consultest, Ohringen Switzerland, 1119-02
- Test report by SACR, autumn 2003
- Modelling by Dr. Andrew Faeh, Ingenieurbureau Heierli AG, Zürich, Switzerland