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### **IMPROVED PERFORMANCE GROUTED MACADAMS - HIGH PERFORMANCE APPLICATIONS OF GROUTED MACADAM**

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# **Improved performance grouted macadams - High performance applications of grouted macadam**

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## **Summary**

From various studies, it has been found that a grouted macadam is a good pavement design in situations where severe static loads appear. The high stability and yet flexible properties of the grouted macadam are obtained by the use of bitumen in the stone skeleton. It is obvious that from the different examined parameters, the bituminous film around the aggregate has a strong influence on the mechanical properties of the grouted macadam. Also, the obtained experiences in field applications demonstrate that the quality of the porous asphalt (support coat) has highly defined the performance of the total combined system. In this paper, the further improvement of a grouted macadam will be presented by the use of a polymer modified bitumen. Furthermore, the various design parameters which are relevant to the grouted macadam are illustrated by a laboratory study and two field cases.

## **Key words**

Grouted macadam, polymer modified bitumen, cracking, rutting, static loads

## **1. Introduction**

A grouted macadam is a composite pavement that combines the properties of two types of construction materials in the same layer. An example of a similar top layer is a very open graded asphalt concrete mixture (porous asphalt) filled with a (resin) modified cementitious grout. This results in a semi flexible layer being formed, which can sustain heavy and long term weight load.

Grouted macadams are frequently and successfully applied on heavily loaded areas. However, a disadvantage of such a layer can be the appearance of (early) cracking, which could be caused by various mechanisms. According to laboratory studies and field applications, it has been found by several parties, that the quality of the porous asphalt (such as mechanical properties of the components, air voids and resistance against segregation of aggregates) strongly influences the properties of the total system; this in addition to a suitable cementitious grout, which must be applied professionally and under the right weather conditions.

With this knowledge and experience, research has been carried out in a cooperation between Ooms Nederland Holding, Multicell/Cobeton and STEBO-CON. This resulted in an improved and cost effective grouted macadam containing a polymer modified porous asphalt and a cementitious grout, which can be applied easily.

For which the following important improvements are:

- higher stability and resistance against indentation especially at higher temperatures,
- reduced risk of segregation in the porous asphalt,
- consistent uniform thickness of bituminous film around the aggregate,
- increased chemical resistance,
- improved fatigue properties,
- optimisation of stiffness behaviour (at both ends of the master curve spectrum),
- reduced sensitivity to cracking of the grouted macadam.

Especially suited to industrial pavements with heavy loads in areas with a soft soil underlayer, such as container terminals and airport aprons, a careful application of a polymer modified bitumen in a porous asphalt in combination with an easy to apply cementitious grout of high quality, increases the number of suitable applications of grouted macadam. The laboratory study and field experiences, presented in this paper, support these claims.

## **2. The influence of an asphalt mixture on composite behavior**

The mechanical properties of a grouted macadam are subject to the aggregate grading of the porous asphalt, the properties of the bitumen (including the amount) and the type of cementitious grout (strong, medium or weak).

The asphalt concrete for a grouted macadam consists of an adapted porous asphalt mixture containing about 25% air voids. When the air voids content is too low, there is a possibility that not all voids could be filled with grout and if the air voids content is too high the pavement will act as a concrete slab. Gradations which are often used in the Netherlands are ZOAB (Porous asphalt) 8/11, 8/16 and 11/16 (VBW asphalt, 2004), depending on the layer thickness. Examples of a suitable gradation are given in the appendix.

It has been found from research (Menninga, 2002), that the bitumen in the porous asphalt mixture strongly influences the properties of the combined system. When using a harder bitumen, the resistance against indentation will increase at higher temperatures. Furthermore, the stiffness of the grouted macadam will increase when using a stiffer bitumen. Due to this there are limits concerning the resistance against cracking.

In this research it has also been found, that a grout strength of more than 40 MPa will not give any additional contribution to the final strength of the combined system. A disadvantage of a high strength grout is the chance that the concrete properties will dominate, which will cause cracking due to shrinkage, temperature differences or setting differences. When the asphalt properties dominate in the grouted macadam, the obtained stresses are absorbed without any damage.

To improve the asphalt properties, a polymer modified bitumen can be used. In practice, some polymer modified asphalt mixtures appear to have a high toughness and a high stability (especially, the latest with high temperatures (De Bondt, 2004)). Due to the increased viscosity of a polymer modified bitumen, a more uniform and a thicker bitumen film (higher amount of bitumen) can be obtained around the aggregate. This will prevent the asphalt grout from draining off bitumen or segregation (CROW, 2004).

Depending on the polymer modification used in the bitumen, it is possible to increase its resistance against chemicals. This will result in a very suitable pavement for industrial areas.

### 3. Grouted macadam containing polymer modified bitumen

The bitumen film around the aggregate has a strong influence on the mechanical properties of the grouted macadam. Introduction of (high-quality) polymer modified bitumen (PMB) in the grouted macadam will give further improvements of the mechanical properties of the combined system.

#### Bitumen

The rheological properties of elastomer (SBS) modified bitumens in particular are significantly better than conventional bitumens at high temperatures. This can be explained with the complex modulus ( $G^*$ ). The complex modulus is a measurement for the total resistance against deformation of a bitumen during continuous exposure to shear stress pulses and is dependent on load frequency as well as temperature.

In the figure below,  $G^*$  is plotted against the temperature at a frequency of 0,4 Hz of Sealoflex<sup>®</sup> SFB 5-50 (JR) binder in comparison to conventional bitumens. It appears, that the complex modulus of the polymer modified bitumen will be higher at high temperatures than the conventional bitumens. At low temperatures it will be the opposite (Airey, 1999).

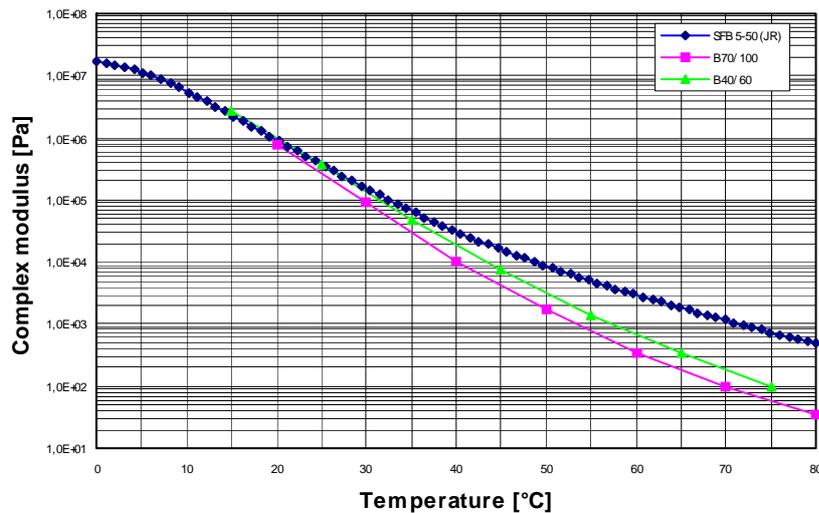


Figure 1. Complex modulus of bitumen against temperature (at a frequency of 0,4 Hz).

#### Laboratory study

For comparing a conventional grouted macadam with a polymer modified version, the following laboratory study has been performed:

- 3 Porous asphalt slabs (about 2 x 1,15 x 0,06 m) were made with asphalt plant mixed material and using roller equipment which was as representative as possible. The porous asphalt gradation was given by the grout supplier for a conventional grouted macadam with 4,3% B70/100 conventional bitumen, respectively 4,3% and 4,7% polymer modified bitumen (wt/wt% on top of total aggregate).

- After 1 day, the porous asphalt plates were filled with grout. The plate with conventional bitumen was filled with a strong grout and the plates with polymer modified bitumen were filled with an easy to handle medium strong grout (STEBO-FLEX<sup>®</sup>). Furthermore, moulds were filled with grout to determine the compression strength after 28 days.
- After two consecutive weeks of hardening outdoors, cores were drilled from the trial plates (Ø 100 and 150 mm).
- The following tests were performed on these cores after pretreatment and 28 days of total hardening:
  - Indentation compression strength 40x40 mm (Stebocon indentation test) at 20 and 40°C (actuator speed 0.085 mm/s).
  - Indirect tensile strength ITS (and toughness) at 0 and 20°C (actuator speed 0.85 mm/s).
  - 3-point bending test (and toughness) with semi-circular bending test (SCB) set up (Jacobs, 2000) at 0 and 20°C (actuator speed 0.085 mm/s).

## Results

The 28<sup>th</sup> days compression strength of the used strong grout was 104 MPa and of the medium strong grout was 42 MPa.

The realized air voids content of the porous asphalt plates was around 30%. After filling with grout, the degree of filling of the determined cores was visual more than 95%.



Figure 2: Detailed sections grouted macadam (1: B70/100; 2: 4.3% PMB; 3: 4.7% PMB).

Indentation tests were performed on the Ø 150 mm cores after 28 days at 20 and 40°C with the use of the hydraulic actuator system (see figure 3).

**Table 1: Indentation compression strength 40x40 mm after 28 days (n=6).**

| Temperature  | [°C]  | 20   | 40  |
|--------------|-------|------|-----|
| 4.3% B70/100 | [MPa] | 16.4 | 8.3 |
| PMB 4.3%     | [MPa] | 18.8 | 8.1 |
| PMB 4.7%     | [MPa] | 19.7 | 8.4 |

From the results, it is obvious that the indentation strength of the polymer modified alternatives is higher than the conventional composition at 20°C. This in spite of the fact that the strength of the used grout is much higher in the conventional composition than the grout in the polymer modified alternatives. At 40°C the indentation strength is much the same as all 3 alternatives.

With the use of the hydraulic actuator system indirect tensile strength and 3 point bending tests were also performed after 28 days at 0 and 20°C. Cores with a diameter of Ø 100 mm were used for the indirect tensile strength and beams of around 150\*40\*40 mm were cut from Ø 150 mm cores for the 3-point bending test (see figure 4).

**Table 2: Average ITS and 3-point bending test results at 0 en 20°C after 28 days (n=6).**

| Test                      |                        | 4.3% B70/100 |      | PMB 4.3% |      | PMB 4.7% |      |
|---------------------------|------------------------|--------------|------|----------|------|----------|------|
| Temperature               | [°C]                   | 0            | 20   | 0        | 20   | 0        | 20   |
| Indirect tensile strength | [MPa]                  | 2.5          | 1.7  | 2.6      | 1.4  | 2.6      | 1.4  |
| Toughness ITS             | [Nmm/mm <sup>2</sup> ] | 3.7          | 4.3  | 4.0      | 5.2  | 4.5      | 5.3  |
| Bending strength          | [MPa]                  | 5.7          | 3.0  | 6.0      | 2.9  | 5.5      | 3.0  |
| Toughness bending         | [Nmm/mm <sup>2</sup> ] | 0.41         | 0.62 | 0.52     | 0.69 | 0.55     | 0.74 |

The toughness of both polymer modified variations appears to be higher than the conventional composition at both temperatures, while the strengths were more or less similar. An explanation for this can be the favorable properties of the high-end polymer modified bitumen against cracking (increased toughness). At a higher bitumen content, the toughness will further increase.



Figure 3: Set up Stebocon indentation test.



Figure 4: Set up 3-point bending test.

#### 4. Grouted macadam in practice

On the basis of laboratory research, the improved grouted macadam is used in the following practical examples.

##### Location: Paleiskade Den Helder

At the location Paleiskade in Den Helder (transshipment of materials for the offshore industry), grouted macadam has been used, both standard grouted macadam, and one section with an improved version (as discussed earlier) of the grouted macadam. The project took place in a so called eco area location with high demands regarding (possible) crack width, the chemical resistance and the resistance against static loads.

##### Pavement construction

The pavement construction as designed by Ooms Nederland Holding is as follows:

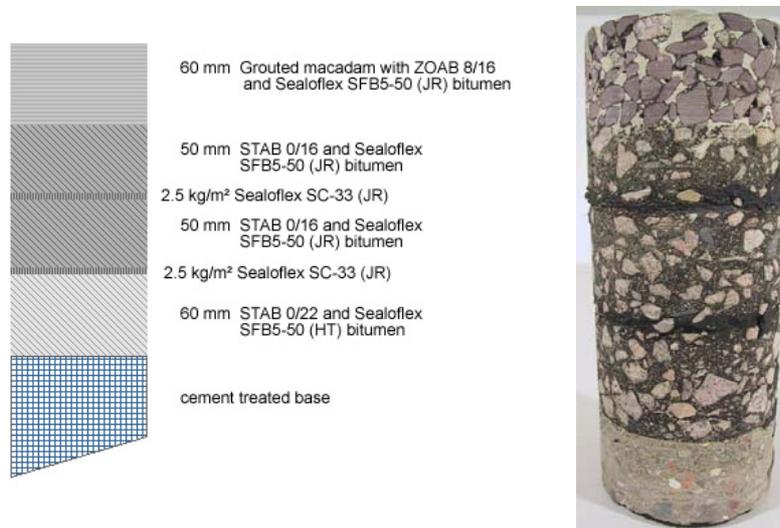


Figure 5. Pavement construction Paleiskade.

In this pavement construction, the liquid density is established by bituminous membranes (Sealoflex SC-33) between the (STAB) base courses (Air pressure tests have justified this).

##### Mechanical properties

After 85 days of hardening, cores were drilled from the grouted macadam (Ø 100 en Ø 150 mm). On these cores, tests were performed after 90 days to determine the indirect tensile and indentation strength at 20°C.

**Table 3: Results indirect tensile and indentation tests at 20°C after 90 days (n=5).**

| Test                                 | Eco area |
|--------------------------------------|----------|
| Indirect tensile strength [MPa]      | 1.6      |
| Toughness ITS [Nmm/mm <sup>2</sup> ] | 7.6      |
| Indentation [MPa]                    | 18.9     |

*Visual inspection after 2 years of usage*

A visual inspection of the eco area has been performed after 2 years of usage. During the inspection, there were no visible spots of cracking, rutting, impression or chemical affecting. There were only differences in color visible at the surface caused by rust or leaked chemical substances (see photo's below as illustration).



Figure 6. Overview location in Den Helder.



Figure 7. Detail of differences in color at the surface after 2 years of usage.

## Euromax Maasvlakte

For the construction of the container terminal Euromax in Rotterdam, a grouted macadam will be placed (period 2006-2008). The grouted macadam has been designed to prevent as much rutting as possible due to not-railed AGV's (Automatic Guided Vehicles).

Especially on this location, even 2 containers will be placed on an AGV. The application containing polymer modified bitumen in the grouted macadam will increase the resistance against rutting, cracking and the affect of chemical substances due to for instance oil leakage. In addition, the uniformity of the porous support layer is strongly improved by this (no draining off / demixing).

### *Pavement construction*

The pavement construction as designed by Ooms Nederland Holding / Unihorn will be as follows:

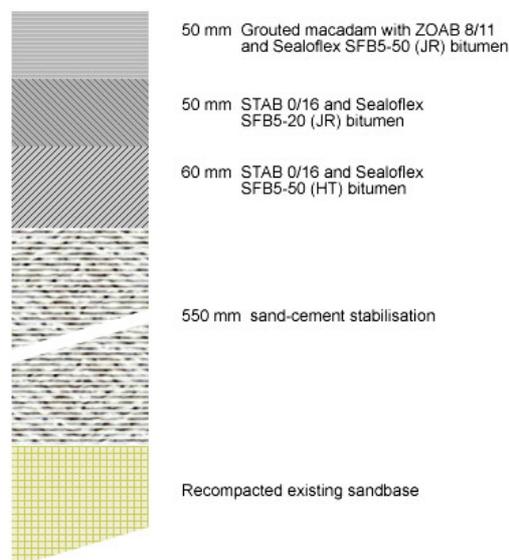


Figure 8. Pavement construction container terminal Euromax in Rotterdam.

Also the layers under the grouted macadam need special attention. At harbor projects constructed in the past, permanent deformation often appeared in the layer below the grouted macadam. This was caused by insufficient attention to the mechanical properties of the bitumen in the intermediate layer. For this project a specially developed polymer modified bitumen will therefore be used in the first layer below the grouted macadam. The Zero-shear viscosity (= measurement for the resistance against rutting due to the bitumen) of this binder is particularly important. (van Rooijen and de Bondt, 2005).

## 5. Conclusion

By means of direct research and the right choices regarding binder and grout, it is possible to realize an optimal, cost-effective grouted macadam for each possible application (approximately 15% cost reduction)<sup>1</sup>.

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<sup>1</sup> Ooms Nederland Holding has started in the mean time to market these products under the name of StabiFalt®.

## Appendix.

Examples of possible gradations of the porous support layer for a grouted macadam can be found in the table 4. Specifications of the polymer modified binder used are given in table 5.

**Table 4: Examples of possible gradations of the porous support layer.**

| Passing sieve [wt/wt %] | Porous asphalt 8/16 | Porous asphalt 8/11 |
|-------------------------|---------------------|---------------------|
| 16 mm                   | 92.4 - 100          |                     |
| 11.2 mm                 | 20.0 - 30.0         | 86.2 - 100          |
| 8 mm                    |                     | 11.1 - 23.0         |
| 2 mm                    | 6.0 - 16.0          | 4.0 - 6.0           |
| 63 $\mu$ m              | 3.0 - 5.0           | 3.0 - 5.0           |
|                         |                     |                     |
| Bitumen (on top)        | 4.3 - 4.7           | 4.3 - 4.7           |

**Table 5: Specifications Sealoflex SFB 5-50 (JR) bitumen.**

| Description   | Test method                  | Requirements                                      |
|---|------------------------------|---|
| <b>Basic properties</b>   |                              |   |
| Penetration at 25 °C  | EN 1426:1999                 | 50 - 80 [0.1 mm]                                  |
| Softening Point R&B   | EN 1427:1999                 | $\geq 70$ °C                                      |
| Fraaß breaking point  | EN 12593:1999                | $\leq -15$ °C                                     |
| Elastic recovery  | EN 13398:2003                | $\geq 85$ %                                       |
| Storage stability<br>R&B <sub>top</sub> - R&B <sub>bottom</sub>   | EN 13399:2003                | $\leq 2.0$ °C                                     |
| <b>SHRP-properties</b>  |                              |   |
| Performance Grade   | AASHTO MP1:1998              | Min PG 76-22                                      |
| <b>Rutting resistance</b>   |                              |   |
| Zero shear viscosity<br>- $\eta_0$ at 40 °C<br>- $\eta_0$ at 60 °C  | Creep test* <sup>1</sup>     | $\geq 17.5 * 10^6$ Pa·s<br>$\geq 2.5 * 10^6$ Pa·s |
| <b>Reflective and temperature cracking resistance</b>   |                              |   |
| Ductility at 5 °C<br>- Elongation at fracture<br>- Total energy till fracture   | EN13589:2003 / EN 13703:2003 | $\geq 30$ cm<br>$\geq 16.5$ J                     |
| *1: Based on draft 1.7 prepared by CEN / TC 336 WG1 TG1; test conditions: 1 mm gap; shear stress 30 Pa; loading time 8 hours. |                              |   |