Development of a durable third generation Porous Asphalt with a high noise reduction.

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ABSTRACT

The use of Porous Asphalt (PA) has many advantages over standard dense road surfaces. A disadvantage however is the lower durability of this type of pavement compared to traditional wearing courses.
Due to stricter requirements for noise reduction two-layer porous asphalt systems were introduced in 2007 in the Netherlands for motorways. Because of the total layer thickness of 70 mm in combination with a (limited) service life of 8-10 years, the two-layer Porous Asphalt system is not quite economically to apply within a DBFM contract (such as A-Lanes A15), because of the 20 years of maintenance.
Experiences in Germany with single layer porous asphalt (OPA), showed that a higher noise reduction than the standard Dutch Porous Asphalt is possible without loss of durability (with the same end of life criteria). An intensive research project started to validate and improve the German OPA mixture. Based on the results it has been found that the used polymer modified bitumen, stone aggregate selection and filler have a huge influence on the durability. Especially a filler containing the right proportions of limestone and hydrated lime improves the durability significantly. Furthermore, selection of a suitable polymer modified binder (PMB) has a strong effect on the durability.
The conducted research project resulted in an approval of the OPA concept by the national Dutch road authorities (Rijkswaterstaat) as replacement for a standard two layer Porous Asphalt. The expected service life of the OPA is 12 years (10 years standard service life and an additional 2 years due to material, production and handling optimization). In 2013, 2014, 2015 and 2016 the OPA is successfully applied (roughly 1.2 million square meters) on the intensively used Dutch motorway A15 between the junctions Maasvlakte and Vaanplein (near the harbour of Rotterdam).
The overall project has resulted in an optimized supply chain for the OPA, including the selection of raw materials, the OPA production, transport, compaction protocol and quality judgement criteria, to get an economically durable Porous Asphalt with a high noise reduction.

Keywords: Durability, Noise reduction, Polymers, Porous asphalt, Ravelling

1. INTRODUCTION

Porous Asphalt (PA) is nowadays widely used on the Dutch main motorways, in order to improve traffic safety and to reduce traffic noise. Compared to dense mixes, surface water can drain through Porous Asphalt due to the large amount of continuous pores in the structure. The material provides good visibility under rainy conditions, thereby preventing the reduction in traffic flow volumes, which normally occurs during rainy / splash & spray conditions. In addition, the absorption of surface water is effective in reducing aquaplaning which occurs when vehicles travel at high speeds on a thin layer of water. A disadvantage is however the limited service life (on average 10-11 years for standard Porous Asphalt on the slow lane) compared to a standard (SMA) asphalt concrete surface (10-15 years).

The standard Dutch single layer PA mixture has a minimum air voids content of 20% and an initial noise reduction of official 4 dB(A). To improve the noise reduction capability a two-layer Porous Asphalt (2L-ZOAB) has been used until now consisting of a coarse graded porous under-layer (25% air voids) and a fine graded porous top layer (20% air voids) with an initial noise reduction of 6 dB(A) [1]. Because of the total layer thickness of 70 mm in combination with a (limited) service life of 9 years [2] of the top-layer, the two-layer Porous Asphalt system is not quite economically to apply for a DBFM-consortium on a project with huge time constraints.

According to the tender requirements of the rehabilitation and widening of the Dutch motorway A15 near Rotterdam, this section had to be partly paved with 2L-ZOAB. This created the possibility (and need) to develop an alternative economical solution for 2L-ZOAB. The alternative consisting of a single layer Porous Asphalt should have a high initial noise reduction in combination with a long service life.

Based on experiences in Germany with a single layer Porous Asphalt (OPA) in combination with a higher noise reduction than the standard Dutch Porous Asphalt, an intensive research project started to validate and improve the German OPA mixture to optimize this concept for the practice and requirements in the Netherlands. In this paper an overview will be given regarding the different steps of the conducted research project:

- Porous Asphalt experiences in Germany.
- OPA8 as an alternative for the Dutch motorway A15 MaVa.
- Validation OPA8.
- Field trial sections.
- Required road construction and working procedures.

2. POROUS ASPHALT IN GERMANY

Systematic construction and testing began in Germany in 1986. Until today, 5 generations of Porous Asphalt (OPA) were developed with increased air void content and acoustic effectiveness [3]. Porous Asphalt is not widely used in Germany and only used in stretches where there are traffic noise problems (near cities).

The latest specification of OPA used in Germany differs from the (outdated) Dutch version; the main characteristics are summarized below [4]:

- Higher voids content 24 to 28 %.
- 45-50 mm thick single layer; 8 mm maximum aggregate size.
- Alternative 50-60 mm thick single layer; 11 mm maximum aggregate size.
- Application of minimal 6.5 m/m% (inside the mixture) polymer modified binder (PMB).
- Waterproof underlayer consisting of a SAMI (Stress Absorbing Membrane Interlayer) or mastic asphalt.
- Maximum initial noise reduction after construction 6 to 8 dB(A) compared to the Dutch reference dense surface (= 7-9 dB(A) noise reduction compared to the German reference dense surface). Decay (loss) in time 0.25 dB(A) per year [5].

Field experience on the motorways in Lower Saxony (Germany) shows that 88% of the OPA stretches were renewed after a service life of 10 years or more (including 15% stretches which were even renewed after 14 years and later). According to the determined lifetime distribution an average service life is calculated of 10.4 years for the truck lane with the (end of life) criterion minimal noise reduction. Furthermore, the results in Lower Saxony show that a single layer OPA8 gave a noise reduction similar to a (German) 2 layer Porous Asphalt with a thickness of 70 mm (ZWOPA); both achieving a noise reduction of approximately 6 dB(A) compared to the German reference surface after 9 years [6], [7].

To get a high quality Porous Asphalt surface the stone aggregate has to meet the tight specifications as described in the German specifications ZTV/TL Asphalt – STB 07 [4] and FGSV publication 750 [8]. Furthermore, the conditions during paving have to be optimal:

- Mastic asphalt or high quality binder course with bituminous membrane (SAMI) below the OPA.
- Continuous paving using a feeder and preferably with a constant speed.
- Paving over the whole width of the road without a joint.
- Degree of compaction minimum 97%.
- Limited roller passes to avoid crushing of aggregate.
- Because of rapid cooling of OPA during rolling, the use of extra rollers is recommended to avoid compaction at low temperatures.

As described in FGSV publication 750 [8], the noise reduction of Porous Asphalt depends on the layer thickness, the void content and the flow resistance. In figure 1 the influences on the noise absorption are visually displayed.

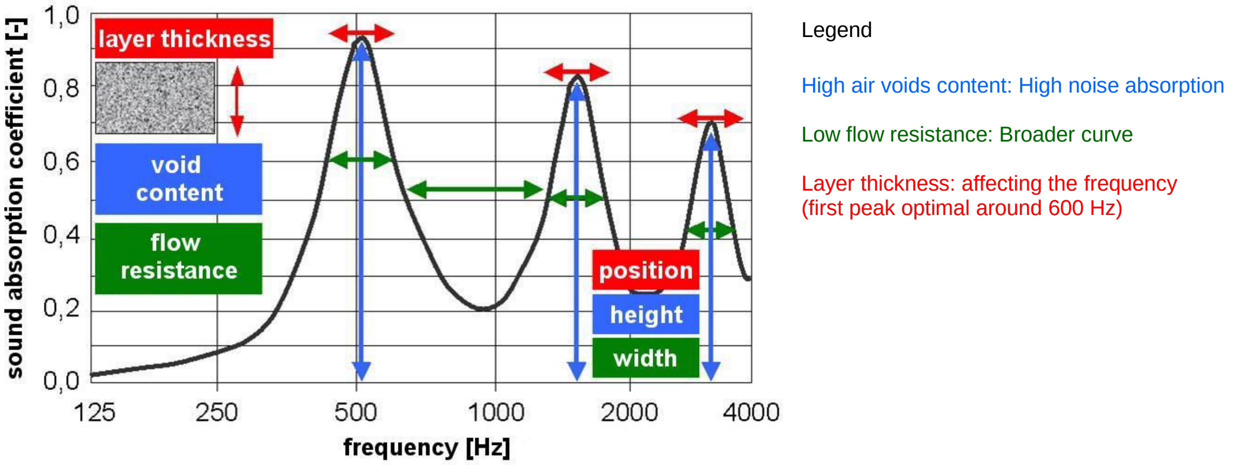

Figure 1: Influences on noise absorption [6].

As displayed in figure 1, variations in the composition of the Porous Asphalt will affect the noise reduction properties. Choosing the wrong (combination of) materials will result in an asphalt layer with limited noise reduction and/or poor durability.

3. POROUS ASPHALT FOR THE DUTCH A15 MAVA

The Dutch motorway A15 is an intensively used main transport axis connecting the port of Rotterdam to the hinterland (including Germany). Due to the increasing traffic and expansion of the harbour the (approximately 40 km) section between the junctions Maasvlakte and Vaanplein (MaVa) needed widening and upgrading. Because of noise limitations this section had partly to be paved with a two-layer Porous Asphalt (2L-ZOAB). Such a Porous Asphalt normally consists of a coarse 45 mm porous under-layer and a fine 25 mm porous top-layer.

The tender combination A-lanes A15 was commissioned by the Dutch road authorities (Rijkswaterstaat) to construct this section and it was realized according to the terms of a DBFM (Design, Build, Finance and Maintain) contract. This means that A-Lanes A15 not only bears responsibility for the entire design and realisation of the A15 project, but also for the financing, management and maintenance of all existing and new infrastructure over a period of 20 years (starting 31 December 2015), after all construction works have been finished.

This long maintenance period implies that with the average service life of two-layer Porous Asphalt (8-10 years) the top layer has to be replaced twice during the contract period. To minimize maintenance costs and road closures (including financial penalties) an alternative was proposed for the two layer Porous Asphalt based on the German OPA8. Rijkswaterstaat accepted this approach with the condition that the (acoustic) properties will be at least equal to the Dutch standard two-layer Porous Asphalt. Another benefit of the single layer OPA8 is that applying a single layer is more cost effective and faster to place.

An intensive research project started on the following topics in 2011 to validate and improve the German OPA8 for the A15 project. In the next sections the conducted steps are (briefly) described.

4. VALIDATION OPA8

OPA8 is a Porous Asphalt as defined in the European standard EN 13108-7 with a design air voids content of 25%. This high air voids content is obtained by using a gap graded stone skeleton with a maximal size of 8 mm, whereby the aggregate stones are bound together by mastic (bitumen, filler and sand). All of these ingredients are important in order to obtain a high durability of the Porous Asphalt.

4.1 Selection of aggregate

The properties of the stone aggregate were determined via 3 main characteristics. Namely, the texture of the surface of the crushed stones, the grain shape of the crushed stones and the petrography (mineral origin) of the stones.

The surface texture can influence driver comfort as the vehicle tyres make contact with the aggregate surface. The micro-texture of the crushed stone is therefore of great influence on the skid resistance, particularly in rainy weather. Furthermore, the aggregate surface is required to have good resistance against polishing. An important factor for this is the polishing stone value (PSV).

A second property is the particle shape of the crushed stones. Because the void content of the Porous Asphalt has to be at least 24% (V/V) after application, the amount of flat stone chips has to be minimized. This property is determined by means of the flakiness index (FI) for aggregates ≤ 8 mm.

Furthermore, the petrography of the material is of importance. Depending on the source of the aggregate the mineralogical composition will differ, which could have an influence on the durability of an asphalt mixture. To get a uniform homogeneous quality with respect to the adhesion between aggregate and bitumen (amongst others the risk of stripping), the right type of aggregate has to be selected.

For the A15 MaVa three types of Grauwacke quarry material were selected and tested for its properties according to the Dutch RAW standard 2010 [6] for the Dutch so called class 3 stone aggregate. The properties are summarized in table 1. Furthermore, the on-road friction was simulated with the use of the German Wehner-Schulze test (PWS) [10]. The results are displayed in table 1 and figure 2.

Table 1: Obtained properties different types of Grauwacke aggregate according to EN 13043.

Aggregate type	PSV	FI	PWS
Irish Grauwacke Leahill	59-62	15-25%	0.398
Bestone Bremanger	60-62	15-25%	0.452
KKW-split Rieder/Harz	56-58	15-25%	0.378
Final specification	≥ 58	≤ 15%	> 0.38

The results show a huge variation in flakiness between different batches of the same type of material. Special attention had to be paid and arrangements with the quarry were made to minimize the variation in this property by strict monitoring of the different deliveries to reach the final FI specification of ≤ 15%.

As shown in figure 2, the friction results for the Wehner-Schulze (PWS) tests are on average the highest for Bestone. KKW-split has the highest initial value. However, the resistance against polishing is less, resulting in the lowest friction value.

The Wehner-Schulze (PWS) test method, developed in Germany in the 1960s and commonly used there, is a test protocol for both cylindrical cores (Ø 225 mm) from road sections or lab samples and gives an indication of the long term skid resistance of a road surface. The test consists of 5 steps, where after each step the friction is measured, see figure 2 for a summary of the friction after each step. The PWS-value is obtained after step 5 (PWS-4). For this study lab samples of OPA8 were prepared.

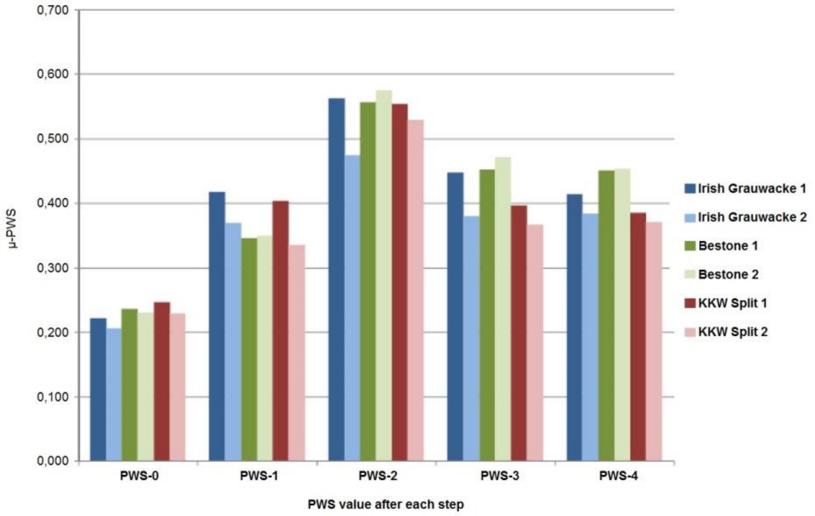

Figure 2: Results Wehner-Schulze tests for the 3 types of mineral aggregate.

Based on the test results both the Irish Grauwacke and the Bestone were selected as mineral aggregate for the OPA8 with a gradation of 5-8 mm.

4.2 Durability Porous Asphalt

Stone loss (or ravelling) is the characteristic failure mode in Porous Asphalt in the Netherlands. This can be either due to cohesive failure (break within the mastic) or adhesive failure (break at the stone-mastic interface). Once the Porous Asphalt starts to degrade, moisture and frost in combination with traffic loading may lead to more severe damage, like pothole forming.

Quite a lot of research has been performed to understand the phenomenon ravelling of asphalt mixtures [11, 12]. Furthermore, a meso-mechanistic Lifetime Optimisation Tool (LOT) was developed [13, 14]. Based on calculations with this LOT model, it was concluded that adhesive failure commonly occurs at low temperatures (mostly, moisture induced damage) and cohesive failure at intermediate temperatures. The latter mechanism is caused by failure due to slow demixing (segregation) of the mastic (the mastic content will decrease inside the top of the mixture caused by temperature fluctuations) and ageing of the binder.

The mastic in a Porous Asphalt consists of a binder (the bitumen), filler and the fine aggregate fraction (< 2 mm). To get a Porous Asphalt with a long service life all these components have to perform well and have to have a good interaction with each other. Through DSR frequency sweeps at different temperatures and DSR fatigue tests (Superpave test set-up), a first selection can be made of suitable binders and combinations of mastics (after severe ageing). In figure 3 the ageing process of different bitumen is displayed graphically (after RTFOT ageing and 4 times PAV ageing; simulating more than 5 years of field ageing). Clearly visible is that the ageing characteristics differ between different binder sources (more stiffening at low frequencies).

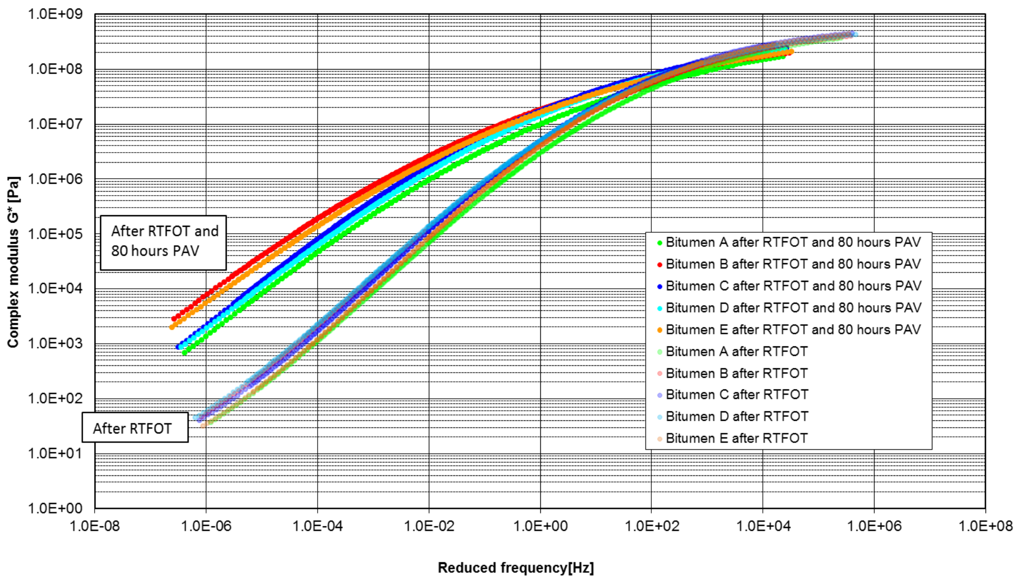

Figure 3: Results DSR master curves for different binders T_{ref} = 20 °C.

As can be seen in figure 3 ageing of the binder is a primary reason for weakening the structure of Porous Asphalt (the binders stiffen due to ageing; binder B and E are more sensitive for ageing). After this frost-thaw traffic loading will initiate and result in ravelling. To improve the mastic a polymer modified binder (PMB) was selected (produced from bitumen source C and D), which exceeds the German specifications as shown in table 2 [15].

Table 2: German specification polymer modified binder [4] and selected PMB.

Properties		PMB 40/100-65 A	SFB 5-50 (PA)
Penetration	[0.1 mm]	40-100	60-90
Softening point	[°C]	≥ 65	≥ 65
Fraaβ breaking point	[°C]	≤ -15	≤ -15
Elastic recovery 25 °C	[%]	≥ 70	≥ 85

As mentioned before, the binder is only one part of the mastic. Despite the behaviour of the binder in the mastic, which is an important factor for the ravelling phenomenon, the type of filler used has also an important influence (in combination with each other). To test the effect of the mastic with the LOT-model, different types of mastics were prepared with different kind of (limestone) filler with and without hydrated lime (as displayed in table 3). The mastics were intensively aged using the RCAT-ageing procedure, which corresponds to 7-9 years ageing in the field [16]). The obtained samples were then tested according to the LOT-model test procedure [17,18] using DSR frequency sweeps and DSR fatigue tests. Furthermore, the stone-mastic interaction was tested using the same DSR fatigue tests [17,18]. The geometry of the cylindrical mastic specimen was developed in the LOT-project [13]. The total height of the specimen is 20 mm. At both ends the cylindrical specimen is enclosed by a 4 mm steel ring to clamp it into the DSR. Over the middle 10 mm the specimen has a diameter of 6 mm.

Table 3: Tested mastics combinations.

Mastic	Description
S2	6.5% PMB S + 6,5% Filler (28% hydrated lime)
S8	6.5% PMB S + 6,5% Filler (0% hydrated lime)
S9	6.5% PMB S + 6,5% Filler (14% hydrated lime)
S10	6.5% PMB S + 5,5% Filler (0% hydrated lime)
Q8	6.5% PMB Q + 6,5% Filler (14% hydrated lime)

With PMB S the selected binder and PMB Q an alternative binder.
For all combinations also a fine sand fraction (< 500 µm) and a drainage inhibitor were added.

Performance comparison of the tested mastics with mixtures used in the field showed that all the tested mastics were expected to perform very well for the criterion winter damage as can be seen in figure 4.

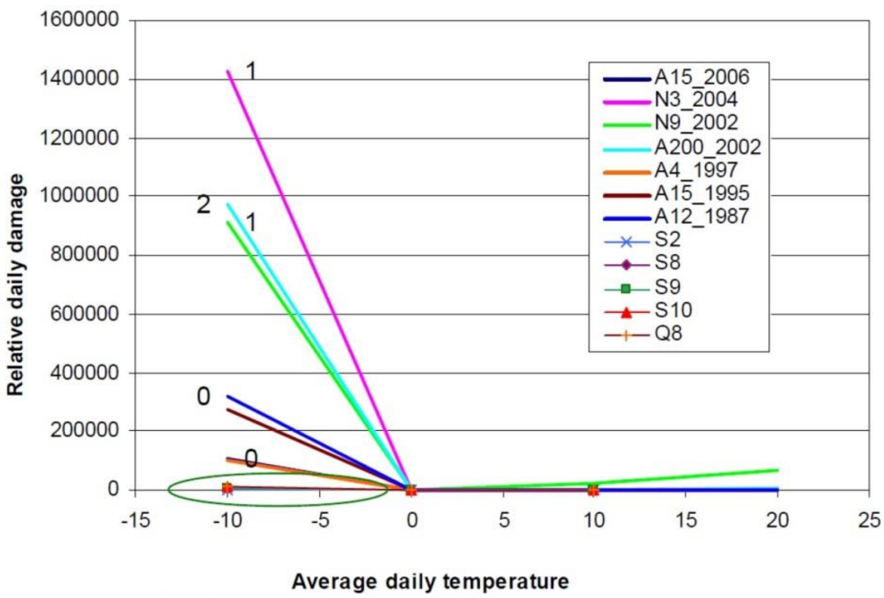

Figure 4: LOT calculations mastics (S and Q) compared with field data [14].

More in detail the relative sequence of performance for the tested mastics is given in table 4.

Table 4: Relative performance mastics according to LOT calculations.

Mastic	Adhesive failure -10 °C	Cohesive failure +10 °C	Overall relative performance
S2	1 (best)	4	2
S8	3	2	3
S9	2	3	1 (best)
S10	4	5 (worst)	4
Q8	5 (worst)	1 (best)	5 (worst)

With PMB S the selected binder and PMB Q an alternative binder.

As can be seen in table 4 the performance is almost opposite for both failure mechanisms. Because ravelling is mostly a low temperature phenomenon, the adhesive performance of the mastic need to be given more emphasis. Based on field experience (see figure 4) mastic S9 will then give the best overall performance. Remarkably, mastic Q8 is the same composition as mastic S9 except for the PMB. This mastic showed a very stiff response behaviour and was highly susceptibility to temperature fluctuations. So both the right binder as well as the right filler have to be selected carefully.

Based on this result, mastic S9 was selected for the OPA8 for the A15 MaVa. Furthermore, the amount of “own” filler from dusty aggregates has to be limited to a maximum of 1.0 %(m/m) of the total OPA8 mixture.

4.3 OPA8 mixture design

With the use of the selected base materials a mixture design was produced based on the German specifications [4]. With the obtained mix composition for the OPA8, laboratory tests were done to determine the optimum height (layer thickness) and gradation for optimal noise reduction in comparison with the standard two-layer Porous Asphalt (70 mm; 2L-ZOAB). For this, asphalt slabs were prepared with the use of a segmented roller compactor with as variable the thickness (height) of the asphalt, the gradation and the way of compaction.

For each slab the input parameters (surface texture; acoustic impedance; flow resistance and mechanical impedance) were determined for the SPERoN-AOT model [19]. Based on the results it has been found that the main influence on the noise reduction was the thickness of the asphalt layer. As can be seen in figure 5, a thicker layer will give a noise absorption peak at a lower frequency than a thinner layer. In comparison with the reference data of 2L-ZOAB (a reference section) and the compacted slabs, it can be concluded that the optimal thickness of OPA8 is between 50 and 60 mm (too thick is also not good).

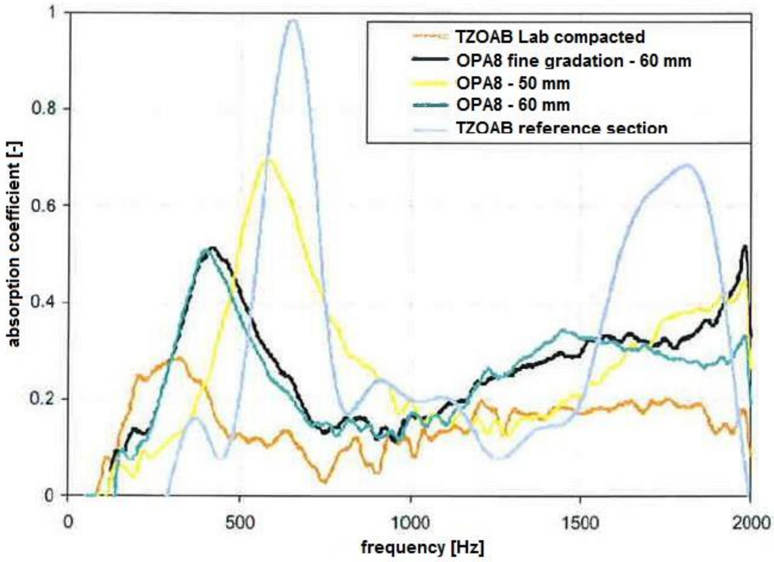

Figure 5: Noise absorption curves from slabs in comparison with 2L-ZOAB reference data.

As can be seen in figure 5, the results of the lab compacted 2L-ZOAB are different from of those of the 2L-ZOAB reference section. The reason for this difference could be a difference in air void content and air voids distribution of both 2L-ZOAB samples. After further analyses of the samples, it was found that the lab compacted 2L-ZOAB was severely overcompacted (too low air voids content). This is indicating that the way and the degree of compaction is an important factor for the noise reduction properties.

4.4 Optimum initial skid resistance

The initial skid resistance of Porous Asphalt is always critical just after paving, because of the mastic film on top of the surface. After wearing off due to traffic, the skid resistance will increase. To improve the initial skid resistance, the Porous Asphalt is sanded with crushed aggregate size 1/3 mm.

Research was performed with the SR-ITD® (Skid Resistance & Smart Ravelling – Interface Testing Device [20] to find the optimal amount of aggregate for OPA8. For this, samples for the SR-ITD (Ø 390 mm and a height of 60 mm) with OPA8 and 2L-ZOAB were prepared with different amounts and types of sanding (Basalt and Asilgrip). The friction coefficient was measured at a rotating speed of 85 km/hr with a locked wheel (0.3 MPa load) and without water (test duration 8 seconds). The results are summarized in table 5.

Table 5: Results skid resistance SR-ITD.

Combination	Amount of sanding [g/m^2]	Friction coefficient [-]
OPA8 - Basalt 1/3	300	0.34
	400	0.57
	500	0.71
	600	0.63
2L-ZOAB - Basalt 1/3	400	0.41
OPA8 - Asilgrip 1/3	300	0.74
	400	0.54
	500	0.56
	600	0.67
2L-ZOAB - Asilgrip 1/3	400	0.62

The results show that on average an amount of 500 gr/m^2 of sanding before the first roller passage is needed for the OPA8 to be equal with the reference 2L-ZOAB. Based on the results, it was decided to use 500 g/m^2 of sanding for the trial sections. Repeated tests in July 2015 confirmed the optimum amount of 500 g/m^2 of sanding (a higher amount will not result in a better initial skid resistance).

5. FIELD TRIAL SECTIONS

Using the optimized laboratory mixture design several trial sections (6 in total) were constructed with 2 types of aggregate and the optimal PMB/filler combination. The layer thickness was between 50 and 60 mm. For the construction of the OPA8 trial sections the experiences from and tools developed within the ASPARi (ASphalt PAving Research & innovation) project [21] were used. In this project the variables during the paving process were systematically evaluated, such as asphalt temperatures, use of equipment, compaction progress and effectiveness of rolling techniques.

Because of the very open structure, the OPA8 is very (too?) easy to compact. To avoid over-compaction (causing early ravelling and potholes) the number of roller passes has to be limited to 5. As displayed in figure 6, after 5 roller passes the air void content will be below the minimum of 24%.

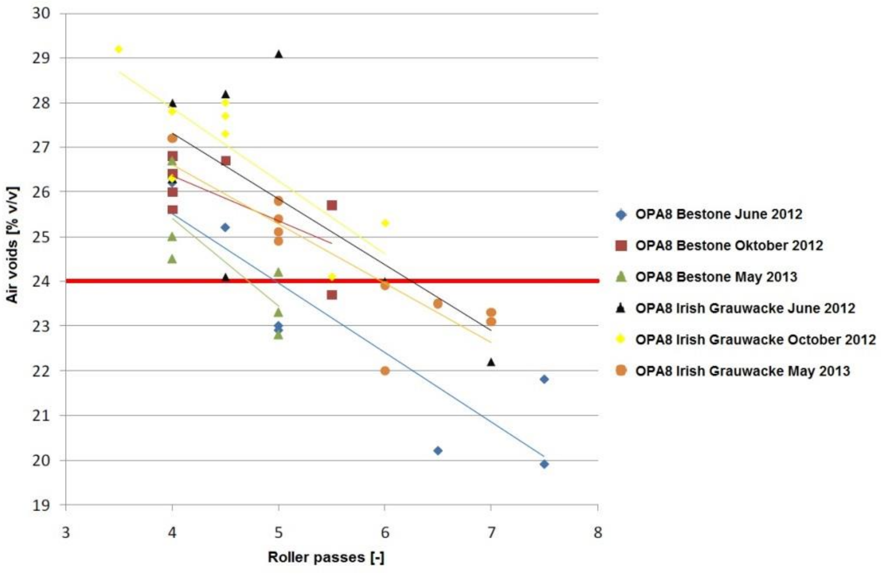

Figure 6: Air voids OPA8 trial sections against roller passes.

5.1 Road surface properties OPA8

The acoustic properties (both statistical pass-by (SPB) and close proximity (CPX) method) were obtained on the trial sections and compared with the standard reference 2L-ZOAB [21]. The CPX-measurements were used to test the homogeneity of the sections. The results of the SPB- measurements are given in table 6.

Table 6: SPB-measurements at a height of 3 and 5 meter.

Section	OPA8 Bestone			OPA8 Irish Grauwacke			TZOAB		
SPBI [dB(A)]	3 meter	5 meter	avg.	3 meter	5 meter	avg.	3 meter	5 meter	avg.
June 2012	-	-	**-**	78.7	77.4	**78.1**	-	-	-
September 2012	79.6	78.4	**79.0**	79.7	78.5	**79.1**	-	-	-
May 2013	78.1	77.4	**77.7**	78.4	77.6	**78.0**	78.3	77.1	**77.7**

As shown in table 6, the sections of May 2013 meet the result of the standard reference 2L-ZOAB. Based on these results, all the practical handling and process conditions of the trial section of May 2013 were used for the OPA8 on the A15 MaVa (target air void content 24% and layer thickness 57 mm).

Furthermore, the tire/road interaction properties (skid resistance and brake deceleration) were measured, according to the Dutch regulations [9]. The results are displayed in table 7.

Table 7: Results tire/road interaction properties.

Combination OPA8	Skid resistance [-]	Brake deceleration [m/s^2]
Dutch specifications	≥ 0.45	$\geq 5.2^*$
Bestone	0.50 - 0.67	5.7
Irish Grauwacke	0.53 - 0.61	5.2

$^{*)}$ Rijkswaterstaat specification

In practice the OPA8 appears to have a deeper and longer dip in the skid resistance in the period just after construction than standard 2L-ZOAB, due to the improved stickiness of the polymer modified binder and the lack of crushed sand in the mastic. To limit this phenomenon the sanding protocol after paving has been optimized for use on the OPA8.

6. REQUIRED ROAD CONSTRUCTION AND WORKING PROCEDURES.

Based on the trial sections and the practical German experiences with OPA8, a dedicated working protocol was established to ensure the achieved quality of the OPA8. This covered amongst others the following aspects:

- Uniform quality of OPA8 asphalt mixture during production. Including the intensive check on all ingredients (stone, filler and bitumen).
- No longitudinal (cold) joints.
- Uniform paving using preferably a feeder and with a constant speed.
- Strict protocol for use of rollers and number of roller passes.
- Sanding the OPA8 for optimal initial skid resistance without damaging the asphalt. For this a special device has been developed (see figure 7, for an example of the 2 devices which were used for the A15-MaVa).

Figure 7: Developed sanding equipment for the OPA8.

In 2013, 2014, 2015 and 2016 roughly 1.2 million square meters of OPA8 was successfully applied according to this procedure.

7. CONCLUSION

The conducted research project has resulted in an approved mixture design of OPA8, which is adjusted for the Dutch paving practice compared to the German version for (mainly) three reasons. First, the required layer thickness was adjusted for optimal noise reduction (equal to 2L-ZOAB) given the heavy traffic conditions on the A15. Also, the initial skid resistance has been ensured by sanding the surface after paving without damaging the OPA8. Furthermore, the mastic has been optimized in terms of performance (lifetime).

The expected service life of the OPA8 (for the A15-project) is 12 years (10 years standard service life and an additional 2 years due to material, production and handling optimization). This means that during the contract period the OPA8 has to be replaced only once.

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