How do we improve the durability of porous asphalt?

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ABSTRACT

How do we improve the durability of porous asphalt?
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Porous asphalt (PA) laid in one or two layers has a long tradition in Sweden. The aim initially was to improve road safety and traffic flow during rain. Over time, the focus has shifted to noise reduction and today PA is used primarily as a measure to limit noise pollution.
Early on it was noted that PA had a shorter lifetime than dense asphalt because of inferior durability. In order to improve the durability of PA laid in two layers a research project started in 2010. Three major test roads were laid in different regions of Sweden. Noise reduction was 7-8 dB(A) when new and reduced by 0.5-1 dB(A) per year. The wear resistance of these PA has been acceptable with minimal raveling and other damage.
A few results and features of the test roads:
- *Drainage is improved by increased cross slope and improved drainage at the roadsides.*
- *A new binder – highly modified bitumen with good adhesion and elasticity.*
- *Mix design: high binder content (≥ 6.3 %), high void content (≥ 23 % by volume), high stone content (85 %) and suitable additives.*
- *Aggregates with good adhesion to bitumen and with good resistance to studded tyres were used.*
- *If raveling tendencies are observed, the road may be sealed with a low content of Fog Seal emulsion.*

Keywords: Durability, Noise reduction, Permeability, Porous asphalt

1. INTRODUCTION

This paper describes the construction and performance of two test roads with noise-reducing asphalt on busy highways. In the summer of 2010, a pavement with two layers of open asphalt of the type Porous Asphalt (PA) according to EN 13108-7 was laid over a length of 2.7 km of motorway E4 through Huskvarna in southern Sweden. Based on the very favourable results from Huskvarna, a new test section was constructed in 2014 on motorway E4 in Rotebro, north of Stockholm.

Porous asphalt laid in one or two layers has a long tradition in Sweden. The first pavement of this type was laid in the middle of 1970's. The aim in the early years was to improve road safety and traffic flow on the road during rain. Over time, the focus shifted to noise reduction and today PA is used primarily as a measure to limit noise pollution [1]. Early on, it was noted that the PA had a shorter lifetime than dense asphalt because of inferior durability. In some cases, the technical lifetime became significantly lower, with a durability of 2-3 years. Note that in Sweden, in wintertime, studs are used in most of the tyres, which results in road wear and pavement lifetimes that are substantially shorter than in countries not allowing studs. Nevertheless, even in Sweden, a lifetime of 2-3 years on roads with moderate traffic volumes is not acceptable.

The main causes of deterioration of durability in the PA pavements were [1]:

- Oxidation of the binder
- Standing water in the construction
- Unsuitable binder
- Low binder content
- Unsuitable aggregate
- Low void content

Some interesting results obtained from the study were that the bitumen had lost much of its elasticity when penetration index was approaching 10-20 and that the risk of damage increased with a high degree of saturation and low void content, which are typical features of porous asphalt, as illustrated in Figure 1 [2]. For a dense asphalt, penetration index would start at approximately the same level, but would be reduced much slower with age. As a result of this early work, a review and development of more relevant testing methods of open asphalt mixes were initiated.

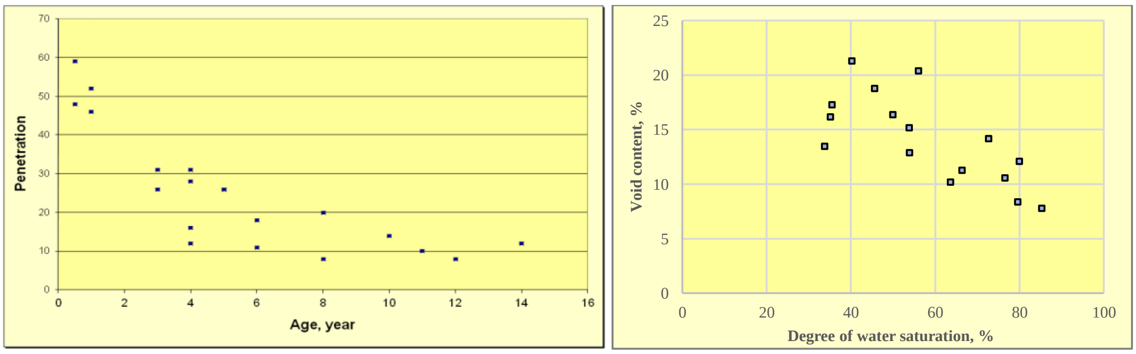

***Figure 1:** (Left) Aging of bitumen in Porous Asphalt. At a penetration of 10-20 the bitumen is considered to lose much of its elasticity. (Right) The influence on void content on the degree of saturation (based on cores). The risk of damage increases with high water saturation and low voids.*

In the early 2000s, the first porous asphalt in two layers was tested in Sweden. It was found to give a greater reduction of noise compared to one layer [3]. Therefore, porous asphalt in two layers became much in demand due to the large noise reduction of 7-9 dB(A). At this time, this was considered as one of the solutions to the noise problems on highly trafficked roads through urban areas. Quite soon, it turned out that even porous asphalt laid in two layers had too short technical and acoustic lifetime. In just a few years, noise reduction was reduced by 4-6 dB(A) while the pavement was damaged; for example through clogging, stone loss and potholes.

Porous asphalt has a uniform material composition with a high proportion of coarse aggregate and a low proportion of fine aggregate/filler. In this way, the high void content with channeled pores can reduce the generation of tyre/road noise, absorb some of the noise and lead away water. The problem with porous pavements is that they age faster than dense pavements and that the water can become trapped. The consequence is that the risk of stone loss/potholes increases, with the result that the favorable noise characteristics deteriorate. In a relatively short time, raveling and potholes will require action. See the example in Figure 2, which is from an early trial section [1].

In order to improve the durability of porous asphalt laid in two layers, a research project started in 2010, in which participants from suppliers, contractors, a research institute (VTI) and a traffic authority took part. Some earlier and/or other documents reporting about this are listed in references [8][4]**Error! Reference source not found.Error! Reference source not found.Error! Reference source not found.**.

Figure 2: ***Severe raveling of double-layer PA after only one year of traffic.***

2. OBJECTIVES

The project described in this paper aims to increase the proportion of noise-reducing pavements on the road network by means of longer durability and with better preservation of noise reduction. The project also aims at developing relevant requirements in the procurement and work on relevant test methods.

In order to achieve this, improved concepts and materials with regard to acoustic and technical lifetime are tried and evaluated. For porous pavements to function under Swedish conditions, they need special adhesives used in high binder and high void contents, as well as aggregate with good adhesion and extreme resistance to studded tyres. Furthermore, both layers must have a pore system that is not becoming clogged too soon, in order to retain the initial good drainage and sound absorption as long as possible. Clogging rate is reduced by using a high cross-slope, extra wear-resistant aggregate, and high void content in both layers.

3. MEASUREMENTS

The characteristics that have been studied in the two double-layer PA test roads are:

- Tyre/road noise emissions on the road, using the CPX method
- Traffic noise emission at building facades
- Defects such as raveling, stripping and potholes
- Development of ruts
- Unevenness (international roughness index - IRI)
- Water permeability
- Macro- and megatexture
- Friction under wet conditions
- Effect of cleaning
- Effect of sealing
- Analysis of the pores in bore cores by Computer Tomography

Drainability

The drainage ability of the pavements have been tested according to EN 12697-40 (Figure 3). The method is a field test of the drainage ability of asphalt pavements that are designed to have permeable properties. The outflow time for water is an indication of the pore capacity to drain water away from the pavement. The method can be used to check if the surface meets the demands on drainage and any deterioration of drainage capacity with time, for example clogging by road debris. No requirements on permeability are related to this method for PA.

Figure 3: Measurement of the draining effect of a porous pavement according to EN 12697-40

Visual assessment of raveling

Estimation of durability has been carried out through a systematic, quantitative estimation of raveling by means of the so-called “French window”, which is stipulated in EN 12272-2 for calculation of raveling for surface dressings. Reasons for raveling can be many, such as mechanical damage from vehicles, lack of adhesion or poor quality of the aggregate. Often it is a combination of these reasons.

Tyre/road noise measurements

Noise measurements have been performed annually, and sometimes more than one time per year, according to the CPX method (ISO/DIS 11819-2). The measured values have been processed and presented as the difference between PA and a reference pavement, corresponding to a "middle-aged" SMA16. In reality, the reference values are averages from measurements performed annually on 3-4 different SMA16 pavements of age varying between 3 and 7 years. The measurements use two “reference tyres”; one that is considered representative of passenger car tyres and one representative of truck tyres (ISO/TS 11819-3). Measurements were carried out at 70 and 90 km/h, but since no significant effects of speed on the noise differences and changes have been detected, only the average noise levels are presented in this paper.

Traffic noise measurements at the façade of nearby buildings
Traffic noise measurements at the facade of houses close to the roads have been carried out at both test roads irregularly.

Geometrical road surface measurements
Measurements with laser-based profilometer systems have been performed annually on these roads and will be followed-up for all relevant parameters such as IRI, rut depth, macrotexture, megatexture, etc.

Wet friction
These measurements are based on the Swedish Transport Administration method "Determination of friction on paved road" that refers to wet adhesion. For the measurements, a "SAAB Friction Tester" from VTI has been used. The method is based on the “skiddometer” principle, which means that the measuring wheel is braked and rotated at about 17 % slip, which at normal speeds provides maximum friction. Friction measurements were performed only on the test road in Rotebro, at three months and one year after construction.

4. TEST ROADS AND RESULTS

4.1. Some common issues
The test sections on E4 in Huskvarna were constructed in 2010 in two lanes in each direction, and the test section on E4 in Rotebro were constructed in 2014 and has three lanes in each direction. A description of the implementation and follow-up of the two test roads follows.

In both test roads a binder from Nynas labeled “Endura D1” was used. It is a PMB with a high content of polymers, based on a medium hard binder. In combination with relatively high binder content, it gives thick binder membranes in the PA, which affects the resistance and aging positively. Upon aging of the polymer in PMB, combustion products are produced that function as plasticizers in the bitumen, which slow down the aging (hardening). The binder is flexible and significantly more sticky than the standard bitumen. The stickiness has not affected the pavement performance negatively, and is probably one of the factors that contributes to good adhesion (durability).

4.2. E4 in Huskvarna
The goal of the pavement in E4 Huskvarna was to lower the noise level by at least 5 dB(A) on average for this road section. When noise reduction is below 3 dB(A) the pavement must be renewed. To achieve this, two layers of PA were laid in the summer of 2010. Figure 4 shows the main section of this test pavement. The contractor for this test road is Svevia AB.

Facts of the test road on E4 in Huskvarna:

- Length: 2.7 km
- Motorway, two lanes per direction, right lane designated K1, and left lane designated K2
- Posted speed limit: 90 km/h
- AADT: 20 000 - 30 000 vehicles (15 % heavy vehicles). Distribution between lanes: 70 % in K1 and 30 % in K2, the main part of the heavy traffic in K1
- Layer thickness of the PA: upper layer 30 mm, lower layer 50 mm
- Aggregates in the upper layer: in K1, rhyolite; in K2, diabase (north) and rhyolite (south), max. size 11 mm.
- Aggregates in the bottom layer: diabase in all lanes, max. size 16 mm.

Figure 4: Test road on E4 in Huskvarna just after the pavement was laid in 2010.

Test sections

Inside the main section, approx. 2.7 km long, which is composed in two slightly different variants, four special test sections, each 100-150 m long, were added in the southbound direction. However, the bottom layer of the PA is the same for the entire test road. The performance of the special sections is compared to that of the main PA section. These are then the considered test sections:

- Main section, part 1: K1, south, Rhyolite, binder content 6.3 %
- Main section, part 2: K2, south, Rhyolite, binder content 6.3 %
- Main section, part 3: K1, north, Rhyolite, binder content 6.3 %
- Main section, part 4: K2, north, Diabase, binder content 6.0 %.
- Special section 1: K2, south, aggregate with steel slag, binder content 5.9 %
- Special section 2: K2, south, Rhyolite, increased binder content 6.9 %
- Special section 3: K1, south, sealing with Fog Seal the first year (0.5 kg/m^2), binder content 6.3 %
- Special section 4: K1, south, sealing with Fog Seal also the second year (0.5 + 0.5 kg/m^2), binder content 6.3 %

Measures before the pavement was laid

Before paving the two new layers of PA, 20 mm of the top of the old wearing course was milled away, including the road shoulders. The cross fall was increased to 3 %, so that water would easier drain out sideways from the pavement. Normally it is 2.5 %. The road shoulders were also paved with PA, but only in a single layer with 16 mm max. aggregate size. It is interesting that the two layers were not laid "wet on wet" (almost simultaneously using two screeds); instead, the bottom layer was laid one day and the top layer the next day. Laying "wet on wet" is the normal procedure in Japan and other parts of Europe, and is believed there to be necessary.

Extensive tests where done in the laboratory, by the contractor, with regard to void content, binder content, grading, binder drainage, water sensitivity as well as the Cantabro test. The latter gave a misleading result because Cantabro does not take into account the density of the aggregate. The difference in particle density was high between rhyolite (2.64 Mg/m^3), diabase (2.88 Mg/m^3) and steel slag (3.63 Mg/m^3). Therefore, specimens of steel slag and diabase received too poor results as compared to the experience of the test road where the materials exhibited excellent durability to raveling. No binder drainage was detected in the binder drainage test, although the amount of binder was high in the various asphalt mixes. Water sensitivity test (ITSR) gave, as expected, good results. The aggregate properties are shown in Table 1.

Table 1: Aggregate quality, where parameters and the single values refer to scales in European Standard EN 13043 (the lower values, the better).

Parameter	**Rhyolite**	**Diabase**	**Steel slag**
Nordic Ball Mill	3	11	7
Los Angeles	15	11	11
Density	2.64 Mg/m^3	2.88 Mg/m^3	3.63 Mg/m^3
Flakiness index	5	7	3

Void content in samples from the road showed void content levels at 25-27 %; which are high for Swedish conditions. However, the pavement samples containing steel slag had just above 20 % void content. Two adhesives were used, cement and amine (Wetfix). Binder content are seen under the heading "Test sections" above.

Sealing with Fog Seal

Fog Seal is an adhesive, which has been tested in recent years as surface dressing and sealing. The purpose of Fog Seal is to increase the pavement durability, especially to reduce the risk of raveling, by spraying a very thin layer of bitumen emulsion on the surface of the pavement. In this case, the emulsion can penetrate further into the open pavement and seal the micro cracks and the contact surfaces between the aggregate, while the bitumen membranes, which settle on the surfaces of the aggregate, can reduce the oxidation of the bitumen; hopefully without clogging the pores significantly, and thus degrade the noise reduction characteristics.

Details of the emulsion:

- About 52 % residual bitumen
- Bitumen penetration: 70
- Breaking speed: about 15 minutes in good weather
- Amount of emulsion: 0.3-0.4 kg/m^2.

A distance of about 200 m in K1, southbound direction, was sealed in the fall of 2010. Another seal was conducted in autumn 2011 on half of the section that was sealed in 2010. As reported previously, stone losses have been small on these sections. In the autumn of 2013, the entire K1 in both directions was sealed (Figure 5).

Figure 5: Sealing with Fog Seal of the PA on E4 in Huskvarna, September 2010.

Permeability/drainability
Drainage performance has been measured in annual inspections using the drainage test according to EN 12697-40 (Figure 3). The results are shown in Figure 6. The sections with double layers generally have a high draining effect (permeability). The section with steel slag has, as expected, lower drainage capacity, because the void content is substantially lower than that of other sections. Notably, the sealed sections have not significantly poorer drainage capacity than those that were not sealed. The difference in outflow time is small between measurements in 2012 and 2013.

These measurements were performed before the pavement was cleaned. The short drainage times (10-30 s) indicate that the pores are not yet clogged with road dirt, but there is still a continuous pore system that can absorb noise and water. The measurement in 2014 showed a much longer drainage time in K1, probably due to the surface sealing in the autumn of 2013. The two test sections previously sealed (2010 resp. 2010 + 2011) and the steel slag in K2 had the largest changes from 2013 to 2014 (Figure 6).

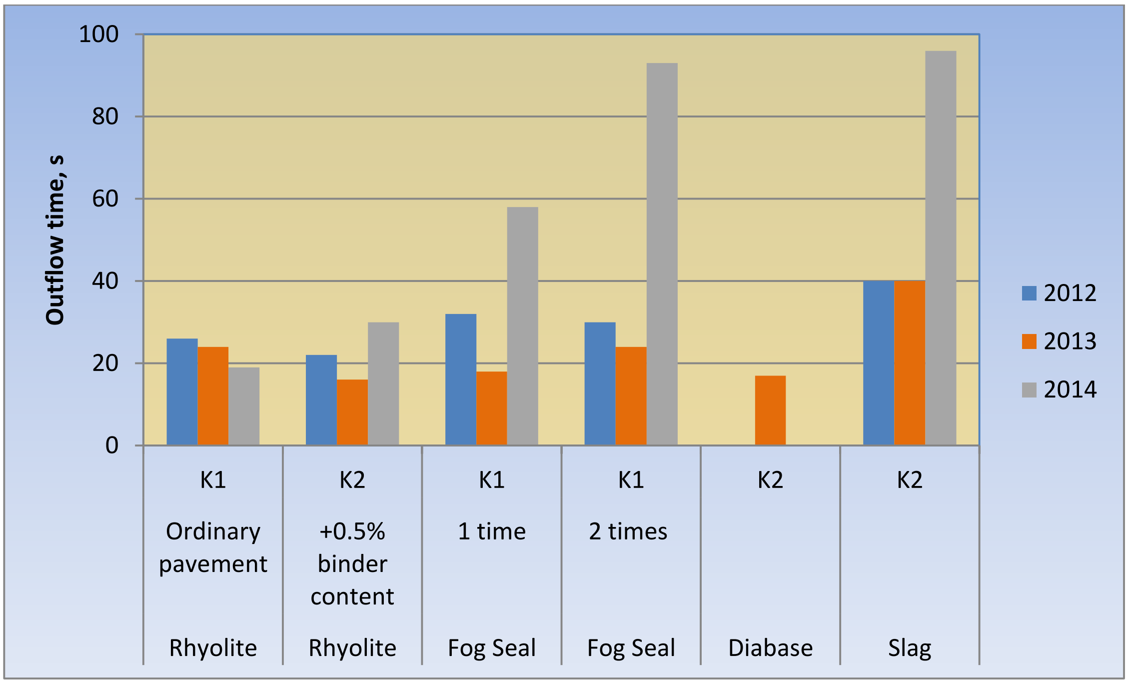

Figure 6: Result from drainage test. By "ordinary pavement" is meant here the PA version laid on the main section

Stone loss
At the inspections in 2013 and 2014, investigation of raveling was carried out by means of the so-called "French window", stipulated in EN 12272-2 for calculation of stone loss for surface dressing (Figure 7). Over the four years, raveling has been small, besides some smaller parts in the beginning of the K1 south section, where raveling has been moderate. By means of a frame randomly placed on the road surface in the wheel tracks or the surface between the wheel tracks, the number of stones larger than 4 mm was calculated. When the entire surface is covered with stones there is about 300 pieces of stones with grading 8/11 mm within this frame.

Laboratory analyses of drill cores
In the spring of 2011 drilled core samples from some of the test sections were collected. Another sampling was made in 2014. In order to study void structure in the two open asphalt layers, and to see if dirt is stuck in the pores, the samples have been examined by X-ray analysis (Computer Tomography) at the Royal Institute of Technology in Stockholm. The results have not yet been reported. According to visual examination it appears that the open asphalt layers have good adhesion and durability.

Figure 7: Stone content is high and the open pores are visible between the particles. The number of particles (8/11) within the frame is approximately 360 and three are lost. The pavement (K2 south with rhyolite) was four years old when this photo was shot.

Noise measurement results

Noise measurements were performed with the CPX method according to ISO/DIS 11819-2) yearly from 2010 until 2015. The measurements have been carried out during the summer (June-July) in all lanes and directions, and have given the results for the main section presented in Table 2 (results from 2015 were not yet available). Tyre P1 is supposed to be representative of car tyres and H1 representative of truck tyres (ISO TS 11819-3).

The measured values are the difference between the PA pavement and the reference, i.e. a set of 3-4 SMA16 "middle-aged" pavements. If the reference had been a set of SMA11 instead, the noise reduction values would have been 1 to 1.5 dB lower than in Table 2. All measurement values are corrected to the reference temperature of 20 °C. Much more about the noise measurements is reported in [4][5][6].

Measurement of noise at a building façade (equivalent 24h level) gave a reduction in A-weighted noise level of 11 dB in 2010, after the new pavement was laid, and compared with the year before. This also includes the effect of a reduced speed limit (from 110 to 90 km/h), which normally should have contributed approx. 2 dB to the noise reduction.

Table 2: A-weighted noise reduction in dB of the main section of the PA pavement at 80 km/h, based on CPX noise measurements for two tyres at six different times. The noise reductions are relative to the annual average of the noise levels of 3-4 SMA16 pavements. From [6].

Lane & track	Reference tyre	New June 2010	1 month July 2010	1 year July 2011	2 years July 2012	3 years July 2013	4 years July 2014
Slow (right) lane Right wheel track	P1	8.1	7.2	6.8	6.6	6.0	3.6
	H1	6.7	7.0	7.2	7.4	6.2	3.0
Slow (right) lane Between tracks	P1	8.1	7.7	7.8	7.4	6.7	4.5
	H1	6.7	7.1	7.6	7.2	6.3	3.7
Fast (left) lane Right wheel track	P1		7.5	7.0	6.8	6.5	5.9
	H1		7.0	7.0	7.3	6.5	5.3

Cleaning
After the first winter, the road surface was cleaned by a “regular” road cleaning machine, ejecting water spray and sucking up the resulting dirt water, but no effect on noise reduction could be observed. Since no noise deterioration took place the first year, it is not expected that cleaning would be effective. A cleaning trial with an advanced machine designed especially for cleaning of PA were conducted in 2014 when the surface was four years old and clogged in the slow lane, but no effect on noise was measured [6].

Road surface geometrical data
Measurements of the geometrical properties of the road surface have been carried out annually by the VTI Laser RST vehicle. Unevenness, represented by IRI values, was 0.7-0.8 mm/m after three years of service, with the highest values measured in the fast lanes (K2). These are excellent values. The K1 lane had rut depths of about 8 mm and K2 had 4-6 mm; with the highest value for the section in the northern direction, using diabase as the aggregate. For Swedish conditions with studded tyre wear over three winters, these values are good. MPD values are slightly lower in K1 than in K2, probably due to more clogging and wear. The Fog Seal has to some extent affected the MPD values in K1 (reduction of 0.06-0.08 mm) and is the likely cause of an extra noise deterioration there.

4.3. E4, Rotebro, Stockholm

The need for traffic noise reduction measures is great in Stockholm, including the approach roads, and one option of considerable interest is to use noise-reducing pavements. Based on the excellent results on E4 in Huskvarna, a test section on the E4 motorway in Rotebro (between Stockholm and Arlanda airport) was re-paved with double-layer PA in the summer of 2014. This road has three lanes in each direction. See Figure 8.

Figure 8: The test road E4 in Rotebro, Stockholm, after a few months of traffic.

The length of the test road is about 1450 m. The road section is travelled by over 70 000 vehicles per average day, of which about 10 % are heavy vehicles. The distribution between the lanes K1, K2 and K3 is estimated to be 30, 40, and 30 %. The posted speed limit is 80 km/h during the winter and 100 km/h the remainder of the year. From November to mid-April about 55 % of the private cars are fitted with studded tyres. The preparatory work before the test road was paved included increasing the cross slope to 3.0 %, making the base course dense, adjusting the rails and improving drainage in the lateral direction.

The pavement consists of porous asphalt in two layers; 30 mm PA11 on top of 50 mm PA16. The same type of binder as was used in Huskvarna was used here. The binder content was 6.6 % in the top layer. Void content was 24-26 % according to drill cores from the road. A large number of studies were conducted in the laboratory, which showed good results, among others that the coarse aggregate (8/11 mm) tried here had a low Ball Mill value (3.8), as would be required for a road with this much traffic.

The paving was going well. Also in this case, the lower layer was paved the day before the top layer. An open asphalt mix behaves differently than a dense asphalt mix and requires a longer shutdown of traffic than normal. No binder runoff was observed during transport or laying. The contractor was Peab Asphalt. Even the road shoulders were paved with two layers of PA, allowing the water to drain out of the travelled lanes.

There was a heat wave resulting in air temperature about +30 °C during the works, which meant that the binder became even more sticky than at more normal temperatures. The road was partially closed to traffic during the paving work. The lower draining layer had not been trafficked before the upper layer had been added and also the top layer had to rest a while before the traffic was admitted. Some minor surface damage occurred in the southern part of the test road when some concrete foundation and adhesive strips were removed prior to traffic was admitted. Otherwise, the road looked good.

For the contractor, this paving procedure means that paving the porous asphalt takes longer and requires more planning than for conventional dense asphalt. It also requires more testing, especially of asphalt mixes. Considering all the work and the disturbances that occurred in the different stages of the paving process, the pavement got a smooth and homogeneous surface with the expected good noise characteristics.

This test road will be monitored in the same manner as the test road in Huskvarna with respect to, among other things, noise, condition of the road surface, IRI, rutting, texture, friction, particles from wear, drainage, raveling, etc. Some sections will be sealed with Fog Seal emulsion in 2015 in order to improve durability, while also measuring if and how much this operation affects the noise reduction and pavement drainage capacity.

The follow-up work in 2014 and 2015 show that the test road received good acoustic and technical characteristics so far. A-weighted noise reduction was about 7 dB compared to a nearby SMA16. After one year, tyre/road noise reduction has degraded by about 0.5 dB, a good value for PA on such a high-volume road. A large number of roadside noise measurements have been performed at the adjacent facades and other measuring points in the vicinity. They showed a noise reduction of about 10 dB compared to the old worn-out asphalt that was replaced with PA. The speed limit has been reduced in 2015 by 10 km/h, which should account for about 1 dB of the noise reduction at the roadside. No large raveling, potholes or other defects have been observed after the first year. The pavement also has good homogeneity, adhesion, smoothness and no serious rutting. The test road will be followed up until 2017. A normal SMA 16 on such a high-volume road with typical Swedish traffic (including studded tyres in winter) would have an expected lifetime of five years. If the PA can endure as long as that and still provide noise reduction it will be great.

5. SUMMARY OF RESULTS

The test road on E4 in Huskvarna, where a number of test sections with two layers of porous asphalt (PA) have been tested for five years, is a success story so far. Noise reduction after one year of traffic was about 7 dB(A) and after four years 3-6 dB(A) with the highest values in K2 (fast lane). After five years noise reduction is still the same as after four years. No severe raveling or other types of damage have been observed during these five years. For a PA to function well under Swedish conditions, a number of conditions must be met, such as good drainage, using special binders, using high binder- and void content and obtaining good adhesion between aggregate and binder.

The construction of the test road on E4 in Rotebro 2014 worked well and the follow-up in 2015 suggests noise reduction and drainage ability of the same level as the test road at E4 Husqvarna.

It must also be noted that there have been no special problems with winter friction or freeze-thaw damage on either of these roads, despite the winter climate in Sweden. However, deicing requires more salt than on dense surfaces and a preventive deicing policy must be observed.

A few other results and features of the test roads are:

- Drainage is improved by increased cross slope and improved drainage by using PA also on the road shoulders.
- A new binder – highly modified bitumen with good adhesion and elasticity - must be used.
- There must be no binder drainage from this kind of pavement.
- Mix design should feature high binder content (≥ 6.3 % by mass), high void content (≥ 23 %), high stone content (85 % by mass) and suitable additives.
- Max. aggregate size in the top layer should be 11 mm. Aggregates with good adhesion to bitumen and with good resistance to studded tyres shall be used. In Sweden, lower aggregate sizes, such as 8 mm, would mean more wear due to the studded tyres. If using 8 mm in the top layer, one would have to sacrifice noise reduction for substantially lower lifetime.
- If raveling tendencies are observed, the road may be sealed with a low content of Fog Seal emulsion.
- Road geometrical data (IRI, rut depth, and texture) as well as wet friction have shown good results, in level with SMA pavements; except for slightly higher values for texture (MPD).

6. CONCLUSIONS AND RECOMMENDATIONS

Although the purpose of using porous asphalt (PA) from the beginning was to improve road safety and traffic flow in wet weather; over time, the focus has shifted to noise reduction and today PA pavements are primarily used to limit noise exposure.

Early trials in Sweden showed that PA got shorter lifetimes than dense asphalt, due to insufficient durability. In some cases, the technical lifetime became significantly shorter, with a lifespan of only 2-3 years. The biggest reason was that the binder was oxidized considerably more compared with dense asphalt pavements. Another reason was that water could be trapped in the open pavements. In both cases, this resulted in raveling and potholes in the road. Clogging of the pores caused an extra deterioration of noise characteristics.

The paper summarizes the experiences of double-layer porous asphalt pavements on two test roads in Sweden. It is primarily focused on the asphalt-related factors that affect noise properties. It also considers the importance of a proper road design when PA is used.

Porous asphalt useful for Swedish roads has high air void content and high proportion of coarse aggregate (85 %). This gives a connected pore system, which can lead water away and absorb some of the sound from the tyres. The high void content also allows extra time before the pores are clogged.

The experience of the two test roads reported here is very positive and suggests that a break-through has been achieved which makes double-layer PA useful for application in Sweden for noise-reducing purposes; despite the special conditions resulting from the use of studded tyres. Of course, this type of pavement is significantly more expensive to use than the SMA normally applied; yet it may be favorable to other noise-reducing options.

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