



Asphalt rubber pavements in Sweden – Noise and rolling resistance properties

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Abstract

Asphalt rubber (AR) pavements of the type which is commonly used in Arizona have been adapted for the Swedish climate and conditions. Both a gap-graded and an open-graded version have been constructed at several places and with a few different aggregate sizes. The objective of the work has been to determine the properties of these pavements in comparison to conventional SMA and porous asphalt pavements. In this case the focus has been on noise and rolling resistance properties and how these properties change with pavement age or traffic exposure.

Measurements so far in this study have indicated a couple of dB extra noise reduction due to the use of AR technology. Regarding rolling resistance properties, AR is neutral; i.e. properties are similar to those of SMA and porous asphalt. There are indications that the favourable effects of AR might increase with pavement age, but more time is needed to verify this.

Keywords: Noise reduction, pavement, rubber, asphalt, rolling resistance.

1 Introduction

Asphalt rubber (AR) pavements, also known as rubberized asphalt, have been applied successfully and extensively in Arizona in USA, and to a lesser extent in some other states. Trials have also been made in states in USA and Canada with colder climates, but then mostly with more limited success. The positive properties of this family of pavements reported in North America include good durability, excellent noise reduction, "self-curing" crack reflection, and a way of recycling rubber of old tyres [1].

In Arizona, specifically, the excellent noise-reducing properties have been highlighted, and have been a major driver for replacing much of the earlier cement concrete freeway surfaces in the Phoenix Valley with AR surfaces. However, it must be noted that the cement concrete pavements used in North America and the texturing applied to them often result in extremely

noisy traffic and most other pavements would be "low-noise" compared to them; including a conventional stone mastic asphalt (SMA). It should however be mentioned that there are several ways to obtain rather quiet traffic also from cement concrete pavements, although these techniques were not applied on the pavements in Arizona which were replaced by AR pavements, a situation also common in other states.

The asphalt rubber technique has also gained interest in Europe. For instance Portugal has extensive experience of this methodology, and many other European countries have made trials with asphalt rubber in recent years. In Sweden, some people at the Swedish Road Administration (SRA), reorganized in April 2010 as the Swedish Transport Administration (STA), became interested in the AR concept as it was applied in Arizona and brought the ideas back home to Sweden, attempting to adapt them to Swedish climate and conditions [2]. Since 2007, the SRA has been running a trial programme for AR pavements in Sweden [3]. At the end of 2009, about 15 test sections had been constructed, using approximately 57 000 tonnes covering about 100 lane-km; mainly in the southern part of Sweden (Stockholm region and south of this); the majority of which have been tested for noise.

This paper reports about noise properties of most of the test sections as well as rolling resistance properties on a few of them. In general, comparison is made with stone mastic asphalt (SMA), dense asphalt concrete (DAC), or porous asphalt concrete (PAC) pavements since these are the types which would normally "compete" with the AR pavements. The essential question is "what is the effect of adding rubber to conventional asphalt pavements"?

2 What is asphalt rubber?

Asphalt rubber (AR) is a binder consisting of approx. 80 % bitumen and 20 % ground scrap tyre rubber (crumb rubber) by weight of the binder [1]. The crumb rubber typically consists of 0.5-2 mm rubber granules which are added to bitumen at a high temperature and mixed with a mixer. After the interaction, the hot AR product acquires unique elastomeric properties which is then pumped into a conventional hot plant and mixed with aggregate and placed like a conventional asphalt concrete. The binder content is typically 9-10 % by weight of the total mix, which means that the total rubber content is around 2 %. The significant differences to a conventional asphalt pavement are that the binder content is much higher (50-100 % higher) and that a large part of the binder (about 20 %) is made up of small rubber granules. The resulting mix looks "fatter" than conventional asphalt, with the binder embedding the aggregate more effectively, providing a mix that is more viscous but with rather similar stiffness [4].

There are basically two variants relating to the grading of the aggregate: one which gives a totally dense pavement called "gap-graded" (air voids 7-9 %) and another giving a porous pavement called "open-graded" (air voids 18-20 %) [1]. In Arizona the former is known as Asphalt Rubber Asphalt Concrete (ARAC) while the latter is called Asphalt Rubber Friction Course (ARFC). In Portugal, the "gap-graded" variant has an air voids content which is somewhere in-between of the mentioned two variants.

3 Types of AR tested in Sweden

The types of asphalt rubber pavements tested in Sweden so far are listed in Table 1, together with their designations. The Swedish term for ARG is GAP and for ARO it is GAÖ. Reference pavements have been either SMA 0/16 or SMA 0/11.

Table 1 - Types of asphalt rubber pavements tested in Sweden

<p>ARG 16: Asphalt rubber - gap-graded; essentially similar to a Stone Mastic Asphalt with maximum 16 mm aggregate (SMA 0/16), but with 16-20 % of the binder replaced with rubber granules, and 8.3-9.0 % binder content by mass [3]. Voids content is approx. 2 – 2.5 %.</p> <p>ARG 11: Same as above, but with maximum 11 mm aggregate.</p> <p>ARG 8: Same as above, but with maximum 8 mm aggregate.</p> <p>ARO 11: Asphalt rubber - open-graded; essentially similar to an Open-Graded Asphalt Concrete (OGAC) with maximum 11 mm aggregate, but with 16-20 % of the binder replaced with rubber granules, and 8.3-9.0 % binder content by mass [3]. Voids content is approx. 15-19 %.</p> <p>ARO 8: Same as above, but with maximum 8 mm aggregate.</p>
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The thickness of the Swedish AR pavements is generally 30 mm for 11 mm aggregate size and 25 mm for 8 mm aggregate size. Technically, this means that the AR pavements are thin layers. Test sections have been laid on various highways, ranging from regional highways with 70 km/h posted speed, national highways with 90 km/h posted speed, up to motorways with 110 km/h posted speed. Traffic volume ranges from very small on regional highway to very high on motorways. The tested trial sections were laid in 2007, 2008 or 2009.

4 Measurement methods and equipment

Noise measurements in this project have been made with the CPX method, as drafted in ISO/CD 11819-2, using the CPX trailer (and crew) of the Technical University of Gdansk (TUG) in Poland. Test tyres have been the SRTT (defined in ASTM standard F2493-06) to represent passenger car tyres and either the Goodyear MudTerrain tyre (GYMT) or the Avon Supervan AV4 (AAV4) to represent truck tyres [5]. Test speeds were 50, 70, 80, 90 or 110 km/h, as possible due to speed regulations and safety.

Rolling resistance (RR) was measured with a trailer method, using the RR trailer (and crew) of the Technical University of Gdansk (TUG) in Poland [6]. Test tyres have been the SRTT (defined in ASTM standard F2493-06) and Michelin Primacy (MIPR) to represent passenger car tyres and the Avon Supervan AV4 to represent truck tyres. It is so far only a speculation or hope that the AAV4 can represent truck tyres sensitivity to road surface for RR measurements; as has been demonstrated to work for noise. Test speeds were 50, 70, 80, or 110 km/h, according to what was possible due to speed regulations and safety.

Surface texture measurements were made with a recently modernized version of the VTI mobile laser profilometer. The profile curve was recorded and the texture spectrum was measured between texture wavelengths of 2 and 500 mm (third-octave bands) according to ISO 13473-2. Simultaneously, the Mean Profile Depth (MPD) was measured in accordance with ISO 13473-1. The MPD is a widely used measure describing macrotexture of a pavement surface, although its relation with exterior tyre/road noise is poor.

5 Results of noise measurements

5.1 Test sections in Alingsås-Göteborg constructed and measured 2009

Four different AR pavements (ARO 8, ARG 8, ARO 11, ARG 11) were laid in 2009 on a regional highway through the city of Alingsås near the Swedish west coast. An ARG 11 was

also laid on the E6 motorway through Göteborg on the west coast. The CPX measurement results on these are shown in Figs. 1-2. They are compared with 5 types of dense asphalt pavements with no rubber. The sound levels for each of these types have been averaged over 1-5 different sections within each category. Fig. 1 shows the results for tyre SRTT (representing car tyres) and Fig. 2 shows the results for tyre AAV4 (representing truck tyres).

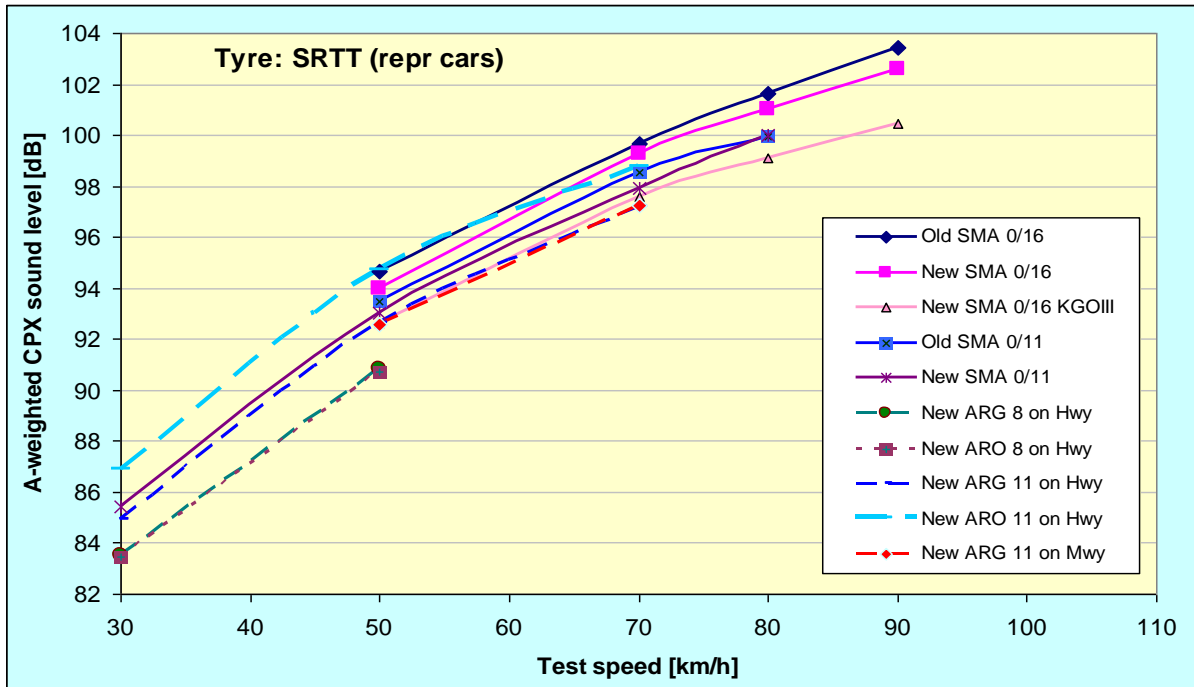


Figure 1 – Noise versus speed for AR pavements in Alingsås-Göteborg, and for SMA pavements in various age and with 11 and 16 mm maximum aggregate size. Tyre: SRTT.

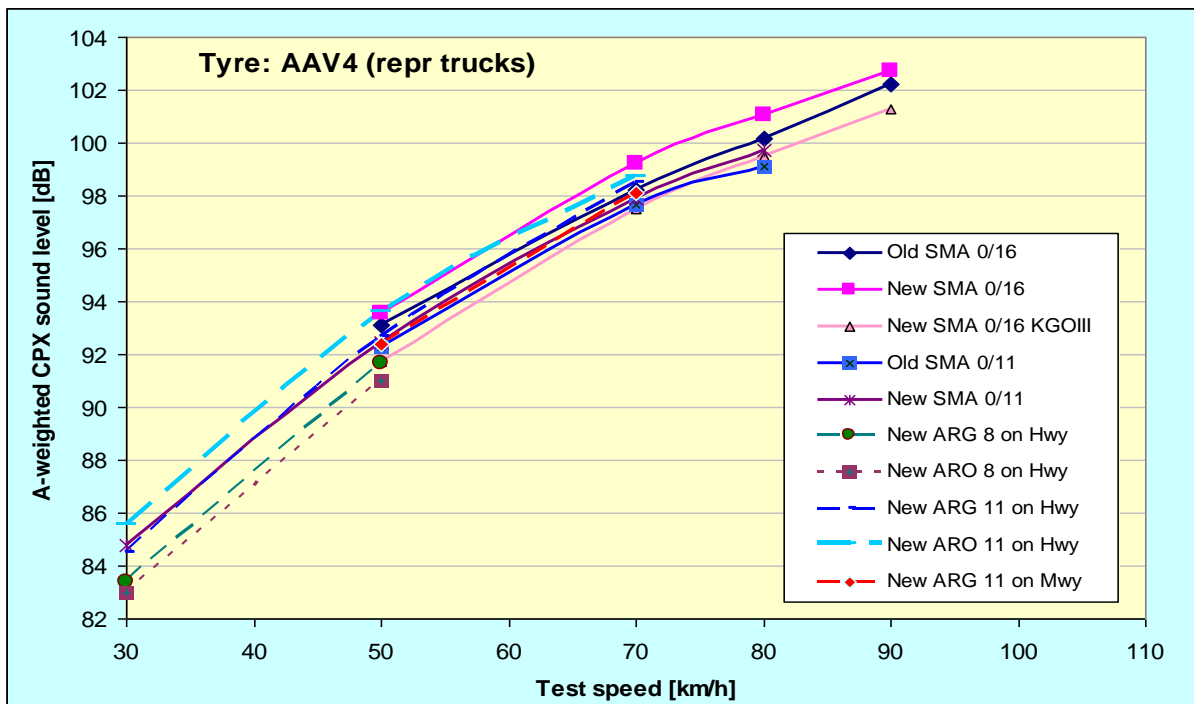


Figure 2 – As Figure 1 but for tyre AAV4.

"New" means that these sections were 1-5 months old when measured; "old" means that the sections were 2-7 years old when measured. Table 2 shows the data in Figs. 1-2 in numbers, but only as an average difference to an old SMA 0/16 for the values at 50 and 70 km/h, since these are the only speeds which are common to most test sections, and "old" SMA 0/16 is the official Swedish reference surface. Table 2 also includes data from 2009 for AR pavements in the region Scania in southern Sweden.

Table 2 – Noise reduction levels compared to the old SMA 0/16 surface type. The blue area contains reference surfaces (SMA), the yellow area contains AR surfaces tested in Alingsås-Göteborg, and the green area contains AR surfaces tested in Scania in southern Sweden.

Type of pavement	Age	A-weighted sound level [dB]		Note
		Tyre SRTT	Tyre AAV4	
Old SMA 0/16	Old	reference	reference	Official Swedish reference
New SMA 0/16	New	0,6	-0,7	
New SMA 0/16 KGOIII	New	2,1	1,1	Equally good as ARG 11
Old SMA 0/11	Old	1,2	0,7	
New SMA 0/11	New	1,7	0,5	
ARG 8 (GAP 8) on urban Hwy	New	3,9	1,5	Similar to Arizona ARAC
ARO 8 (GAÖ 8) on Hwy	New	4,0	2,1	Similar to Arizona ARFC
ARG 11 (GAP 11) on Hwy	New	2,3	0,1	Compare this to SMA 11
ARO 11 (GAÖ 11) on Hwy	New	0,4	-0,5	Very poor result
ARG 11 (GAP 11) on E6 Mwy	New	2,3	0,4	Compare this to SMA 11
ARG 11 (GAP 11) on E6 Mwy	2 years	2,4	1,5	
ARO 11 (GAO 11) local Hwy	2 years	4,2	3,5	= next one. First 300 m
ARO 11 (GAO 11) local Hwy	2 years	5,4	4,3	=previous one. Last 300m
ARG 11 (GAP 11) on E6 Mwy	New	3,9	2,1	
ARG 16 (GAP 16) on E6 Mwy	2 years	2,0	0,4	

The following observations are noted:

- The difference between SMA 0/16 and SMA 0/11 of 0.25 dB per mm max aggregate size (for cars only), i.e. $0.25(16-11) = 1.25$, as suggested in [7] holds here.
- Difference between new and old SMA is approx 0.5 dB (only for cars). This is only half of that suggested in [7].
- The special SMA 0/16 made with the special mixing technique called KGOIII is equally good as SMA 0/11 or ARG 11 for noise reduction of car tyres, and even a little better than the 11 mm mixes for truck tyres.
- Comparing ARG 11 with SMA 0/11, both in new condition, the ARG 11 in Alingsås is approximately 0.5 dB quieter, while the ARG 11 in Scania is about 2 dB quieter. But the latter is probably mostly due to a lower macrotexture of the ARG 11 than the SMA 11.
- The ARG 8 provides a good noise reduction (1.5 dB more than ARG 11 and 3 dB better than a new SMA 0/16, but this is probably more due to the smaller aggregate than due to the rubber. An SMA 0/8 should have achieved almost equally high noise reduction.
- Both open-graded AR on this mid-town highway became great disappointments. They offered no better noise reduction than the gap-graded versions; rather worse. This is totally unexpected. One explanation for it is that it rained the day before the measurements and the weather was such that it is unlikely that the porous layers had dried-up; they were probably filled with water and thus ineffective for noise reduction (there was no time to wait for drying). But on the ARO 11 there was probably also some kind of failure that caused 2 dB higher noise than on the ARG 11 section.

- The ARO 11 in Scania provides for 4-5 dB of noise reduction still after 2 years of traffic. This is comparable to double-layer porous asphalt after the same time, but then one must observe that there is very little traffic on the ARO 11.
- The ARG 11 seems to retain its noise reduction from new to two years of age, even on a motorway with moderately-high traffic volume.
- The same seems to be the case for the ARG 16, which is about 2 dB quieter at the age of 2 years than corresponding SMA.
- In general, noise differences are smaller for the AAV4 tyre than for the SRTT. This correctly reflects the classification of surface noise properties made by truck traffic.

5.2 Test sections constructed in 2007 and 2008 and measured in 2008

This section presents the results measured in 2008. In order to avoid the bias of tyres slightly different in age between the various years, noise reductions have been calculated with reference to old SMA 0/16. The latter reference is actually based on measurements on 6 different SMA 0/16 with ages 1-5 years and on various highways and motorways. Therefore, this reference is relatively stable. Table 3 presents the results.

Table 3 – Noise reduction levels compared to the old SMA 0/16 surface type. The blue area contains reference surfaces (SMA), the green area contains AR surfaces tested in Scania in southern Sweden and the yellow area contains AR surfaces tested elsewhere in Sweden.

Type of pavement	Age	A-weighted sound level [dB]		Note
		Tyre SRTT	Tyre AAV4	
Old SMA 0/16	Old	reference	reference	Official Swedish reference
New SMA 0/16	New	0,9	-0,1	
Old SMA 0/11	Old	1,5	0,5	
New SMA 0/11	New	2,3	1,1	
ARG 16 (GAP 16) E18 Mwy	New	2,3	0,5	
ARG 11 (GAP 11) local Hwy	New	3,3	0,9	
ARO 11 (GAÖ 11) E22 Mwy	New	4,1	2,2	= next one. First part
ARO 11 (GAÖ 11) E22 Mwy	New	5,6	3,4	= previous one. Last part
ARG 16 (GAP 16) on E6 Mwy	1 year	0,8	0,7	
ARG 16 (GAP 16) on E6 Mwy	1 year	0,7	-0,9	
ARG 11 (GAP 11) on E6 Mwy	1 year	0,9	-0,3	
ARO 11 (GAO 11) local Hwy	1 year	4,1	3,1	= next one. First 300 m
ARO 11 (GAO 11) local Hwy	1 year	4,6	3,4	= previous one. Last 300m

The following observations are noted:

- Differences between new and old and between 11 and 16 mm SMA are rather similar to those measured in 2009, indicating that the references are acoustically stable. The major difference is that "old" is about 1 dB noisier than "new"; whereas this difference was only half as large in 2009.
- ARG 16 is about 1 dB quieter than its counterpart in SMA 0/16 both when new and when one year old.
- ARG 11 is about 1 dB quieter than its counterpart in SMA 0/11 when new and 0.5 dB noisier than SMA 0/11 when one year old.
- ARO 11 is 4-6 dB quieter than old SMA 0/16 when ARO is new, reduced by about 1 dB one year later.
- Trials were not made with ARO 8 (which is the one most similar to Arizona ARFC), but if the usual difference between 8 and 11 mm aggregate (approx. 1.5 dB) is maintained, the

ARO 8 offers a probable potential of 7 dB noise reduction when new and 6 dB at one year of age.

- The latter observation means that the ARO surfaces with 11 and 8 mm maximum aggregate size offer noise reductions almost similar to those of double-layer asphalt concrete. This is achieved with only around 17 % of air voids and a layer thickness of 25-30 mm. However, one shall then note that the ARO most probably are substantially more economical.
- Regrettably the ARO 11 laid on the E22 motorway in Norrköping (the one with the best noise reduction in Table 3) failed soon after placement. Within six weeks of placement, severe raveling caused numerous safety issues on the highway and a decision was made to remove and replace the wearing course only eight weeks after placement [7].
- The observations above are valid for the SRTT tyre; i.e. representative of light traffic. For the AAV4 tyre (heavy traffic), all differences between surfaces are smaller, usually indicating 1-2 dB lower noise reductions than for the SRTT.

5.3 Test sections constructed and measured in 2007

Finally, this section presents the results measured in 2007. In 2007, the AAV4 tyre was not yet considered for an ISO reference, and instead the GYMT tyre was used. However, essentially, this tyre gave similar surface comparisons as regards noise levels as the AAV4; with the exception of porous surfaces, which are underestimated. Table 4 presents the results.

Table 4 – Noise reduction levels compared to the old SMA 0/16 surface type. The blue area contains reference surfaces (SMA), and the green area contains AR surfaces tested in Scania in southern Sweden.

Type of pavement	Age	A-weighted sound level [dB]		Note
		Tyre SRTT	Tyre GYMT	
Old SMA 0/16	Old	reference	reference	Official Swedish reference
New SMA 0/16	New	0,9	-0,7	Only one surface included
Old SMA 0/11	Old	-		No such surface tested
New SMA 0/11	New	1,2	0,9	Only one surface included
ARG 16 (GAP 16) Natnl Hwy	New	0,9	-0,2	
ARG 16 (GAP 16) on E6 Mwy	New	1,4	-1,0	
ARG 11 (GAP 11) on E6 Mwy	New	2,4	-0,7	
ARO 11 (GAO 11) local Hwy	New	5,8	1,0	= next one. First 300 m
ARO 11 (GAO 11) local Hwy	New	5,6	0,8	= previous one. Last 300m

The following observations are noted:

- Differences between new and old and between 11 and 16 mm SMA are rather similar to those measured in 2008, regarding "new" and "old" differences. However, the difference is that SMA 0/11 is only about 0.5 dB quieter than SMA 0/16 when new; which is about 1 dB less than in 2008 and 2009. The reason is probably that only one such surface of each type is included.
- ARG 16 is about 0.5 dB quieter than its counterpart in SMA 0/16 when new.
- ARG 11 is about 1 dB quieter than its counterpart in SMA 0/11 when new.
- ARO 11 is 5-6 dB quieter than old SMA 0/16 when ARO is new.
- The observations above are valid for the SRTT tyre; i.e. representative of light traffic. For the GYMT tyre (heavy traffic), all differences between surfaces are small. This tyre seems not to discriminate appropriately between surfaces.

5.4 Noise reduction over the time period 2007-2009

Four of the AR pavements have been monitored for noise each year. The noise reduction of these four pavements versus age of the surface (time) is shown in Fig. 3. The noise reduction is calculated with an "old" SMA 0/16 as the reference, as this is the most stable of the tested surfaces and also the official reference surface in Sweden. The left part of Fig. 3 is for the SRTT tyre and the right part for the AAV4 tyre; although the first year this tyre was not available; instead the GYMT tyre was used. This might show an incorrect development from year 0 to year 1 in the right part of Fig. 3. The uncertainty (95 % confidence) is estimated to be ± 0.5 dB.

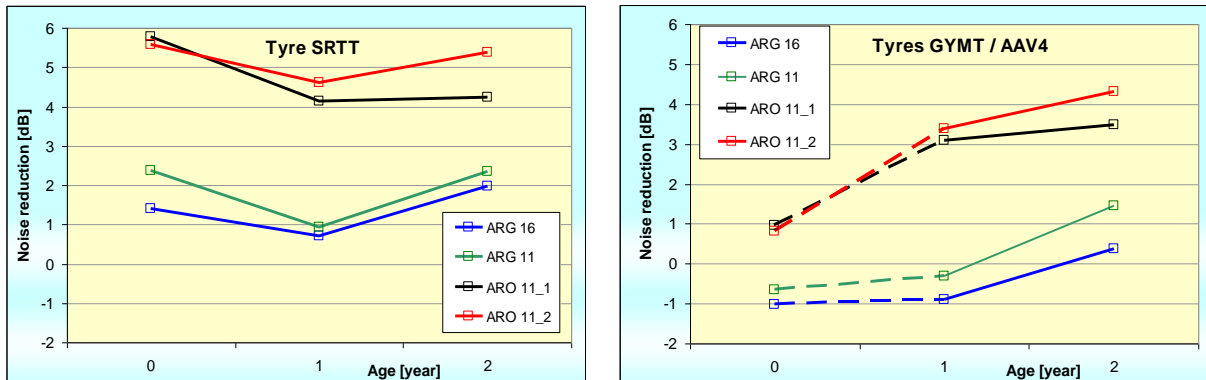


Figure 3 – Change in noise reduction over the two years studied so far.

It appears that the noise reduction of the AR pavements do not deteriorate with time, as is the case for most other low-noise surfaces. However, there are two things one must keep in mind here:

- (1) The studied time period is only two years so far. This corresponds to about $\frac{1}{4}$ of the normal lifetime of a highway pavement in Sweden, considering the wear of studded winter tyres.
- (2) The traffic volume on the ARO surfaces is very small. However, this site is subject to dust pulled around by wind in the open landscape. The ARG surfaces are located on motorways with medium-to-high traffic volume.

6 Results of rolling resistance measurements

Rolling resistance values are measured and processed as the rolling resistance coefficient (RRC). Only the speed of 80 km/h is used for these evaluations. Where 80 km/h was not used, an interpolation or extrapolation has been done from the other speeds (50, 70 or 110 km/h). Since the speed influence is rather small, the error in this is marginal in relation to other errors. The obtained values are plotted in Fig. 4 as a function of macrotexture expressed as the MPD value. RRC values are the average for the 3 test tyres used and for both driving directions (where it applies). The AR pavements are shown as symbols filled with green. Triangles denote dense pavements (including the SMA and the 3 ARG) and the diamonds denote porous pavements (including the ARO pavement and 5 porous asphalts).

It appears that the correlation between RRC and MPD is good, with 77 % of the total variance explained by the regression. The slope of the regression is very close to the slopes obtained for several other data sets (not reported here).

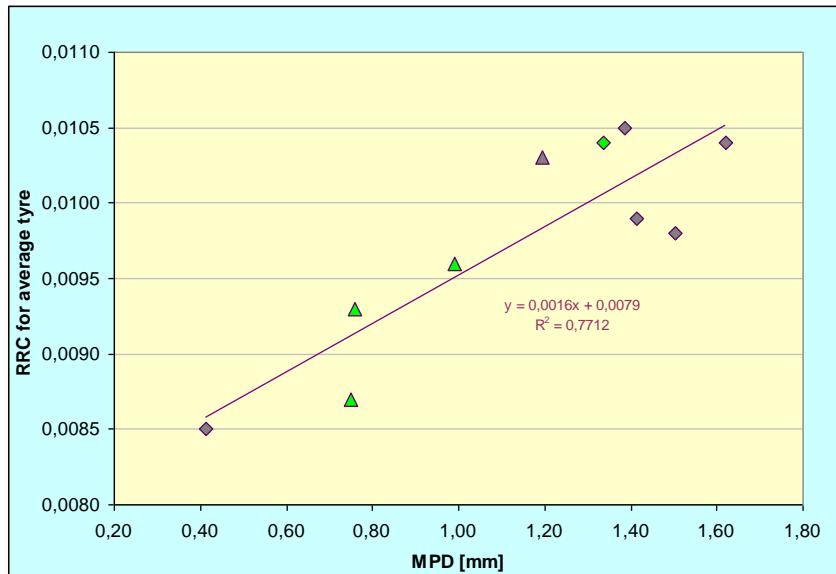


Figure 4 – Results of the rolling resistance measurements, presented as the RR coefficient (RRC) as a function of MPD. RRC values are the average for the 3 test tyres used. Test speed was 80 km/h. The AR pavements are shown with symbols filled with green colour, where the 3 triangles denote the ARG and the diamond denote the ARO pavement.

The AR pavements follow the same relation RRC-MPD as the other pavements. Consequently, there is nothing to win or lose in terms of rolling resistance by using AR in comparison to conventional asphalt pavements. It only depends on the macrotexture. Therefore, if one compares to the SMA 0/16 pavement, which is the dominating pavement type on Swedish highways, the three ARG pavements offer substantially lower RR, namely about 10 %. The data point for the SMA is the uppermost (grey) triangle. This would correspond to a saving of about 2 % of fuel consumption and CO₂ emission. However, the same would be gained if conventional asphalt with equally low MPD values would replace the rougher SMA 0/16. Another conclusion is that the open-graded AR, the ARO 11, creates higher RR than the dense, gap-graded ones, which is mainly if not entirely due to its greater texture depth. Thus, one may say that the noise reduction of ARO versus ARG is obtained while sacrificing some rolling resistance.

7 Discussion

What can one say about the effect of the asphalt rubber on noise reduction (NR); i.e. comparing the ARG with an SMA pavement and the ARO with a porous asphalt concrete; using similar aggregate sizes in the comparison? When using such pavement pairs for comparison the grading curves are reasonably similar in shape and what differs is mainly the binder proportions and material. The author's best estimation is the following:

- ARG 16: Use of rubber gives a favour of 0.5 - 2 dB for car tyres and ±1 dB for truck tyres
- ARG 11: Use of rubber gives 0.5 - 1 dB favour for car tyres and -0.5 -1.5 dB for truck tyres
- ARO 11: According to the simple relation between NR and the product of voids and thickness; see Fig. 11.38 in [8] (verified later by many other data sets), 18 % voids and 30 mm thickness should give only about 1 dB of extra NR due to porosity compared to ARG 11. But it gives about 3 dB extra NR compared to ARG 11. Thus the total "rubber favour" is 2-3 dB.
- ARG 8: Use of rubber gives about 1 dB favour for car tyres and similar for truck tyres
- ARO 8: The author's speculation (this test section had voids filled with rain water when measured) is that this would give a favour of around 2 dB for car and 1 dB for truck tyres
- The trend is that the favour is smaller when pavements are new; larger when they get older

The author does not believe that the reason for the favourable NR is a softer pavement. Rather, it is probably a better optimized texture due to the higher viscosity of the binder

combined with much higher binder content. This and the "cushion" provided by the voids and the binder might result in a better alignment of the upper faces of the stones, which gives a smoother surface in contact with the tyres, due to the rolling in the paving process in combination with the action of traffic. It is somewhat similar to the reason for noise reduction of commercial thin asphalt layers. Another potential contribution might be lower stick-snap noise generation [8] resulting from the lower adhesion between tyre rubber and rubber/binder in AR. For long-term durability, the effective cover of the aggregate provided by the AR binder will protect the layer from oxidation by air exposure and following disintegration.

8 Conclusions

The results of this study suggests that the AR technique provides more favourable conditions for noise reduction, than for similar pavements not using rubber, such as SMA and porous asphalt concrete. The noise reduction advantage would be 1-3 dB; mainly due to low-noise-optimized texture. This is about twice as much as this author expected. Present indications after two years of traffic exposure suggest that the noise advantage might become greater with time and age of the AR pavements. Rolling resistance properties of AR are neutral; i.e. either better or worse than conventional asphalt.

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