Tire/road noise on rubberized asphalt and cement concrete surfaces in Sweden
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This investigation, which has been financed by the Swedish Association of Local Authorities, is part of a larger research programme; a project by the Swedish Council for Building Research named "Use of rubber powder and rubber granulate in road surfaces". The purpose of this project is to establish how and to what extent maintenance costs, winter maintenance, traffic security and noise levels can be influenced if a rubberized asphalt surfacing of type "RUBIT" is laid on longer, continuous stretches of road.

Mr. Kent Gustafson, the Swedish Road and Traffic Research Institute (VTI), has been project manager for the VTI part of the programme.

The investigation was also linked with a parallel study of noise emission on cement concrete surfaces in Sweden which is part of a more general study of such surfaces, sponsored by the Swedish Road Administration. Mr. B.Å. Hultqvist, VTI, was project manager for this project.

Dr. Ulf Sandberg, VTI, has planned the experiments, assessed the results and produced the main parts of the report. All measurements have been performed by Dr. Jerzy A. Ejsmont, Technical University of Gdańsk, Poland, who also collaborated in the planning of the experiments and production of some parts of the report as well as analysed some of the measurements. A special measuring trailer from the University of Gdańsk has been used for the noise measurements as part of a regular research collaboration.

Ms. Eva Gustavsson, VTI, has assisted at the experiments and analysed part of the measurements as well as conducted all computer evaluations. In part of the tests, Ms. Maria Berlin and Mr. Glenn Lindqvist, VTI, have assisted. The report has been typed by Ms. Karin Nilsson and Ms. Barbro Stjärnborg.

The Regional Road Administration in Malmöhus län have provided security vehicles, signs and an assistant for the measurements in Skåne. The Police and the Swedish Army have successfully contributed several times to the "protection" of the measurement trailer registered in Poland...
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SUMMARY

Three road surfaces of the RUBIT type, i.e. asphaltic concrete mixed with rubber granulate, so-called rubberized asphalt, have been tested for external noise emission. These have been compared with a conventional, smooth asphaltic concrete surface (HAB12T) and a conventional, rough chip seal surface (Y1 8-12).

Similarly, three cement concrete surfaces have been tested in a parallel project where the same reference surfaces were used.

The RUBIT surfaces all contained 3% rubber and had 12 mm maximum chip size. They were, however, in somewhat different conditions; one surface being quite new and one being two years old and densely trafficked.

The tests have been performed with the so-called trailer method. A special trailer constructed to measure tire/road noise, from the Technical University of Gdańsk, has been used. Sound levels as well as frequency spectra have been measured.
Five different types of car tires have been used for the tests: one smooth reference tire, two "summer" type tires, one "winter" type tire and one studded "winter" tire. These cover more or less the whole range of car tires, regarding noise emission.

The results show that the RUBIT surfaces emitted noise equivalent to that from the reference surfaces. The exceptions were that the "summer" tires gave 1-3 dB(A) higher noise levels on the oldest RUBIT surface than on the other surfaces (including the reference surfaces), and the non-studded "winter" tire gave the lowest noise on the rough reference surface.

Consequently, traffic noise reduction can not be used as an argument for using RUBIT surfaces of the types tested here. If a RUBIT surface shall have a potential to reduce traffic noise to a considerable extent, it must probably have an unrealistic large proportion of rubber.

Concerning cement concrete surfaces they proved to be more noisy than the conventional bituminous surfaces used as references here. The highest difference was noticed between a rough chip seal and the cement concrete surfaces for a tire with a winter tread pattern.

In all cases the high-frequency noise (over 1 kHz) and low-frequency noise (below 250 Hz) was much higher on the cement concretes than on the bituminous surfaces. The differences between cement concrete surfaces of different age and wear were relatively small.
DÄCK/VÄGBANE BULLER PÅ GUMMIAASFALTBELÄGGNINGAR OCH CEMENTBETONGBELÄGGNINGAR I SVERIGE

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SAMMANFATTNING

Tre vägbeläggningar av typen RUBIT, dvs asfaltbetongbeläggningar med inblandning av gummigranulat, har provats vad avser extern bulleremission. Dessa har jämförts med en konventionell, slät asfaltbetongbeläggning (HAB12T) och en konventionell, skrovlig ytbehandling (Y1 8-12). Vidare har tre cementbetongbeläggningar provats i ett "parallellt" projekt. RUBIT-beläggningarna har samtliga haft 3% (viktprocent) gummiandel och 12 mm max stenstorlek. De har däremot skilt betydligt i tillstånd, från en alldeles nylagd yta till en två år gammal starkt trafikerad yta.

Provningarna har utförts med hjälp av den s.k slapvagnsmetoden. En speciell slapvagn, byggd för mätning av däck/vägbanebuller, från Tekniska högskolan i Gdańsk har använts. Ljudnivåer som har viktats med s.k A-kurva har uppmätts liksom frekvensspektra.

Fem olika däcktyper (personbilsdäck) har använts vid provningarna: Ett slätt referensdäck, två sommardäck, ett odubbat vinterdäck och ett dubbat vinterdäck. Dessa täcker i stort sett in alla förekommande fall vad avser bulleremission.

Resultaten visar att RUBIT-beläggningarna gav en bullerpåverkan som är likvärdig med den från referensbeläggningarna. Skillnaderna överstiger
knappast ca 1 dB(A). Undantagen var dels att den äldsta RUBIT-ytan gav 1-3 dB(A) högre buller än de övriga ytorna (inkl. referenserna) för sommardäck, dels att det odubbade vinterdäcket gav lägst buller på den skrovliga referensytan.

Man kan således inte motivera användning av RUBIT-beläggningar av här provad typ med att de reducerar vägtrafikbullret. För att en RUBIT-beläggning skall ha utsikt att reducera trafikbullret nämnvärt måste den antagligen ha orealistiskt stor gummiandel.

Vad gäller cementbetongbeläggningar, visade de sig ge högre bulleremissjon än de bituminösa beläggningar som var jämförelseobjekt. Skillnaderna var omkring 2 dB(A) till cementbetongens nackdel. Bullerökningarna var i stort sett koncentrerade till låga frekvenser (under 250 Hz) och medelhöga och höga frekvenser (över 1 kHz). Cementbetongytorna var även bullrigare än RUBIT-ytor.

Skillnaderna i bulleremissionen från de mönstrade bildäcken var små mellan de olika cementbetongvägarna oavsett beläggningarnas ålder och grad av slitage.
1. BACKGROUND

Investigations at the Swedish Road and Traffic Research Institute (VTI) have shown that the variation of traffic noise levels on different road surfaces, with similar traffic, is as large as the variation of vehicle noise levels from separate vehicles on one surface. This applies to free-flowing traffic at a posted speed of more than 50 km/h. Consequently, it is as easy or as difficult to influence the overall traffic noise by choice of road surface as by selection of vehicles.

A consequence of the above is that the road authorities as well as vehicle manufacturers and drivers should assume the responsibility for reduction of traffic noise.

The type of road surface which is regarded as the one giving the lowest emission of road traffic noise is drainage asphalt. When new, such a surface can give at least 5 dB(A) lower traffic noise than a non-porous and smooth asphaltic concrete surface (Ref. 1). There are also some indications that a soft surface gives lower noise than a hard one - for example with an extreme porous all-rubber surface, reductions in vehicle noise have been measured to 10 dB(A) (Ref. 2).

A rubberized asphalt surface contains normally about 3 % rubber in granulated form which has been supposed to give a significant reduction of noise. Such surfaces exist under the trademark "RUBIT" (in USA "Plus Ride"). Recently, a number of RUBIT surfaces have been laid in Sweden for experimental reasons and the VTI has been commissioned to investigate their function; including also the noise properties.

In the noise measurements, it was found necessary to coordinate the measurements of noise properties on cement concrete and RUBIT surfaces with the testing of noise properties of some car tires, the latter of which was planned to be conducted in another experiment. Certain tires and reference surfaces could thereby be used for all three purposes and measuring equipment borrowed from Poland could be used to rationalize the measurements.
2. PURPOSE

The purpose of this study was to investigate how the noise emission from tires rolling on RUBIT surfaces and cement concrete surfaces in Sweden differ from the noise emission from tires rolling on conventional asphalt surfaces.

3. HYPOTHESES ABOUT NOISE EMISSION ON ROADS WITH A RUBBERIZED ASPHALT SURFACING

There are two properties in a rubberized asphalt surface which can contribute to a relatively low noise emission:

1. The rubber mixture makes the road surface somewhat softer. This can lead to lower noise being emitted from the road surface itself (nearest to the tire/road contact patch) as well as the impact between tire pattern blocks and road surface perhaps being a little "softer", that is the tire/road mechanical impedances will be different compared to the case when the surface is a normal asphaltic concrete.

The VTI has shown that brand new asphaltic concrete surfaces are somewhat more silent than those that are older (at least one winter season), and that this difference cannot be a consequence of the difference in macrotexture only. Furthermore, bituminous surfaces seem to be more silent than cement concrete when the same texture is concerned. The differences are small, but measurable. See further Ref. 8.

However, as the difference in hardness between rubberized and conventional asphaltic concrete surfaces is rather small, the difference in noise, if any, is expected to be small.

2. The macrotexture of new RUBIT surfaces is more or less like that of conventional asphaltic concrete when it is still new. Asphaltic concretes will, normally, become compact and smooth with time and wear, whereas the macrotexture of RUBIT surfaces will stay rough or
even become rougher with time. This has been observed in earlier experiments with RUBIT surfaces laid near VTI.

Since a too smooth macrotexture usually gives higher noise levels than surfaces with a certain moderate macrotexture, a RUBIT surface should present a good compromise between smooth and rough texture. However, the noise effect of this is probably quite small.
4. PREVIOUS NOISE MEASUREMENTS ON RUBBERIZED ASPHALT

At the VTI, measurements were made from 1977 to 1979 on a RUBIT with 3% rubber granulate and 12 mm maximum chipping size and a RUBIT with 6% and 16 mm maximum chipping size. The results are summarized in the following.

4.1 Tire/Road Noise in A-weighted Levels

According to Appendix 1, which is an extract from VTI Reprint No. 45, the RUBIT surfaces gave about 1 dB(A) lower tire/road noise than conventional, dense asphaltic concrete surfaces and 2-3 dB(A) lower noise than the relatively new chip seals. 1 dB(A) is approximately the smallest change in noise that the ear can detect under ideal conditions.

4.2 Noise Emission at Low Frequencies

Due to the noise insulation of buildings, the character of sound is changed when transmitted through facades into dwellings. This means that low-frequency traffic noise is the most important within dwellings. This applies when all windows are properly closed and made draughtproof. The low-frequency noise also strongly dominates inside vehicles. It is, consequently, interesting to distinguish the influence the RUBIT surfaces have partly on the low-frequency noise, partly on the high-frequency noise.

Please see extracts from VTI Reprint No. 56 in Appendix 2 (Figs. 7-8, noise from "summer" and "winter" tires, respectively). There one can see that the RUBIT surfaces emit low noise levels only when they are new, i.e. when they are extra soft; but also asphaltic concrete surfaces emit low noise levels directly after the laying.

After one or several winter seasons, the RUBIT surfaces gave noise levels that were neither low nor high. Consequently, there is no significant advantage in using RUBIT for improving the indoor environment.
4.3 Noise Emission at High Frequencies

High or medium frequencies are important near the road (outdoors) and, together with low-frequency noise, also for indoor environment when windows are more or less open. See Figs. 11-12 in Appendix 2. The RUBIT surfaces give medium noise levels at high frequencies.

4.4 Traffic Noise

As traffic noise is strongly dominated by tire/road noise in free-flowing traffic, it is possible to generalize the above to traffic noise as a whole provided it comes from free-flowing traffic. If the traffic accelerates or decelerates, the difference between the surfaces, as regards traffic noise, is smaller than for tire/road noise - frequently even negligible.

4.5 Other Measurements

The authors know only two more measurements that have been performed on noise emission from rubberized asphalt. The first was made about 10 years ago as part of a thesis at the Chalmers University of Technology. The tire/road noise on 7 different surfaces was compared: three Topeka, one RUBIT (3 % rubber, 16 mm chipping size), one conventional asphaltic concrete with 22 mm chippings, one "Mastiphalt" and one "SCB special". The result was that the RUBIT surface was one of the three loudest; however, the differences were very small (Ref. 3).

The second one was made in Denmark (Ref. 10) on a RUBTOP surface with max 8 mm chippings. It was found that traffic noise on this surface was within 0.5 dB(A) from other similar surfaces of conventional construction.

4.6 Other Rubberized Asphalt Surfaces

It is not impossible that a RUBIT surface with somewhat better noise properties than the ones tested, can be manufactured. In this case it ought
to contain more rubber than 6 % (percentage by weight) and the chippings should not be bigger than 12 mm, preferably maximum 10 mm. It should furthermore be manufactured with a relatively open texture.

It has been suggested that a rubber additive in the binder could possibly have an effect on noise. Some years ago VTI tested a drainage asphalt (HAB12D) with a rubber additive in the binder (road E4 at Nyköping). The rubber proportion there was 18 % (by weight) of the binder. It did not give lower noise than the corresponding surface without such rubber additive. For such an additive to be efficient, the proportion of rubber probably must be increased considerably.
5. ROAD SURFACES

5.1 Test Surfaces

The following road surfaces were included in the measurement programme as test objects:

RUBIT Glumslöv (E6)

This is an asphaltic surface with 3% rubber (by weight), 12 mm maximum chipping size and a larger proportion of stone than conventional surfaces. It is laid on the E6 motorway (with 4 lanes and a posted speed of 110 km/h) between Glumslöv and Hilleshög, for a stretch of about 1 km, but only in the southbound lanes. The surface was slightly more than 2 years old at the time of the measurements. The noise was measured in the right wheel track of the right lane. See Fig. 1.

RUBIT Norrköping

The same type of surface as at Glumslöv is laid on Söderleden (2 lanes, 70 km/h) in Norrköping, for a stretch of 450 m at the underpass under road 799. The surface was slightly more than one year old at the time of the measurements. The right wheel track in both directions was used for the measurements.

RUBIT Arboga (E3)

This is the same type of surface as at Glumslöv but laid with repaving. It is situated on road E3/E18 (2 lanes, 90 km/h) from the exit at Arboga (direction Örebro) to the province border, about 13 km. The surface was about one month old at the time of measurements. The texture of the surface was very inhomogeneous with patches of bleedings and patches of fairly open texture. See Figs. 2-3.
Figure 1  The RUBIT surface at Glumslöv. The surface is two years old and one can see the dark rubber particles between the bright chippings.

Figure 2  The RUBIT surface at Arboga. This surface is completely new. The same scale as above.
Figure 3 The RUBIT surface at Arboga. Note the inhomogeneity of the surface, with patches of bleedings mixed with more open-textured areas.

CE4, in wheel track

This cement concrete surface was 11 years old at the time of the measurements and is situated on the E4 between Väla and Hyllinge north of Helsingborg (4-lane motorway, 110 km/h) for a stretch of about 4 km. The right wheel track of the right lane was used in both directions for the measurements.

CE6, in wheel track

The second cement concrete surface was 17 years old. This site is on the E6 between Fosie and Vellinge (about 12 km), south of Malmö (4-lane motorway, 110 km/h). The measurements were made in the right wheel track of the right lane in both directions. See Fig. 4.

CE6, between wheel tracks

As above, but the measurements were performed in the left lane, between the wheel tracks, i.e. on the part of the road surface that was least worn. See Fig. 5.
Figure 4 The surface of the cement concrete CE6 (in the right wheel track). The chippings are exposed.

Figure 5 The surface of the cement concrete CE6 (between the wheel tracks). The chippings are relatively unexposed.
5.2 Reference Surfaces

The test surfaces were compared to the following "conventional" road surfaces:

**HAB12T**

HAB12T was a smooth, dense asphaltic concrete surface with 12 mm maximum chipping size. This surface was 4 years old at the time of measuring. It is situated on road RV 34, 1 km south of the roundabout at Jägarvallen, Linköping, where there is a 2-lane long straight with very wide shoulders. The posted speed is 90 km/h. Measurements were performed in both directions.

**Y1 8-12**

This rough reference surface was a single chip seal with 8-12 mm chippings, one year old at the time of measurements. It is laid on road 1025 (2 lanes, 70 km/h) within the Regional Road Administration in Östergötlands län, just south of the T-intersection with road 1024 at Västerlösa, 5 km north of Mantorp and it has been only lightly trafficked. Measurements were made in both directions between the wheel tracks.

Qualification as Reference Surfaces According to ECE Proposal

The HAB12T surface meets the requirements for the smooth reference surface for tire/road noise measurements according to the proposed standard (Ref. 4), while the Y1 8-12 surface satisfies the demands on the rough reference surface.
5.3 Texture Measurements

In another investigation, the road surface texture has been measured by VTI on the reference surfaces HAB12T and Y1 8-12 with the mobile laser profilometer (Ref. 9). This yielded the following results:

HAB12T

Macrotexture level, $L_{Ma} = 48.4$ dB (corresponding to 0.26 mm RMS)

Megatexture level, $L_{Me} = 47.8$ dB (corresponding to 0.25 mm RMS)

Y1 8-12

Macrotexture level, $L_{Ma} = 61.5$ dB (corresponding to 1.19 mm RMS)

Megatexture level, $L_{Me} = 57.0$ dB (corresponding to 0.71 mm RMS)

Based on studies of the correlation between the profilometer values and sandpatch measurements, the macrotexture values above can be converted to an estimated equivalent sandpatch texture depth of

for HAB12T: 0.40 mm
for Y1 8-12: 2.54 mm

The sandpatch texture depth of the RUBIT surfaces has been measured by the VTI Road Department to:

RUBIT Glumslöv 0.93 mm (measured 4 months before the noise measurements)

RUBIT Norrköping 0.91 mm (measured 5 months before the noise measurements)

RUBIT Arboga 0.54 mm (measured the same month)
On the cement concrete surfaces there are no known texture measurements. However, using a complicated procedure, the sandpatch texture depth has been estimated from the low-frequency noise emission of the P tire by inter- and extrapolating the measurement values of HAB12T and Y1 8-12. This has given the following roughly estimated sandpatch texture depth for the cement concrete surfaces:

- CE4, in wheel track: 0.2 mm
- CE6, in wheel track: 0.4 mm
- CE6, between wheel tracks: 0.5 mm
6. MEASURING METHOD AND INSTRUMENTATION

6.1 Test Method Selection

There are four "on-the-road" methods which can be used for road surface noise comparisons, namely the coast-by, trailer, on-board and traffic methods. The first two are subject to international standardization trials by the ECE (United Nations Economic Commission for Europe). See Refs. 4 and 5.

In the coast-by method, the vehicle with the test tires coasts by a roadside microphone which is placed 1.2 m above the road level and 7.5 m from the centre line of the vehicle path. At least five runs should be made and averaged. This method is judged to be the most relevant when emission to the external environment is considered but is also the most time-consuming and weather dependent. The method is very sensitive to disturbance from other traffic and background noise. It is practically impossible to use this method on a motorway with very dense traffic, not only because of disturbances but also due to safety and technical problems (e.g. to turn around, it is necessary to use road exits which are usually quite distant).

In the trailer method, a test wheel is mounted on a trailer which is towed by a car or truck. A microphone is positioned close to the tire/road contact area. The microphone position recommended for passenger car tires by the ECE proposal is 0.2 m outside the undeflected tire sidewall, 0.1 m above the road level and 0.2 m behind the vertical axle plane (Ref. 4). The wheel and microphone can be screened from outside noise by a special enclosure. The method is relatively independent of wind conditions and noise from other traffic and requires only one test tire at a time. The method is recommended in environments with disturbing traffic, for instance on highly trafficked motorways where no other method is possible without closing the road. The biggest disadvantages are that it is a near-field type of measurement and that it is unsuitable for testing on surfaces with significant sound absorption, unless some corrections are applied (which are difficult to determine).
The on-board microphone method is similar to the trailer method, with the exception that one of the wheels of the vehicle is used as the test wheel; thus no enclosure can be used for reduction of disturbing noise, and also sound reflections are uncontrolled. The on-board method is less suitable for measurements in noisy environments than the trailer method.

The traffic method is based upon measurements of overall noise emitted by single vehicles passing by a stationary microphone at the roadside. To get reliable results, it is necessary to measure noise from at least 100 cars and 30 trucks as well as their speed. Grades on the test sites cannot be accepted and there must be no reflecting objects within 50 m from the microphone. The results cannot be related to any particular type of tires.

In this project, the trailer method was chosen as its advantages overrun the disadvantages. All of the measured road surfaces were placed on roads with high or medium traffic. None of the surfaces had any significant sound absorption. As the test trailer from the Technical University of Gdańsk was readily available, and to be used in other, similar measurements, the cost of these additional measurements was very low. An extra advantage was that it was possible to utilize some results of measurements by the trailer method on reference surfaces, which had to be performed for other reasons. Grades on two of the sites and reflective environments on at least one of the sites made it impossible to use the traffic method, which otherwise would have been the most relevant.

6.2. Description of the Test Trailer

The trailer used for the measurements, "Tiresonic Mk3", was built at the Technical University of Gdańsk, Poland. It is shown in Fig. 6. The test wheel of the trailer is enclosed in a semi-anechoic enclosure formed by the sound-reflective road surface and the trailer chamber lined with polyurethane foam to suppress reflections. The suspension was designed to make possible a ground clearance under the lower edge of the chamber of 20-40 mm. The measuring microphone was positioned as described in paragraph 6.1.
During preliminary tests at the TUG laboratory (with the trailer at standstill), the amplitude and frequency response of the semi-anechoic chamber was investigated by comparing the noise when the chamber was in position and when it was lifted away. The latter represents a free-field case (with reflecting road surface). See Fig. 7. The response characteristic was found to be reasonably flat, at least for the important range of frequencies. For a typical tire with summer tread pattern, the difference from free field conditions in A-weighted sound level amounts to max. ±0.5 dB(A) over the range 250-10 000 Hz. Any deviations from ideal characteristics are the same for each tested road or tire so that the relations between the tested roads are not disturbed in this study.

The trailer was also tested for background noise influence which appeared to be negligible for typical tire/road combinations (see Ref. 5).
During all measurements the tires were loaded to 3.0 kN and the cold inflation pressure was 190 kPa.

For each tire/road/speed combination, at least 3 or 4 runs were averaged. Each run was 16 s in duration, except on some of the reference surfaces when sometimes 8, 32 or 64 s was used. Even with the minimum 3 times 16 s, the measuring accuracy is practically uninfluenced by random errors, except those arising from inhomogeneous texture on the road surfaces.

6.3 The Test Tires

To reliably compare noise emission on the road surfaces it is necessary that different and representative tires be used during the measurements. Tires of different types may interact with road surfaces in different and
sometimes even opposite ways. The tires chosen for the experiment were selected in such a way as to cover a wide range of designs typical of present cars. All tires were of the 165R15 size. A short description of the test tires is given below (see also Fig. 8).

- Tire P is a standard reference tire without tread which can represent the extreme case when the tire tread pattern is worn out.

- The tires S and M represent ordinary "summer" tires.

- The tire G represents "winter" (snow) tires without studs, in this case with a relatively aggressive pattern. There are "winter" tires with more "closed" patterns but these are, in terms of noise emission, more similar to the S and M tires.

- The tire GS is the same as G, but with studs, and thereby represents the most common tire type in wintertime in Sweden.

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<td>165 SR 15 XZC</td>
<td>MICHELIN</td>
<td>Summer Tire</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>165 R 15 86 G M+S FROST</td>
<td>GISLAVED</td>
<td>Winter Tire</td>
<td></td>
</tr>
<tr>
<td>GS</td>
<td>165 R 15 86 G M+S FROST</td>
<td>GISLAVED</td>
<td>Winter Tire with 108 studs</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 8** The selected test tires
7. REMARKS ON THE MEASUREMENTS

7.1 Safety Precautions

The trailer method, if performed in a proper way, is a very safe method. During all the measurements the trailer was marked with reflective signs "MÄTNING" (= measurement) and the towing car had yellow flashing lights on the roof. Measurements on the motorways E4 and E6 were additionally supported by two follow-up trucks supplied by the road authorities. The first truck was running approx. 100 m behind the test trailer and the second about 700 m behind. Whenever it was necessary to exchange tires, these were exchanged in safe parking areas.

7.2 Test Site RUBIT Norrköping

These tests were performed in September 1989. The weather was clear and sunny. The measuring site was located in a very inconvenient place: in a grade, in a curve and with a junction on one side. The traffic volume of light vehicles was very high and some runs had to be repeated. During some of the runs a grass mower operated close to the roadside, but it was not audible in the earphones. The measurements were performed in both directions, one test at a time.

7.3 Test Site RUBIT Arboga

The tests were performed in September 1989. The humidity was very high and the measurements were interrupted by drizzles several times. Each time they were resumed when the surface appeared dry. The traffic intensity was rather low. The surface of the test site was very nonuniform due to bleeding on some spots and it was audible that noise was re'sted to the trailer position on the road. See Fig. 3. The measurements were performed in both directions.
7.4 Test Site RUBiT Glumslöv

The tests were performed in September 1989. The humidity was very high and there were occasional showers near the road. The measuring site was located on a small hill and in a gentle curve. The traffic was very dense and some of the tests were repeated because of traffic disturbances. The measuring runs were conducted only in one direction, in the right lane.

7.5 Test Site Cement Concrete (CE4)

The tests were performed in September 1989. The weather was good and the traffic was of medium or low intensity. Part of the road was under reconstruction which was a big nuisance since the trailer had to pass an area sprayed with bitumen. Fortunately, it was after passing the measuring site. The measurements were performed in both directions.

7.6 Test Site Cement Concrete (CE6)

The tests were performed in September 1989. The weather was unstable with a constant danger of rain. Traffic intensity was medium or low. The measurements were performed in two lanes (left and right) and in both directions (to and from Malmö). In the left lane, the test wheel was running between the wheel tracks while in the right lane it was running in the right wheel track.

7.7 Speed Control

The test speed was controlled by the driver by aid of a specially designed speedometer showing the deviation between nominal and true speeds of the car and trailer unit. The precision in the speed adjustments was mostly better than ±1 km/h - typically 0.5 km/h.
8. RESULTS

8.1 A-weighted Sound Levels

The sound levels in dB(A) are to be found in Table 1. Note that these levels are measured with the trailer method, i.e. with the microphone in the near field. According to Ref. 5, 20 dB should be subtracted from these values to correspond to the levels which would have been measured with the coast-by method 7.5 m from the vehicle.

Table 1. The measured sound levels in dB(A) for all the surfaces and tires that were included in the investigation.

<table>
<thead>
<tr>
<th>Road surface</th>
<th>Speed km/h</th>
<th>P</th>
<th>S</th>
<th>M</th>
<th>G</th>
<th>GS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUBIT Glumslöv</td>
<td>50</td>
<td>87.7</td>
<td>91.0</td>
<td>91.3</td>
<td>90.7</td>
<td>96.1</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>91.4</td>
<td>95.0</td>
<td>95.9</td>
<td>96.1</td>
<td>100.5</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>93.0</td>
<td>98.5</td>
<td>99.9</td>
<td>99.9</td>
<td>103.2</td>
</tr>
<tr>
<td>RUBIT Norrköping</td>
<td>50</td>
<td>85.0</td>
<td>88.6</td>
<td>88.4</td>
<td>88.8</td>
<td>95.3</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>89.5</td>
<td>93.6</td>
<td>93.4</td>
<td>94.5</td>
<td>99.5</td>
</tr>
<tr>
<td>RUBIT Arboga</td>
<td>50</td>
<td>83.7</td>
<td>88.8</td>
<td>88.8</td>
<td>89.8</td>
<td>95.5</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>88.5</td>
<td>93.4</td>
<td>93.4</td>
<td>95.4</td>
<td>100.2</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>92.8</td>
<td>97.6</td>
<td>96.9</td>
<td>100.3</td>
<td>103.4</td>
</tr>
<tr>
<td>HAB12T</td>
<td>50</td>
<td>84.4</td>
<td>88.6</td>
<td>88.8</td>
<td>89.4</td>
<td>94.8</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>89.8</td>
<td>93.8</td>
<td>94.1</td>
<td>94.9</td>
<td>100.0</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>93.0</td>
<td>98.0</td>
<td>98.1</td>
<td>100.0</td>
<td>103.4</td>
</tr>
<tr>
<td>Y1 8-12</td>
<td>70</td>
<td>93.0</td>
<td>93.4</td>
<td>93.5</td>
<td>91.9</td>
<td>100.0</td>
</tr>
<tr>
<td>CE4 in wheel track</td>
<td>50</td>
<td>86.8</td>
<td>90.6</td>
<td>90.4</td>
<td>91.7</td>
<td>96.6</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>93.0</td>
<td>96.1</td>
<td>95.7</td>
<td>97.5</td>
<td>101.8</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>97.9</td>
<td>100.2</td>
<td>99.6</td>
<td>102.4</td>
<td>105.5</td>
</tr>
<tr>
<td>CE6 in wheel track</td>
<td>50</td>
<td>87.6</td>
<td>91.1</td>
<td>91.2</td>
<td>91.8</td>
<td>96.2</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>93.7</td>
<td>96.6</td>
<td>96.4</td>
<td>98.1</td>
<td>101.4</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>97.1</td>
<td>101.0</td>
<td>100.6</td>
<td>102.9</td>
<td>105.3</td>
</tr>
<tr>
<td>CE6 between tracks</td>
<td>50</td>
<td>89.2</td>
<td>90.1</td>
<td>90.4</td>
<td>91.1</td>
<td>96.0</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>93.9</td>
<td>95.4</td>
<td>95.6</td>
<td>97.1</td>
<td>100.9</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>98.3</td>
<td>100.1</td>
<td>99.9</td>
<td>101.8</td>
<td>104.7</td>
</tr>
</tbody>
</table>
The results are presented as charts in Figures 9-13. In the charts the bars are located from left to right in ascending roughness order of the road surfaces, i.e. the smoothest texture to the left and the roughest to the right. Observe that the lowest level in the charts is not the "zero level". Furthermore this lower level is different for different speeds. A difference of 1 dB(A) is said to be the absolutely smallest difference detectable by the human hearing and a difference of 9-10 dB(A) is said to represent a doubling of the subjective impression.

Corresponding comparisons for the cement concrete surfaces are shown in Figures 14-18.

8.2 Frequency Spectra

In Figures 19-23, the frequency spectra in third octave bands of the RUBIT surfaces are presented and compared to the smooth reference surface HAB12T as well as the rough surface (Y1 8-12).

Similarly, in Figures 24-28 the corresponding spectra for the cement concrete surfaces are presented and compared to the smooth reference surface HAB12T as well as the rough reference surface Y1 8-12.

8.3 Comments Regarding Drainage Asphalt Surfaces

As previously reported, no porous asphaltic concrete surface (drainage asphalt) was included among the reference surfaces although this would have been interesting. However, the effect of drainage asphalt on traffic noise is well known already, see e.g. Table 1 in Ref. 6. This table applies to overall road traffic noise, whereas in this report tire/road noise is discussed. However, at speeds at or above 50 km/h the overall noise is more or less equal to tire/road noise. If a drainage asphalt surface (0-1 years old) had been included in Figures 9-13, its bar would have ended at least 5 dB(A) beneath the one for surface HAB12T, provided the measurement had been performed with an appropriate method (the trailer method is not suitable in this case).
Figure 9  Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire P is the smooth reference tire from PIARC.
Figure 10  Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire S = "Summer" type tire, Firestone Cavallino S1.
Figure 11  Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire M = "Summer" type tire, Michelin XZX.
Figure 12  Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire G = "Winter" type tire, non-studded, Gislyved M+S Frost.
Figure 13  Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire GS = "Winter" type tire, studded, Gislaved M+S Frost.
Figure 14  Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire P is the smooth reference tire from PIARC.

CE4 RWT = Cement concrete, in right wheel track
CE6 RWT = Cement concrete, in right wheel track
CE6 BWT = Cement concrete, between wheel tracks
Figure 15 Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h.

Tire S = "Summer" type tire, Firestone Cavallino S1.

CE4 RWT = Cement concrete, in right wheel track
CE6 RWT = Cement concrete, in right wheel track
CE6 BWT = Cement concrete, between wheel tracks
Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h.

Tire M = "Summer" type tire, Michelin XZX.

CE4 RWT = Cement concrete, in right wheel track
CE6 RWT = Cement concrete, in right wheel track
CE6 BWT = Cement concrete, between wheel tracks
Figure 17  Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire G = "Winter" type tire, non-studded, Gislaved M+S Front.

CE4 RWT = Cement concrete, in right wheel track
CE6 RWT = Cement concrete, in right wheel track
CE6 BWT = Cement concrete, between wheel tracks
Figure 18  Sound levels in dB(A) measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire GS = "Winter" type tire, studded, Gislaved M+S Front.

CE4 RWT = Cement concrete, in right wheel track
CE6 RWT = Cement concrete, in right wheel track
CE6 BWT = Cement concrete, between wheel tracks
Figure 19 Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire P is the smooth reference tire from PIARC.
Figure 20  Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire S = "Summer" type tire, Firestone Cavallino S1.

Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire S = "Summer" type tire, Firestone Cavallino S1.
Figure 21  Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. 
Tire M = "Summer" type tire, Michelin XZX.
Figure 22  Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h.
Tire G = "Winter" type tire, non-studded, Gislaved M+S Frost.
Figure 23 Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire GS = "Winter" type tire, studded, Gislaved M+S Frost.
Figure 24  Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h.
Tire P is the smooth reference tire from PIARC.
Figure 25  Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. 
Tire S = "Summer" type tire, Firestone Cavallino S1.
Figure 26 Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire M = "Summer" type tire, Michelin XZX.
Figure 27  Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h.  
Tire G = "Winter" type tire, non-studded, Gislaved M+S Frost.
Figure 28  Frequency spectra measured on the different road surfaces at the speeds of 50, 70 and 90 km/h. Tire GS = "Winter" type tire, studded, Gislaved M+S Frost.
9. DISCUSSION

The measured noise levels for the three RUBIT surfaces show that the surface in Glumslöv is 1-3 dB(A) noisier than the others, if the "winter" type tires are excluded. This could e.g. be on account of:

- It is rougher than the others
- It has become stiffer (more compacted) than the other two (it is the oldest one and has been exposed to the most intensive traffic)
- Owing to chip loss, cavities have appeared in the texture. These may cause high frequency "air pumping" or "air resonant" noise (the enclosed air is compressed and expanded when the tires roll over the cavities).

It should also be noted that the Glumslöv site is not fully representative of RUBIT, since it has too small a proportion of fine material (< 4 mm) and thus too big a proportion of the big stones. Because of this deficiency in the proportioning of the mix, the surface has a rough texture and it could also have influenced the chip loss tendency.

On the whole, the RUBIT surfaces in Norrköping and Arboga are, as concerns noise, equivalent to the reference surface HAB12T. The differences are essentially within 1 dB(A).

For the winter tires, the differences between the surfaces are only 0-2 dB(A), which is almost negligible. The only notable thing is that the rough chip seal (Y1) is the most silent one when testing with tire G.

Usually, new asphalt surfaces (like the "RUBIT Arboga" here) are 1-2 dB(A) more silent than old asphalt surfaces like the HAB12T. In spite of the RUBIT surfaces being considerably younger than the HAB12T surface, they display no advantage concerning noise. The oldest one even seems to be worse than the reference surfaces.

As regards frequency spectra, their form is influenced by the texture. Smoother surfaces usually emit less noise at low frequencies and more
noise at high frequencies and vice versa. The RUBIT surface at Glumslöv seems to give more noise even at high frequencies (though not when using "winter" tires). In order to cause such an effect, its texture ought to be both rougher and denser and this could be the case due to wear and compacting. However, it is likely that the "pockets" in the surface due to the chip loss play a role here to generate the high frequency noise, and the roughness may have caused the low frequency noise.

As to the rest, the frequency spectra of the surfaces are similar and cannot be interpreted as more or less discriminating for any of the surfaces.

Are there better RUBIT surfaces as regards noise influence? All those that have been tested here have had a rubber proportion of 3% and 12 mm maximum chipping size. Bigger chippings would give higher noise levels, while smaller chippings would give lower levels; however, the same applies to conventional road surfaces. A larger rubber proportion would maybe reduce noise; however, 6% would probably not be enough, but even larger proportions would have to be used.

The cement concrete surfaces used in this experiment appeared noisier than both the smooth and rough reference surfaces no matter what tires and what test speeds were used. Generally, they also appeared noisier than the RUBIT surfaces. The typical increase of noise in comparison to the smooth asphalt road surface was around 2 dB(A). For the "winter" tire without studs, the increase was as high as 6 dB(A) in comparison to the rough chip seal. It must be pointed out that the tested cement concrete surfaces had no artificial anti-skid treatment like brushing, grooving etc., in which case they might have been even noisier.

For most speed and tire combinations the highest sound levels were observed on the worn cement concrete (RWT). However, with the exception of the results for the P tire, the difference in noise between the concrete surfaces was no more than 1 dB(A).

Generally, low-frequency noise (up to 250 Hz) emitted by the tires when running on the cement concrete surfaces, was higher than on the smooth
asphalt road, but lower than on the rough chip seal. In the range 250-1000 Hz, the differences between all the surfaces were rather small. Above 1 kHz the cement concrete surfaces were louder than the smooth asphalt surface and very much louder than the rough surface. The highest difference was actually observed for the smooth tire P. One possible explanation, which is supported by a visual inspection of surface photos, is that in some cement concrete surfaces there has been a considerable chip loss, which has created small cavities in the surface. The cavities are sealed by the tread rubber, particularly when the tread is completely smooth, and this increases noise generated by the air-pumping mechanism. The same phenomenon was observed in Ref. 8 (Fig. 8, p. 7:20).

A good deal could be said about comparisons between the different tires, but this is not within the scope of this report.

Note that these measurements only deal with the noise in the vicinity of the road. The noise inside the vehicles can be affected differently by the road surfaces.

10. CONCLUSIONS

The RUBIT surfaces that have been tested here don't give lower noise levels than conventional asphalt surfaces or chip seals but are essentially equivalent to these. On the contrary, the oldest RUBIT surface seems to increase the noise level somewhat when using "summer" type tires. The increase is, however, not very alarming.

As RUBIT surfaces do not reduce noise significantly, good noise properties cannot be incentives for using such surfaces. Any marketing of present types of RUBIT surfaces for noise reduction would appear false.

The use of cement concrete surfaces of the type tested here would mean higher traffic noise than the use of conventional bituminous surfaces, no matter if they are smooth- or rough-textured.
REFERENCES

1. SANDBERG, U.: Reduktion av trafikbuller genom användning av dränerande vägbeläggning (Reduction of traffic noise by using drainage road pavement). VTI Preprint No. 92, Swedish Road and Traffic Research Institute, Linköping (1984). (In Swedish)


APPENDIX 1: SUMMARY OF EARLIER COMPARISONS

Difference in tire/road noise between some road surfaces. The most interesting bars to compare are those marked by shadowing. RUBIT seems to be equal to or somewhat more silent than the "conventional" asphalt concrete HAB12T and HAB16T as well as the chip seal (surface dressing) Y1 12-16.

Extract from VTI Reprint No. 45 (Figure No. 2 in this Reprint):

Difference between tire noise on pavement OGEAM and other pavements. Dry roads, 90 km/h. Volvo 142 (1972) with tires Firestone S1 Cavallino 165SR15 ("summer" type).

Notes: The dashed bar is power train noise calculated from measurements of overall vehicle noise and tire noise respectively. The numbers above the pavement specification, are the maximum aggregate size (mm). Pavements marked x are typical on Swedish roads. Others are experimental, uncommon or temporary.
APPENDIX 2: NOISE AT LOW AND HIGH FREQUENCIES VERSUS ROAD TEXTURE (EARLIER MEASUREMENTS)

Extract from VTI Reprint No. 56.

Comments: The figures show tire/road noise at low frequencies (400 or 500 Hz, Figs. 6-9 in the Reprint) and at high frequencies (2500, 3150 or 8000 Hz, Figs. 10-13) respectively, as a function of the macrotexture of the road surfaces. Filled triangles represent RUBIT surfaces. When these fall beneath the regression lines, it means that they are more silent than the majority of the surfaces.

Fig 6-13: Noise vs. tire/road texture critical band levels. The actual regression in fig. 7 could be seen as the superposition of 2 roughness excitations: L_ALD due to tire tread, L_ALV due to pavement; see procedure in /14/