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POROELASTIC ROAD SURFACES - STATE-OF-THE-ART REVIEW

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ABSTRACT
The poroelastic road surface type was invented in Sweden 20 years ago. Early tests indicated excellent acoustic and wear properties, but adhesion to the base course was inadequate and friction and fire problems were noted. In later years, new variants of poroelastic surfaces have been tested in projects in Japan and Sweden. This paper reviews the developments so far, and reports briefly on some recent tests in Japan of adhesion, friction and fire properties, the results of which seem promising. However, to-date there are no poroelastic road surfaces which have left the experimenting stages, but full-scale tests are being planned.

1 - INTRODUCTION
The most common road traffic noise abatement measure is to build noise barriers along the road (in Sweden it happens to be the exchange of windows to more efficient ones, but this is another story). This will give a reasonable noise reduction, generally 5-12 dB, for those who live in the acoustical shadow zone. However, barriers are expensive and they seriously impact the visual appearance of the area; in some cases the residents have even opposed to the barriers.

In search for alternative noise reduction measures, the use of extra effective low noise road surfaces has been considered. In order to be a realistic alternative to a noise barrier they need to reduce the sound levels by at least 5 dB, preferably by around 8 dB, and such reduction should not only be valid for a new surface but persist for a reasonable time, i.e. until the surface can be relaid. This is their weak point. Porous surfaces seem to be the only ones that have the potential of being effective to the extent mentioned above, but so far no surface type has remained that effective for more than a few years.

A relatively new surface type that may have a potential for meeting the efficiency criterion is the double-layer porous surface called "Twin-lay". This surface type is designed especially with longterm efficiency in mind, relying on periodic cleaning with high-pressure water jets. In another paper at this conference, measurements indicating a noise reduction of 6-7 dB of a newly laid Twin-lay are reported [1].

However, the surface type which seems to hold the best potential for becoming a real efficient noise reduction measure is the poroelastic road surface. This paper attempts to give a review of the achievements so far and the status in development of such surfaces.

2 - WHAT IS A POROELASTIC ROAD SURFACE?
A poroelastic road surface consists of granules or fibers of rubber bound together with a binder of e.g. bitumen or polyurethane. It may also contain some sand and/or stone material. The lack of fine-graded material in the surface will make it highly porous (generally 25-35 % voids); the high content of rubber (at least 20 % by volume) makes it elastic.

3 - HISTORY AND EARLY TRIALS IN SWEDEN
The poroelastic road surface was invented and patented at the end of the 70's by Mr. Nils-Ake Nilsson, then at the acoustic consultant company IFM Akustikbyran AB in Stockholm. A first and very brief

presentation of the surface appeared in [2]. By that time only some promising acoustic laboratory experiments had been made, indicating a tire/road noise reduction of around 5 dB(A). Acoustic development in the 80's increased the noise reduction effect to 10 dB(A) [3]. A summary of all acoustic measurements made before 1990 is presented in Table 1. Not many tests other than acoustic were made, except very simplified tests of wear, rolling resistance and durability, for example utilizing the VTI road simulator. The material was either elongated fiber-like rubber particles or granules of rubber bound together with polyurethane (bitumen was also tried). Rubber was obtained from scrap tires. See Fig. 1, where the right part is a sample from the Oslo street mentioned in the next section.

Poroelastic surface type	**Porosity in %**	**Test site**	**Posted speed [km/h]**	**Age**	**Year of test**	**Measurement by**	**Measuring method**	**Noise reduction**	**Comments**
<8 mm, 28 mm thick	≈ 35	Vintrosagatan Hagsätra, 2 lanes	70	0	1989	Akustikbyrån	CPB	7.5 dBA	Car, 40 km/h, 3rd gear
<8 mm, 28 mm thick	≈ 35	Vintrosagatan Hagsätra, 2 lanes	70	0	1989	Akustikbyrån	CPB	8.0 dBA	Car, 50 km/h, 3rd gear
<8 mm, 28 mm thick	≈ 35	Vintrosagatan Hagsätra, 2 lanes	70	0	1989	Akustikbyrån	CPB	8.5 dBA	Car, 50 km/h, 4th gear
<8 mm, 28 mm thick	≈ 35	Vintrosagatan Hagsätra, 2 lanes	70	0	1989	Akustikbyrån	CPB	9.0 dBA	Car, 60-70 km/h, gears 4+5
Width: 2 ×0,60 m	≈ 40	Stora Holm, Gothenburg (no road)	–	0	1981?	Akustikbyrån	Coast-by of car	≈ 8 dBA	Summer tires 50-70 km/h
Width: 2 ×0,60 m	≈ 40	Stora Holm, Gothenburg (no road)	–	0	1981?	Akustikbyrån	Coast-by of car	12 dBA?	Studded M+S tires 50-70 km/h

Table 1: Summary of the Swedish field tests before 1990 (CPB = Controlled Pass-By test).

Three field tests were made in the 80's. First, two strips were laid on a closed-down airport (the two last lines in the table). They performed well there during at least 10 years (with no traffic exposure). The second was a trial in 1987 on a Stockholm street where 6 m^2 of rubber panels was laid to check durability (See Fig. 2). These panels performed well during the winter when they were tested. After that trial, a two-lane local street was paved with the material, see the four first lines in the table. Unfortunately, this was a total failure, since after 6 months the surface had to be removed due to patches loosening from the base-course.

4 - TRIAL IN NORWAY

A large project concerning development of porous asphalt surfaces with the main purpose of obtaining

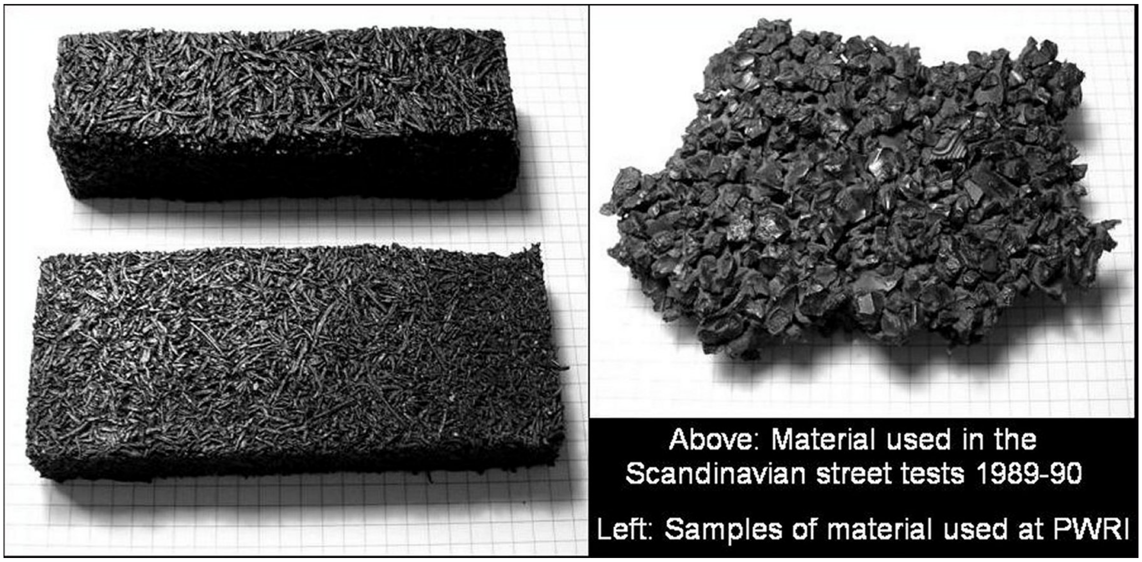

Figure 1: Poroelastic materials used (scale: mesh size is 5 mm square).

noise reduction was conducted in the Oslo area in Norway beginning in 1989. As part of this, on a two-lane street with rather light traffic, a 130 m long poroelastic road surface with 8 mm rubber granules (same material as used in the Swedish tests, see Fig. 1) bound with 13 % polyurethane was laid on a porous base course. Its voids content was 35 % and the thickness was 19 mm. The Norwegians put a lot of effort into obtaining an optimum binder content. The noise reduction was found to be 7-9 dB(A) for a car. Measurements of L_{eq} noise levels of the actual traffic over approximately 1 hour before and after laying the surface, normalized for traffic differences, gave a noise reduction of 5-6 dB(A), approximately half of that obtained in the Swedish tests. The friction was found to be 0.36 as an average measured with the "Mu-meter" (sideway force coefficient with smooth tires). This is not acceptable but was probably typical of the unworn state of this surface.
Some time after laying of this surface, small patches loosened from the base course in one of the two lanes, but this could generally be ascribed some problem during the laying. The other lane was fine after a few months. However, when snow came in the early winter, the snow plow ripped off large parts of the surface, which was soon removed completely by the road authorities. The problem with the snow plow could have been foreseen and the plow could have been adjusted to avoid the problem.
A problem noted when laying the surface was that the street had to be closed for five days when laying it and afterwards, mainly for hardening, which is a long time for roadwork, usually not acceptable. The cost of the surface was approximately five times that of a conventional asphalt concrete.
More about the Norwegian experience can be read in [4].

5 - TESTS WITH MIXES OF RUBBER AND SAND

A project has been running in Sweden since 1996, with the aim to develop a poroelastic road surface that contains a large proportion of rubber mixed with a large proportion of sand. It is run by Acoustic Control AB, an acoustical consultant company in Stockholm under the direction of Mr Nils-Ake Nilsson; the original inventor of the surface type, in cooperation with Gothenburg Street Company, owned by the City of Gothenburg.
Test sections have been laid in 1996 and 1997, possibly also later. Due to ongoing work on creating legal protection for the technology (patent pending etc.), further information cannot be delivered. The experiments in 1996 used rubber granulate with a certain amount of stone/sand together with various bituminous binders. The mix was such that a highly porous surface with an optimized elasticity was obtained. The target is that the final mix should be manufactured in a normal asphalt plant, laid by means of a conventional asphalt laying machine. In 1997, further variations in the proportions between rubber and stone/sand were studied together with variations in binder characteristics as well as various types of rubber granulate.
A noise reduction of 12-14 dB(A) compared to conventional dense asphalt concrete (max 11 mm chippings) has been measured for a mix with inadequate durability, and 7-10 dB(A) is expected for one with better durability. No noise increase during wet conditions has been recorded, which means that the noise

Figure 2: Panels of poroelastic material being laid on a street in Stockholm, in order to test durability over a winter season.

reduction is maintained even during rainfall. Dry and wet friction is stated to be comparable to that of a dry normal dense asphalt surface.

Early problems with adhesion (ballast particles loosened e.g. when a car was placed on the road and steered tires turned) are claimed to be solved. Likewise, early mixes tended to get depressions if a car stood on the surface for a longer period (which disappeared after some minutes). This depression problem has since been reduced by certain binder modifications.

It has been expected that the surface price may be in the interval of 8-13 USD/m ^{2} when used on longer road sections. Full-scale tests with asphalt plant production remain to be made.

An interesting idea resembling the on-going tests in Sweden, and probably started earlier, is a surface called GPUX, after the inventor Mr Graham Potter in the United Kingdom. This is an elastic, truly flexible surfacing consisting of 1/3 of rubber mixed with a stone aggregate, sand and polyurethane binder. They have been or are working on a low-cost elastomer polymer binder. The elasticity is very high, but it is not known what the porosity is, probably it is not very significant. Successful trials (so far) have been made to apply it to cement concrete blocks. Most experiments seem to have been made in Japan. Although the surfacing has been made primarily for obtaining ice-free roads in winter climate, there seems to be a noise benefit also. Results are not yet published, but this author has received information via personal communication with Graham Potter Associates in the U.K.

A similar material, with up to 25 % (by volume) of stones substituted by rubber, has been developed at the US Army Cold Regions Research and Engineering Lab (CRREL).

6 - ONGOING PROJECT AT PWRI, JAPAN, AND VTI, SWEDEN

Six years ago, research on poroelastic road surfaces was started at the Public Works Research Institute (PWRI) in Japan. Some papers have been produced on this, see for example [5] and [6]. Already in 1997 attempts were made to start a cooperation between PWRI and VTI on this subject, but it failed due to financing problems for the Swedish part. However, from 2000 also the Swedish part has some funding for this research and the two institutes will now work together with this. No results are yet available from

VTI, but a Swedish-Japanese workshop was held in Stockholm in 1999, see [4]. The institutes consider the main problems that need research to be: (1) Adhesion to the base course, (2) Durability − wear resistance, (3) Wet friction, (4) Cost, (5) Fire resistance.
The construction of the surface used by PWRI so far is based on elongated fiber-like rubber particles (like in the Swedish experiment in Gothenburg in 1981 mentioned above), which seem to have formed a very strong material. See the left part of Fig. 1. Only new rubber has been utilized so far. Trial surfaces have been laid on the PWRI test track (PCC base), for example on a circular track exposed to automated heavy vehicle traffic. So far, the surface there has resisted without any serious impairment about 180 000 heavy truck passes. Furthermore, the surface has been laid on a small local street, exposed to only very few vehicles, at which place it has now been in operation without any defects for three years.
The PWRI studies have attempted to improve the safety and functionality of the poroelastic surface, with work concentrated on three main factors: fire resistance, adhesion to the base course and wet skid friction. A brief status report follows; see also another paper [6].
Fire resistance was thought to be a potential problem, since rubber may burn intensively. In the experiments carried out by PWRI, 36 liters of diesel oil or gasoline was sprinkled over the surface. At a certain moment, the fluid was ignited with a torch, after which observations were made on pavement materials, height of flames, generation of smoke, etc. Three surfaces were compared: dense asphalt concrete, porous asphalt concrete and panels of a poroelastic surface. See Table 2 for results. It appeared that regarding spreading speed and flame height, the poroelastic surface was observed to be *safer* than the dense asphalt concrete.

Surface type	Burning of fuel and pavement materials	Flame height	Smoke generation
Dense asphalt concrete	Fuel oil spreading over the pavement surface strongly burned in reddish flames but the pavement did not burn	2.5-3.0 m	Fuel oil incompletely burned shooting a column of black smoke
Porous asphalt concrete	Fuel oil evaporating through the voids of the pavement was ignited, shooting blue flames. However, pavement materials did not burn	Appr. 0.3 m	Only little smoke was observed
Poroelastic surface	Fuel oil evaporating through pavement voids was ignited; rubber panels burned-up, shooting reddish flames. Fire spread over pavement at very slow speed	1.0-1.5 m	Column of black smoke was observed from the burning rubber panels

Table 2: Results of fire resistance experiments at PWRI.

Adhesion to the base course was an issue to be studied at an early stage, since this was the most serious reason of failures in the Scandinavian experiments. First, polyurethane resin was applied as an adhesive. The repeated shearing stress caused by running of heavy trucks, however, ripped off the rubber panels from the base course (which was a semi-flexible pavement). Later, the use of epoxy resin has solved this issue. Shearing tests have been carried out under various conditions in temperature and humidity, as well as with various volumes of adhesive, etc... The results show that the adhesion stress of epoxy resin between the rubber panels and the base course (a semi-flexible pavement) exceeds 0.8 MPa (which is the maximum shearing stress obtained from calculations) under all tested conditions, except when the adhesive is applied under wet base conditions.
Wet friction is the third important issue, since tests on the first rubber panels showed unacceptably low friction. To solve this problem, PWRI and 12 private companies carried out joint research in 1998. Four types of poroelastic surface have been developed, which have met the goal to exceed the wet friction of a dense asphalt concrete (see Fig. 3). It appears from the figure that the new types of poroelastic material (types A-D) have sufficient wet friction. The wet friction coefficients of the new poroelastic materials tend to decrease as vehicle speed increases, just as is the case for most surfaces. However, they still have satisfactory values; i.e. higher than the 0.40-0.45 generally observed for dense asphalt concrete. The wet friction coefficient of the earlier type of poroelastic material was much lower. The addition of texturing materials, such as small sand grains, etc., have caused this improvement in friction.

7 - CONCLUSIONS

The tested poroelastic road surfaces have been very effective for reduction of road traffic noise − the effect being 5-15 dB(A) compared to conventional dense asphalt surfaces. It means that they may compete

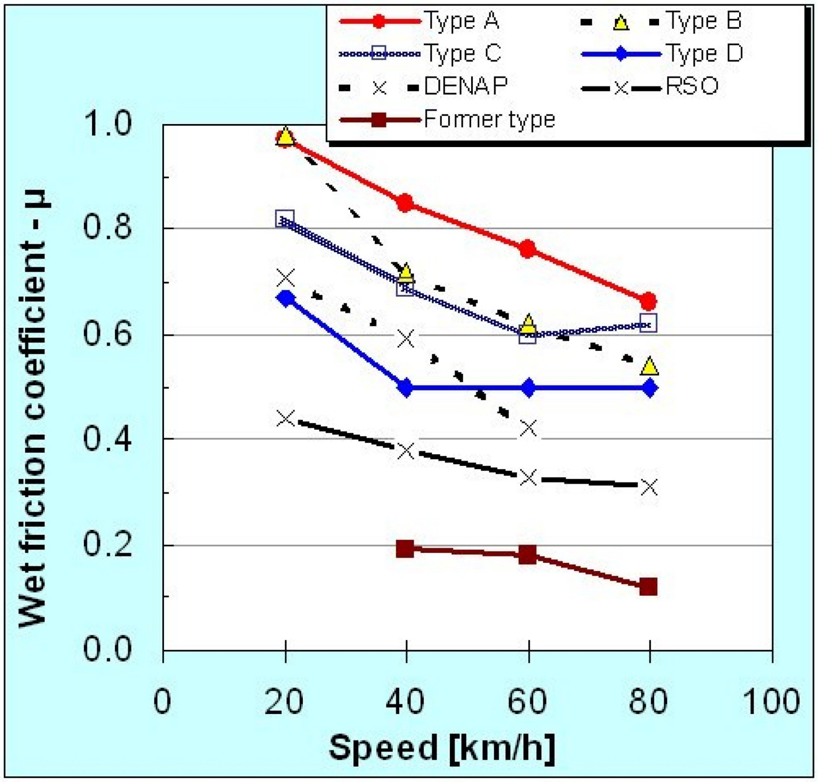

Figure 3: Wet friction coefficient measured on different types of poroelastic surface, compared to a former material of the same type, and a dense asphalt concrete (DENAP); the "RSO" is the Japanese standard for lowest acceptable friction coefficient on roads (note: friction has been measured with a skid resistance measuring vehicle, which measures the dynamic friction at 100 % slip (locked wheel), using a standard ASTM tyre with a smooth tread pattern).

acoustically and economically with e.g. building of noise screens.
A lot of development is still needed in order to make the poroelastic surfaces durable and safe. However, ongoing research points at reasonable possibilities to solve the problems encountered so far. More and alternative possibilities will be explored, for example one may try to avoid the use of epoxi resin to provide adhesion against the base course. It is also important to study adhesion to different types of base course. It is possible to obtain a satisfactory friction when the surface is new; it needs to be studied how this can be maintained throughout the lifetime. By using rubber from scrap tires, one may reduce the cost of the material, at the same time as one can get another lifecycle of tire rubber.
The most successful materials so far are sufficiently promising to justify full-scale road tests. These will teach us a lot more about the performance of the material, probably pointing at new problems that need solutions. Possibly, the poroelastic surface may very much reduce clogging, since the elastic movement due to rolling tires should avoid dirt from getting stuck.

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