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LOW-NOISE ROAD SURFACE TECHNIQUES AND MATERIALS

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ABSTRACT
This paper reviews the state-of-the art in designing and building low-noise road surfaces. The following are considered: resin-bound surface dressing, thin bituminous layers, porous asphalt, porous cement concrete, exposed aggregate technique for cement concrete, diamond grinding of cement concrete, special structure: the "euphonic" pavement, special material: expanded clay. They are examined from the following viewpoints: description, acoustic and non-acoustic performances and drawbacks. It is concluded that any significant progress requires widening the sound absorption spectrum of the pavement structure with respect to present achievements.

1 - INTRODUCTION
This contribution is a partial digest of [1]. From basic studies, one can point out three basic rules for designing a silent road surface. These are: 1°) the surface must be provided with sufficiently deep macrotexture (minimum texture depth: 0.5 mm) making up a random, closely packed, homogeneous array of small to medium size aggregates (maximum size: 10 mm), 2°) or, the role of macrotexture can be played by a porosity made of pores connected to the surface and to one another (minimum: 15% connected voids) which moreover will provide some favorable sound absorption if the layer is sufficiently thick (minimum: 40 mm) and, 3°) megatexture must be minimized namely by ensuring in all cases that macrotexture is homogeneous and, when laying concrete, by using a longitudinal smoothing beam. This holds for porous surfaces too. These rules will moreover guarantee one of the most important safety requirement i.e. wet skidding resistance.

2 - LOW-NOISE TECHNIQUES AND MATERIALS

2.1 - Surface dressing: resin-bound
This is a high-performance surface dressing which consists of a layer of resinous binder densely spread with high-PSV, small size aggregates (typically: calcined bauxite 2/4).
Though not designed for that purpose, it happened to be one of the quietest surfaces. The reasons are the following: 1°) the initially liquid binder smoothens out any megatexture of the underlying surface and, 2°) the closely packed array of thin stones forms a uniform, deep macrotexture. This explains some dramatic results reported after overlaying a fine-textured cement concrete typical of Austrian roads. The CPX noise reduction obtained on six road sections in Austria was about 8 dB(A).
The main problem is the rather high cost because the components are both of high quality.

2.2 - Cement concrete: exposed aggregates
The technique consists of spraying on the fresh concrete surface a set retarding agent (essentially sugar) and to brush away the mortar that has not set after one or two days which creates a certain surface texture by exposing the aggregates.
Very good performances regarding tire/road noise limitation can be achieved through that technique only if some good practice rules are complied with. Namely: 1°) the grading must be optimized so as to obtain a rather fine, homogeneous macrotexture and, 2°) a longitudinal smoothing beam must be used instead of a transverse one in order to avoid any megatexture that could still be amplified by the set

retarder accumulating in the depressions. Provided those conditions are carefully complied with, cement concrete optimized that way can be almost as silent as porous asphalt while easily meeting other comfort and safety requirements as those related to evenness and skidding resistance.
The problems are that, firstly, that technique requires good quality, hence expensive stones to be used in the full depth of the layer when they are only needed on top of the surface. Secondly, departing from the best grading for strength can make it delicate to meet the requirements in that respect. Those drawbacks can be overcome by resorting to two separate layers: the underlying layer being designed for strength and the top layer being texture-optimized.

2.3 - Cement concrete: diamond grinding

It consists of planing the road surface by means of a set of closely spaced diamond discs forming thin (typically 3 mm wide) parallel, longitudinal grooves. Thanks to the close spacing, the edges remaining between the grooves are also left smooth because most remaining peaks are split off in the process.
To our knowledge, the technique has been purposely applied to reduce traffic noise in Belgium. It was in all cases on very noisy transversely grooved cement concrete otherwise in good condition. The overall traffic noise reduction (from SPB measurements) was about 5 dB(A) which significantly alleviated the disturbance but did not draw the noise down to the level of a really silent surfacing like a porous asphalt for instance. Unlike longitudinal grooving of the fresh concrete, this kind of grooving does not induce shimmy of the steering, which could be hazardous to motorists.
This is of course a rather expensive treatment. It costs approximately 1 EURO per square meter and per mm depth. One does not know yet how long that texture resists wear.

2.4 - Bituminous wearing course: porous asphalt

Porous asphalt has a very high stone content (typically: 81-85%) with a typical grading of 0/14 with a gap at 2/7 which provides a high voids content (typically: more than 20%). Variants are experimented like smaller maximum aggregate size and double layer with different gradings.
The following acoustical performances have been established. Based on the CPB method using as reference one or several cars coast-by, engine off, Belgian and French studies involving dozens of different surfaces have consistently shown that porous asphalt reduces tire/road noise by 3 dB(A) on average as compared to dense bituminous macadam. However, one should notice that comparisons between individual sections exhibit a wide scatter so that the largest reduction can go up to 9 dB(A), but an increase up to 3 dB(A) can also be observed. Now, when compared to the noisiest surfaces, the best performing porous asphalt provides up to 16 dB(A) reduction of car tire noise. Regarding the overall traffic noise, the reductions are of course less than for tire noise alone; they are however still very significant but they depend, of course, on the traffic speed and the percentage of heavy vehicles. As an example, compared to a transversely grooved, rather worn cement concrete, a medium quality porous asphalt typically yields a reduction of 6-7 dB(A) on L_{eq} at 7.5 m for a motorway traffic with 20-30% of heavy vehicles. Porous asphalt has also been reported, based on stationary vehicles with running motor, to absorb petrol engine noise typically reducing the 7.5 m level by 2 or 3 dB(A). Another advantage that should not be overlooked is the noise reduction provided by porous asphalt by rainy weather. In short, it can be said that to ensure significant acoustical effectiveness − say a 3 dB(A) reduction of traffic noise as compared to a dense bituminous surfacing - porous asphalt must meet the following minimum requirements consistent with the Belgian, French, Dutch and Italian specifications: 1°) total voids content $\leq$20 %, 2°) maximum aggregate size between 10 and 16 mm, and 3°) layer thickness $\geq$40 mm. Now, other performances of porous asphalt, than those bearing on noise should not be overlooked, like: 1°) reduction of glare from the headlights of approaching vehicles by rainy weather, by night, 2°) reduction of splash and spray behind vehicles in rainy weather and, 3°) high resistance to rutting.
Porous asphalt is not free of drawbacks however. Pores tend to get clogged by mud, dust, spilled oil, etc. which is liable to spoil the performances that depend on drainage and porosity. A number of reports contain results of observations of the development over time of the acoustical performance of porous asphalt road sections exposed to traffic and weathering from which it can be stated that: 1°) except under adverse particular conditions such as small thickness, voids contents or aggregate sizes, or very aggressive traffic (studded tires), a satisfactory stability − i. e. a maximum increase of 2 dB(A) − may be reasonably expected for noise levels after 3 to 4 years of service and, 2°) gradual clogging, which shows itself in a serious deterioration of permeability, does not seem to have such a detrimental effect on acoustical performance as could be feared. This has been confirmed by an experiment with intentional clogging followed by water jet cleaning, in which a relatively modest variation of only 2 dB(A) was observed. Also, it has been observed, after having followed up porous asphalt sections for 7 years, that there is no relation between the increase tire noise/road and the decrease of permeability.

Instead, surface texture deterioration is likely to have the essential influence. The double layer technique is well suited for urban uses: either the dirt stays on the top layer where it can be easily cleaned or it is washed away through the coarser underlayer. Although some claim to be able to clean porous asphalt and restore its performances regarding drainage, others are doubtful of the effectiveness of the available cleaning means and question the high cost/benefit ratio of such a policy all the more as, to be effective, cleaning must occur repeatedly (typically twice a year) and start at an early stage of the lifetime of the layer. The point is that monitoring the effectiveness of a cleaning machine relies on measuring the drainability by means of a device of the type "outflowmeter" which can be suspected to be more sensitive to horizontal drainage (which is improved by just cleaning the macrotexture) than to in-depth drainage (which pressurised-water devices can probably not carry out effectively). As clogging − possibly by chemicals harmful to the environment − can dramatically raise the costs of dumping the used material, it can be economically interesting to recycle it. Winter maintenance on porous asphalt can be a concern. Exhibiting dissimilar thermal properties due to its porosity as compared to dense bituminous macadam, porous asphalt behaves somewhat differently under some winter conditions. One can notice some time lag in either direction between the development of the surface temperature between adjacent dense and porous surfaces under changing weather − icing or thawing − as well as under salting. Some accidents have been reported which were assigned to such problems. However, few if any statistics have been reported on accident rate reduction on wet roads thanks to porous asphalt as compared to the alleged excess of accidents by ice and snow.

2.5 - Cement concrete: porous concrete

Porous concrete has an open, draining structure similar to porous asphalt but where the binder is cement mortar.

Though used on pedestrian areas and parking lots as early as in 1983 namely in Japan, the first known experimental section in porous concrete on roads was laid in The Netherlands in 1990. Since then, plenty of apparently successful trials have been reported essentially at the 1998 Symposium on Concrete Roads in Lisbon namely from BE, FR, ES, DE, and JP. In Japan, noise reductions with respect to a dense graded asphalt amount to 6-8 dB(A) and 3-4 dB(A) for a car respectively on dry and wet road surfaces at speeds ranging from 40 to 75 km/h. For a truck, the figures were respectively 4-8 dB(A) and 2-3 dB(A) at 40 to 60 km/h. In Belgium, six low-noise experimental sections included a porous concrete. Considering the reference speed of 70 km/h, the reductions with respect to the dense bituminous section were 6 dB(A), 5 dB(A) and 3.5 dB(A) for cars, two axle and multi-axle lorries by the SPB method. The figures were respectively 4 dB(A), 6 dB(A) and 2.5 dB(A) for the section in porous asphalt. In Germany, as compared to a rather smooth, longitudinally textured (by means of burlap) cement concrete, a two years old porous concrete on motorway exhibits reductions of 4.3 dB(A) and 7.0 dB(A) for cars at 120 km/h, respectively lorries at 80 km/h by the SPB method. In Spain, experimental sections laid in 1994 and 1997 in so-called "High Performance Porous Concrete" offered a noise reduction of 5 dB(A). From an experimental section laid in Nantes by LCPC in 1994, it is concluded that their porous concrete layer was acoustically equivalent to a porous asphalt according to the French-German CPB measurement method at the reference vehicle speed of 90 km/h.

To ensure the required strength, while aiming at the maximum possible voids content, additives must be used. Among the problems encountered are a low initial friction due to the added polymers in the mortar coating the aggregates and excess megatexture due to a poor workability. Extra costs as compared with a conventional concrete 22 cm thick as compared to a 4 cm porous concrete laid over 18 cm of conventional concrete are estimated in Belgium as roughly 40%. In Germany, the same comparison, though based on 18+8 cm and 26 cm, yields 20% to 35% extra costs; but, there is no significant cost difference with an equivalent structure including porous asphalt. Of course, the same problems as with porous asphalt regarding clogging and winter maintenance will most certainly arise.

2.6 - Bituminous wearing course: thin layer

Besides the classical maintenance technique resorting to the so-called surface dressings, a lot of new formulae have been developed in the recent years to meet specific needs namely regarding surface characteristics. They are thin (less than 2 cm thick) and very thin (thickness between 2 and 4 cm) bituminous layers. Among the very thin layers are the "Slurry seal" and the "Ultra-thin, grained surfacing". In the category of thin layers, one finds the "Stone Mastic Asphalt (SMA)", the "Gap-graded thin surfacing" and, the "Open-textured thin surfacing". All are gap-graded, which imparts them a rather open though not really draining texture.

Regarding noise, in view of the variety of mixes and laying techniques, it is difficult to assign any collective performance to those surfaces the variety of such materials available in France, for instance,

one can roughly conclude that thin layers are just like porous asphalt or 2−3 dB(A) above based on the peak noise level of a car at 90 km/h. The reason for the rather low noise of thin layers as compared to classical surface dressings is that they consist of a mix that is spread and rolled. The latter action, thanks to the gap-grading that leaves to the stones a certain degree of freedom, produces a "flat" surface due to the stones exposing an upper horizontal side.
Thanks to their high content of stones and to being gap-graded, thin layers are resistant to rutting. Thin and very thin layers have become popular because they provide a means to make quick maintenance of road surfaces, thus minimizing traffic disturbance. They are mainly used as a provisional treatment until a more durable repair can be applied. Thin and very thin layers are less resistant against tangential stresses; therefore, they are not recommended for use in locations where such stresses occur like crossroads, roundabouts, steep slopes, etc.

2.7 - Special structure: euphonic pavement

The so-called "euphonic" structure consists of a wearing course of 40-60 mm in porous asphalt laid on a continuously reinforced concrete slab including resonators of about 500 cm^3 each. This is a radical extrapolation of the concept of the multilayer sound absorbing pavement initially made of two different porous asphalt mixes.
Small-scale experiments have shown that thanks to the combination of layers absorbing sound in very different frequency domains, one can approach the ideal case of a constant absorption coefficient of about 0.6 throughout the relevant frequency range. In particular, not only tire/road noise but also the low frequency components of vehicle noise could be abated, which is particularly desired in urban conditions where engine and exhaust noise could prevail. Of course, the advantages of porous surfaces ascribable to drainage are likely to be enhanced since water flow through the cavities and the drains is rather easier than in a porous mix all the more as clogging is less likely to be a problem and, if it were, cleaning of the rather thin top layer would probably be easy.
Full-scale experiment is still necessary to evaluate this solution.

2.8 - Special material: expanded clay

Expanded clay aggregate is a lightweight aggregate (300-700 kg/m^3) obtained from clay by expansion and firing in a rotary kiln at ± 1,100 °C. Expanded clay aggregate is a stony, non-combustible and imputrescible material. It has a rough aspect and a rounded shape. The surface exhibits a micro-porous brown-colored crust. The interior is cellular in texture and black in color. There is also a crushed-type expanded clay aggregate. Experiments with road surfaces containing light expanded clay aggregate started in the USA in 1950 and have been continued in Scandinavia and Italy for widely different purposes. Depending on the type of wearing or base course or on the material used for it (recycled, new), the proportions (by weight) of lightweight aggregate in mix compositions range between 5 and 35 %, a presence of conventional aggregate being preserved.
The structure, thickness, macrotexture of the surfacing and the rough texture and peculiar structure of expanded clay are responsible for interesting acoustical performances. As compared to ordinary asphalt concrete, noise reductions of 3.7 to 5.0 dB(A) have been reported from measurements on some Italian motorways. This seems to be partly due to sound absorption by the pores of the particles exposed on top of the pavement. Expanded clay is claimed to have several beneficial effects when used (in a proportion of 5 to 35 %) in a road surfacing, namely: 1°) high and durable skidding resistance, 2°) less risk of damage to vehicles due to projection of loose chipping, 3°) good adhesion of binder to aggregate, thus extending pavement service life, 4°) expanded clay aggregate surfaces produce little or no glare by reflected sunlight 5°) this type of aggregate has a good durability thanks to its resistance to freezing, thawing, sulphate and salt action and, 6°) it is possible to reduce the consumption of first-class aggregates (e.g. basalt) in asphalt mixes by using expanded clay in combination with lower-class materials (such as limestone).
As far as mechanical tests are concerned, there are for the time being no adaptations to, or reference values for, lightweight aggregates. It is not advisable to use normal expanded clay aggregate in road pavements carrying high volumes of heavy vehicle traffic, as there may be problems with low compressive strength. "High-strength" or "structural" expanded clay aggregate however can be used without any problems in motorway pavements, because of their high compressive strength.

3 - CONCLUSIONS

The quietest road surfaces today are either porous or fine-textured. Both solutions yield similar traffic noise reduction potential i.e. roughly 3 dB(A) with respect to an ordinary dense bituminous concrete which in turn lies roughly 10 dB(A) lower than the noisiest rough-textured surfaces like paving blocks, surface dressings and old-fashioned cement concrete. Dense surfaces have achieved their best possible noise performance. Still quieter solutions than single-layered porous surfaces can be sought for by widening the sound absorption spectrum of the pavement with a view to extend its noise abating capability to all noise sources including mechanical noise. Though still unclear, mechanical impedance could be another factor influencing vehicle noise emission that could be taken advantage of by softening the pavement. Both prospects will likely call for solutions involving multi-layered pavement structures.

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