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NOISE CHARACTERISTICS OF AN EXPOSED AGGREGATE CEMENT CONCRETE SURFACE

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Abstract

On high-volume roads cement concrete surfaces may be economically favourable in comparison to asphalt concrete. When a bypass for motorway E4 in Uppsala (Sweden) was built, cement concrete was therefore selected as the wearing course. It is well known that noise characteristics of cement concrete surfaces may be poor unless a suitable texture is created.

Earlier, the Swedish Road Administration has used the exposed aggregate technique to create a favourable surface texture on newly laid cement concrete on some motorways in Sweden, with both good and poor results. This time a special aggregate grading of the top layer was selected, attempting to combine the desire to have excellent durability against the wear of studded tyres in winter, and the desire to limit tyre/road noise emission from the motorway. Being a bypass, this motorway at some locations run rather near to suburban areas where noise immission might become a serious issue.

Noise measurements were made with the CPX method, using four test tyres. The results on the exposed aggregate cement concrete (EACC) were compared with similar measurements on SMA surfaces with the same maximum aggregate size. As a reference for comparison three SMA 0/16 were chosen since this is the surface type that would normally be used on a motorway of this kind.

The results indicated approx. 2-3 dB(A) lower tyre/road noise emission on the EACC than on the SMA 0/16 which was better than expected. In the paper the probable causes of the relatively low noise emission are analyzed. The positive results suggest that with a suitable proportioning of the aggregate in the surface layer and high quality exposure technique, the EACC may be used as a standard technique for texturing of cement concrete.

1. INTRODUCTION

Cement concrete road surfaces are frequently used on high-volume streets and highways, in particular on high-speed motorways. High volumes of traffic travelling at high speeds often result in substantial road traffic noise nuisance for people living close or fairly close to the road. At the same time, for reasons of safety in wet weather, high speeds require an appropriate surface texture on the pavement which can provide sufficient drainage of water from the tyre/road interface. Thus, cement concrete surfaces often require special surface treatments during construction or afterwards to obtain a sufficiently high texture and if this is made in the ”wrong” way, such texture may cause excessive noise. One of the most common ways, mostly resulting in excessive noise, is to create longitudinal or transversal "grooves" by applying steel tines that cut a pattern in the still fresh concrete surface. In Europe, unsuitable textures are generally avoided in noise-sensitive areas, but many states in the USA still experience problems with traffic noise on tined cement concrete surfaces. In some cases resurfacing has been necessary because of noise problems, resulting in expenditures which could have been avoided had existing knowledge been utilized from the beginning.

This paper presents results from a construction project in Sweden where the so-called exposed aggregate cement concrete (EACC) technology was applied in order to create suitable texture on cement concrete surfaces.

2. EARLIER EXPERIENCE

The exposed aggregate cement concrete (EACC) is a special technique by which the sand between the aggregate (the chippings) is removed before the concrete surface hardens. A special retarder is sprayed onto the freshly laid cement concrete surface, supplemented by a cover by a thin foil, to further delay the hardening of the few mm closest to the surface. This makes it possible to wash or sweep away the sand between the aggregate after one or two days without affecting the aggregate. This treatment exposes the aggregate and prevents the surface from becoming too smooth to be safe. Sometimes, the EACC surface has been called "whisper concrete", but the author thinks that this is a misleading name.

EACC is by no means a new technique. This type of surface has been applied since the beginning of the 1990’s in Austria, Belgium, the Netherlands, United Kingdom and Sweden [1]. Trials have also been made in Australia [2]. It has been observed that in comparison to conventional cement concrete textures, the EACC offers favourable characteristics provided the grading of the aggregate is appropriately designed. This means that the maximum aggregate size should not be higher than (say) 16 mm; preferably maximum 8 mm.

For example, Austrian SPB measurements indicated 0-2 dB(A) noise reduction compared to conventional asphalt concrete surfaces [3]. In the Netherlands, C_{road} values for the Dutch noise calculation procedure give a noise reduction of 0 dB(A) for light vehicles and 2 dB(A) for medium and heavy vehicles [4] provided an "optimized" texture is achieved. Our own tests in Sweden in the early 1990's on motorway E6 through Halland suggested 0-2 dB(A) noise reductions in comparison to the "normally" used SMA 0/16 surfaces; with the best value for an aggregate size of max. 8 mm, and EACC with 16 mm aggregate giving similar noise emission to the SMA surface with similar grading [5]. The best noise reductions reported, as seen by this author, had been achieved with a 7 mm aggregate in which case approx. 3 dB(A) noise reduction in comparison to an SMA surface had been achieved [6].

The optimism in the 1990's regarding the future prospects regarding this type of surface does not seem to have been realised in the present decade. It is true that the EACC is sometimes used in Belgium, the Netherlands, Austria and Germany, but its success has not been as high as this author expected, given its noise reduction potential in comparison to alternative cement concrete texturing methods.

3. THE TESTED SURFACE

The EACC reported here was laid on the new 2x2 lane motorway bypassing the city of Uppsala in Sweden, which is part of the E4 running north-south through Sweden. Due to the recognized long-term durability of cement concrete, the Swedish Road Administration (SRA) wanted to lay a cement concrete here, rather than the conventional SMA 0/16 which is almost exclusively used on motorways in Sweden. However, it was recognized that a cement concrete surface needs to have a proper texture to combine the requirements of rather high texture depth for wet friction safety reasons and a rather smooth texture for noise-reducing purposes. Therefore, the EACC technique was selected, based on the rather positive results of a similar project on motorway E6 on the Swedish west coast (Halland region) in the 1990's. This author then recommended the use of an 8 mm maximum aggregate. However, the SRA selected a solution using a 16 mm aggregate size; the reason being that they feared that a smaller aggregate would jeopardise durability. This author then expected that there would be approximately the same noise emission as for the conventional solution - the SMA 0/16.

The paving was made by a German company using a slipform paver and a super-smoother. The final surface is shown in Fig. 1 where also a conventional SMA 0/16 surface has been added in order to facilitate the comparison. These photos have been chosen among a large selection in order to be representative of the average surfaces.

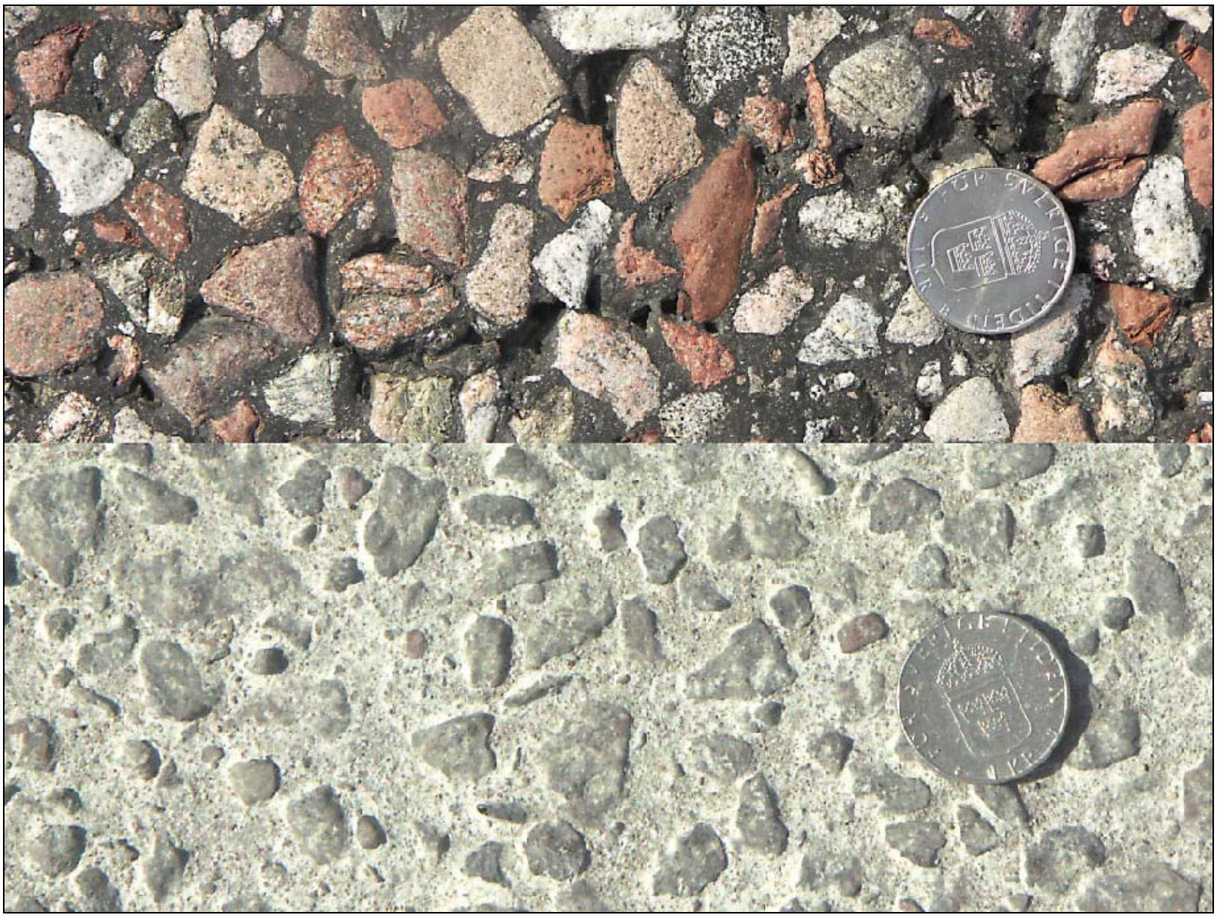

Fig. 1. Close-up views of an SMA 0/16 surface (reference or control surface in this paper) in the top part and the EACC surface below. The coin has a diameter of 25 mm.

The following observations may be of interest for comparison purposes:
- Although the EACC surface has a nominal maximum aggregate size of 16 mm, the fraction between 11-16 mm seems to be relatively low in comparison to the SMA surface
- The macrotexture of the EACC is only somewhat lower than that of the SMA

4. NOISE MEASUREMENTS AND TEST TYRES

4.1 Noise Measurement Method

The noise measurements were made in September 2006, some weeks before the bypass was opened for traffic. The surface was then already 2-3 months old. The measurements were conducted by the Technical University of Gdansk (TUG) using their CPX trailer; operating at 50, 80 and 110 km/h in accordance with 2nd ISO/CD 11819-2; except for the test tyres.

The measurements were made on a 600 m long test section; in both directions and in the two lanes. One run per lane was made and all reported measurements are averages for the runs in the two directions, for the two lanes and for the two microphones. Thus, each measurement includes approximately 2400 m of measured length for two microphones and for the four tyres shown below.

4.2 Test Tyres

The test tyres were the A and D tyres of the mentioned draft standard (ongoing work in the ISO group ISO/TC 43/SC 1/WG 33 had already decided that tyres B and C are no longer "needed"), plus two new tyres which are currently among a number of tyres considered to replace the A and D tyres. The four test tyres were:

"CPX A"	Avon ZV1 (this is intended to represent the characteristics of car tyres)
"CPX D"	Dunlop Arctic (this is intended to represent the characteristics of truck tyres)
ASTM SRTT	Standard Reference Test Tyre (SRTT) currently being standardised by ASTM
MudT	Goodrich MudTerrain (intended to represent the characteristics of truck tyres)

The test tyres are shown in Fig. 2.

Fig. 2. The four test tyres used in the CPX noise measurements. All are in dimensions suitable for car tyres. Nevertheless, the two left ones are intended to represent typical behaviour of car tyres and the two right ones are intended to represent typical behaviour of truck tyres as regards road surface noise characteristics.

4.3 Reference Surface

Although, a great number of road surfaces were measured under similar circumstances in 2004-2006, and thus there is a database with several road surface types suitable for comparison, in this paper only one reference surface type will be used; namely an SMA 0/16 (Stone Mastic Asphalt with max. 16 mm aggregate size). The reason is that this type of surface would be the only one considered by the SRA as an alternative surface on such a motorway in Sweden. Due to the widespread use of studded tyres in wintertime on this motorway (around 75 % of all car tyres in wintertime would use metal studs), it is considered that only a 16 mm aggregate would ensure the best durability and SMA would be the most durable type (except for the EACC).

SMA surfaces may give a variation in CPX- or SPB-measured noise levels of 1.0-1.5 dB(A) even for the same aggregate size (max-min levels). Therefore, for comparison, CPX measurements on three different SMA 0/16 surfaces were included in the reference database, their ages ranged 1-4 years. The overall and spectral values for these three were averaged arithmetically to constitute a "reference surface" of the SMA 0/16 type. A typical photo of such a surface is shown in the upper part of Fig. 1.

All surfaces reported here were measured in the months September-October when air temperatures were 10-15 ^{o}C, with the exception of one of the SMA surfaces measured in July when air temperature was around 30 ^{o}C. No temperature corrections were made.

5. RESULTS

First, the results in terms of A-weighted overall sound levels, expressed as the difference between the SMA and the EACC surfaces (i.e. the "noise reduction" of the EACC relative to the SMA) are shown in Fig. 3.

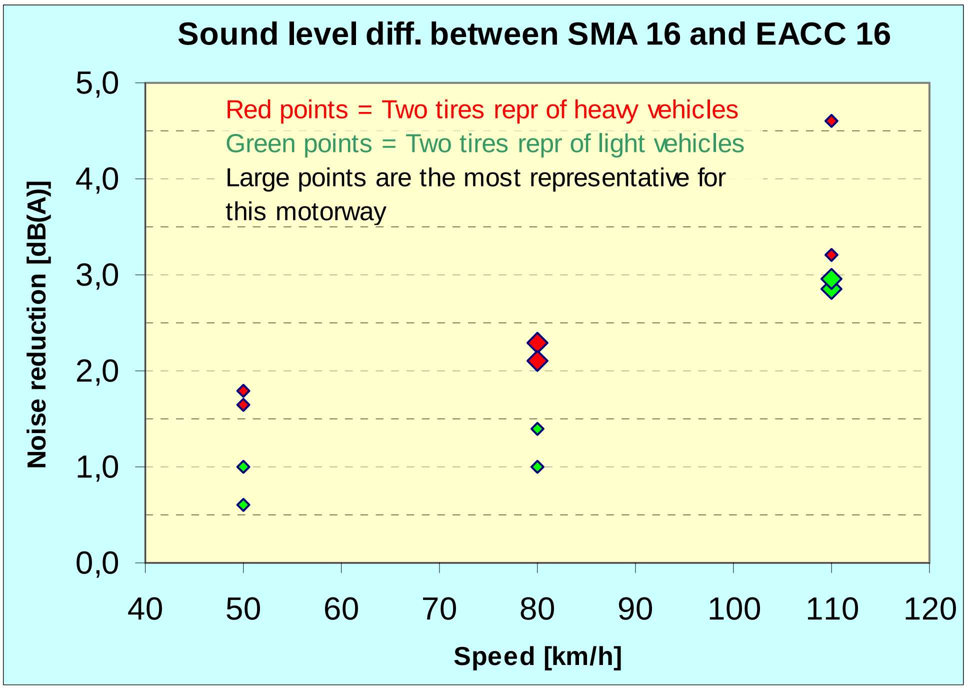

Fig. 3. "Noise reduction" of the EACC relative to the SMA (both with maximum 16 mm aggregate), measured with the CPX method at nominal speeds of 50, 80 and 110 km/h. The green points are for tyres CPX A and ASTM, which are selected to represent light traffic; the red points are tyres CPX D and MudT, which are selected to represent heavy traffic. The largest points are the most representative ones in terms of actual speeds for the traffic on this road.

The A-weighted third-octave band frequency spectra are shown in Figs. 4 and 5 for both the EACC surface and the (averaged) SMA surfaces. In order to make the results clearer, the spectra for the tyres CPX A and ASTM have been averaged and are shown in Fig. 4, while Fig. 5 shows the averaged spectra for the tyres CPX D and MudT.

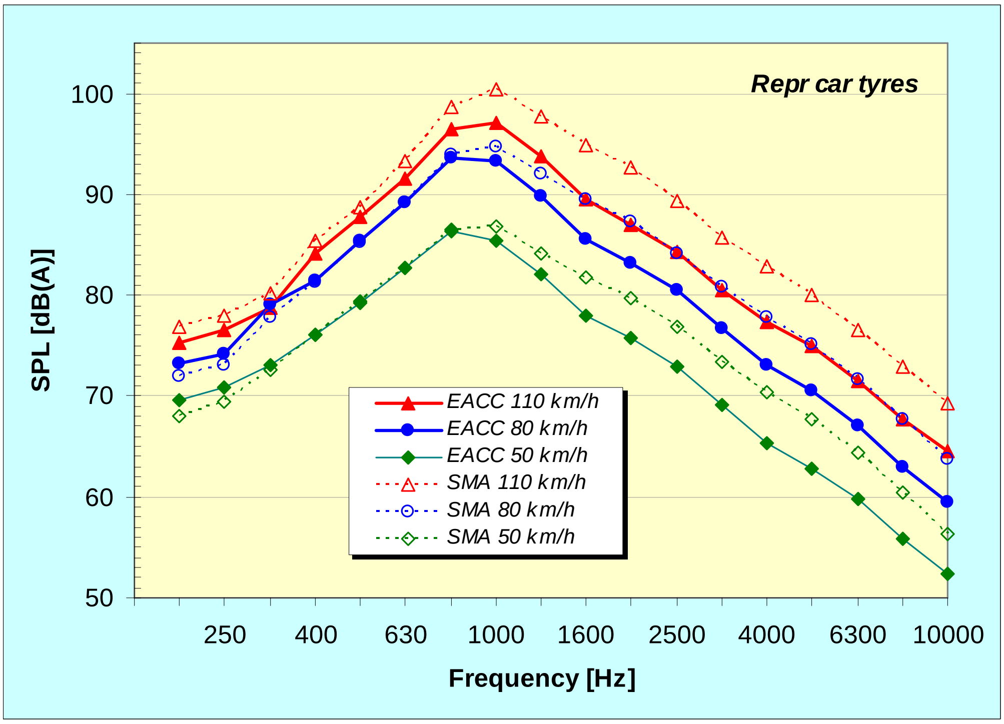

Fig. 4. A-weighted frequency spectra of the EACC and the SMA, measured at nominal speeds of 50, 80 and 110 km/h. Spectra averaged for the CPX A and ASTM tyres (representative of car tyres).

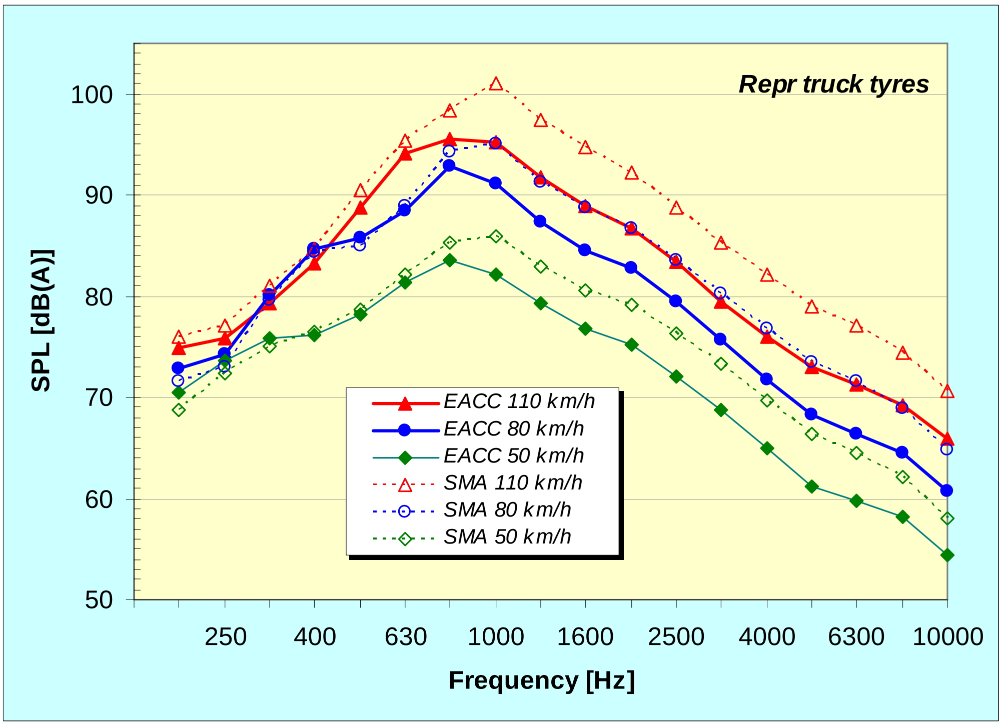

Fig. 5. A-weighted frequency spectra of the EACC and the SMA, measured at nominal speeds of 50, 80 and 110 km/h. Spectra averaged for the CPX D and MudT tyres (representative of truck tyres).

6. DISCUSSION

First, it should be noted that if the reference surface would be the virtual reference surface used in the new noise prediction models HARMONOISE, IMAGINE and NORD 2000 (i.e., an average of a DAC 0/11 and an SMA 0/11), one should subtract 1.5 dB from all reported SMA 0/16 levels and spectra. This means that the noise reduction values will be 1.5 dB lower than presented above, when using the quieter reference surface of the mentioned models.

As stated above, given the 16 mm maximum aggregate size, the author expected approximately the same noise emission as on the corresponding SMA surfaces. However, they appeared to be 0.5 - 4.5 dB(A), with 2-3 dB(A) as the most typical values. These were surprisingly high noise reductions; higher than measured earlier for any EACC with such a large aggregate size; and even comparable to the best measurements on an EACC with a 7-8 mm aggregate. This justifies a closer look at the data.

From the frequency spectra, the following features can be noted:

- There is almost no noise reduction at frequencies below about 800 Hz.
- There are consistently high noise reductions above about 1000 Hz of 5-7 dB.
- The noise reductions above about 1000 Hz increase somewhat with increasing speed, especially at around 1000 Hz.
- The peak in the spectrum moves from 800 to 1000 Hz when speed increases from 50 to 110 km/h.

How can this be explained in terms of generation mechanisms? The lack of any important noise reduction at 300-600 Hz suggests that the mega- and macrotexture impact mechanism creating tyre tread and sidewall vibrations are rather similar on both surface types [1]. Since the EACC is just somewhat smoother than the SMA, this is logical. The small difference in texture may be what one can see the effect of at 300-600 Hz at the highest speed. The dramatic difference at frequencies above 1000 Hz would normally be explained by reduced air pumping resulting from better air drainage. According to [1], it is typical that there is a significant negative noise-texture correlation at the higher sound frequencies and the texture wavelengths around 3-6 mm. From Fig. 1 it is obvious that on the EACC there is a significantly higher proportion of chippings in the size range 6-11 mm than on the SMA, which should result in somewhat higher texture profile spectrum in the 3-6 mm range.

Thus, one can expect that there would be a certain effect of this texture feature at the high frequencies; resulting from a somewhat lower enveloping effect of the tyre tread rubber on the EACC surface than on the SMA; i.e. the air channels in the tyre treads will not be so well tightened against the road surface on the EACC. But this author finds it very unlikely that it could give an effect on air pumping as high as 5-7 dB.

Therefore, one shall look for alternative explanations. One potential effect could be changed stick-slip behaviour [1]; i.e. on the EACC surface stick-slip would be much less prominent. The stick-slip should be largely affected by the friction between the rubber and the larger chippings and possibly also by the mortar between the chippings. Perhaps this explains the differences? But it could also be that there is a substantial difference in the stick-snap mechanism [1], given the very different binders used and the more polished and larger chippings in the SMA than the EACC. On the SMA surface the rubber will stick more firmly to the surface than on the EACC before the rubber/surface contact is released and larger radial forces then occur in the tread rubber. The author thinks that this could well be a major effect that could perhaps explain most of the difference in noise spectra at the high frequencies.

As a result of the interesting results, new measurements will be made in 2007, including repeated CPX noise, friction and texture measurements. Also rolling resistance measurements will be attempted. Finally, measurement of the stick-snap effect on bore cores will be tried in the Chalmers laboratory where there is a laboratory device for such tests.

7. CONCLUSIONS

The EACC surface with maximum aggregate size of 16 mm, as constructed for the E4 motorway bypassing Uppsala in Sweden, has appeared to be a much more favourable surface than expected in terms of noise characteristics. Especially at speeds 100 km/h and above, which is the case for most motorways; it offers good noise reduction properties in comparison to other dense surfaces with large chippings. For example, it has noise characteristics superior to an SMA 0/16 surface which would be the other major alternative considered for such a road in Sweden. Its noise advantage lies at frequencies from about 1000 Hz and upwards. Acoustically, despite its large aggregate size, it seems to perform equally well as or better than the earlier tested EACC surfaces with maximum aggregate sizes of 7 or 8 mm, although the larger aggregate here should provide much better durability than the smaller aggregate sizes.

However, the reasons for the good acoustic properties at high frequencies are not clear, except that the proportion of the chippings in the range 11-16 mm is relatively small and that these are replaced with a large proportion of 6-11 mm chippings. Even so, the generation mechanisms that cause the low noise properties at high frequencies are unclear. It seems unlikely to this author that the cause could be purely reduced air pumping, which would otherwise be a “standard explanation” in most cases with similar features. Instead, the author speculates that the stick-slip, or even more likely, the stick-snap mechanism may play an important role in this. However, new measurements are required to study the properties of the EACC surface closer before one can say more about this.

The studied EACC surface seems to be a good solution where cement concrete is used.

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REFERENCES

[1] Sandberg, U.; Ejsmont, J.A. (2002): "*Tyre/Road Noise Reference Book*". Informex, 59040 Kisa, Sweden (www.informex.info).

[2] Samuels, Stephen; Parnell, Jeffrey (2001): "Some recent Australian developments in the reduction of road pavement noise". Paper presented at *Acoustics 2001, The Australian Acoustical Society Annual Conference (Nov. 2001)*, Canberra, Australia.

[3] Haider, Manfred (2004): “Rollgeräuschmessung – Optimierung von erfahren und Grenzwerten”. *Strassenforschung 3.277, Endbericht*, arsenal research, Vienna, Austria, 2004.

[4] See tables of C_{road} values on the website http://www.stillerverkeer.nl .

[5] Sandberg, Ulf; Ejsmont, Jerzy A. (1998): "Texturing of Cement Concrete Pavements to Reduce Traffic Noise". *Noise Control Engineering Journal*, Vol. 46, No. 6, Nov-Dec 1998, pp 231-243.

[6] Andersen, Bent; Bendtsen, Hans; Larsen, L-E. (2005): "Acoustic Performance of Low-Noise Road Pavements". *SILVIA Project Report, SILVIA-DTF-DRI-010-02-WP4-290605* (see http://www.trl.co.uk/silvia/)