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Performance Evaluation of Exposed Aggregate Texturing in Concrete Pavement Based on In-Situ Noise Measurements

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Abstract

Environmental noise at high intensities directly affects human health by causing hearing loss. Although scientific evidence currently is not conclusive, noise is suspected of causing or aggravating other diseases. Environmental noise indirectly affects human welfare by interfering with sleep, thought, and conversation. Noise emission from motorized vehicle includes power unit noise, tire/pavement noise and aerodynamic noise. Among them, tire/pavement noise is noise emission from interaction of the tire and road surface when the vehicle cruises over the surface of pavement. In general, portland cement concrete (PCC) pavement is known to create more noise than asphaltic surfaces though it has the advantage of durability and superior surface friction. However, the results of preliminary laboratory test showed exposed aggregate concrete (EAC) has an effect on reducing tire/pavement noise. Based on the laboratory test, pilot construction of exposed aggregate concrete pavement was completed and series of in-situ measurements were conducted for noise analysis including the pass-by noise measurement and the close-proximity method. Conclusively, it is expected that tire/pavement noise represents significant portion of noise levels at higher frequencies and it would be reduced on special textures of pavement such as exposed aggregate concrete.

***Keywords:** close-proximity method, exposed aggregate concrete, pass-by noise measurement, portland cement concrete pavement, tire/pavement noise*

1. Introduction

The effects of traffic noise are a serious concern in many urban communities throughout the world. It affects the ability of people to carry on conversation, to concentrate at work and school, and to sleep. Protecting individual receivers by reducing pavement noise at the source rather than by using traffic noise barriers may result in substantial cost reductions and improved community acceptance of highway projects. Vehicle noise has been substantially reduced in recent years. This progress has been obtained primarily by reducing power unit noise which is noise emission from the units of the vehicle that takes part in the propulsion of the vehicle. Therefore, vehicle noise emission is dominated today by the noise from interaction of tire and pavement surface, so called tire/pavement noise.

Tire/pavement noise basically depends on the vehicle speed and on the actual tire/pavement combination. Furthermore, tire vibrations and air pumping are important generation mechanism for tire noise on dry pavement. It is obvious that both the road surface and the tire are important when considering sound created by the tire/pavement interaction. So, the reduction of tire/pavement noise is essentially important for the abatement of road traffic noise.[1-3] Until now, tire/pavement noise has been studied for well over 30 years and several large databases have been compiled in the last decade. Recent publications discussing the effectiveness of vehicle noise regulations suggest that vehicle noise cannot be reduced further without tire/pavement noise reduction. Therefore, it is worthwhile to attempt to reduce traffic noise by selecting quieter pavement.

Cement concrete pavements, mostly referred to as Portland Cement Concrete (PCC) pavements, are frequently used on high-volume streets and highways, in particular on

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high speed motorways. In general, PCC pavements have the advantage of durability and superior surface friction when compared to most dense-graded asphalt. However, data collected to date generally show PCC pavements to create more noise than asphaltic surfaces. Therefore, it is now well known that useful and achievable traffic noise reductions may be obtained by appropriate application and design of road surface texture even in PCC pavements.[3] When creating texture on PCC pavements it is important to consider the potential noise impact of the various alternatives. Recent research has shown some new concrete pavement textures to be worth further examination. Surfaces of Exposed Aggregate Concrete (EAC) pavements appear to provide better noise quality characteristics as well as good frictional characteristics and durability. As such, considerable interest exists in PCC surface treatment techniques that would lead to reduced noise levels for highway neighbors.

2. Vehicle noise and pavement textures

2.1 Vehicle noise sources

The noise generated by motor vehicles comes from several different sources. It is common to divide these sources into three broad groups: power unit noise, aerodynamic noise and tire/pavement, and each of them specified below.

- Power unit noise: it is related to the engine, fan, exhaust as well as the power train (transmission). This includes all mechanical noise sources of the vehicle except the tires. Those sources are regarded as the major noise source for many people who are not professionally involved in automotive science.
- Aerodynamic noise: it is related to the turbulent airflow around and partly through the vehicle when it travels at high speed. Aerodynamic noise sources are not important for exterior vehicle noise due to the effective aerodynamic design which is necessary to meet fuel consumption requirements. However, it may be quite important for interior noise.
- Tire/pavement noise: it is related to the interaction of the tire and pavement surface when the vehicle equipped with this tire cruises or is driven over the surface. Tire/pavement noise generation mechanisms can be divided into two main groups according to the media in which they occur and their effects. One is directly related to mechanical vibrations of the tire and the other is aerodynamical phenomena, i.e. air pumping noise. Air pumping noise is generated by the compression of air and rapid expansion as the air is forced out between the road and the tire tread.

Among them, it is reported that the tire/pavement noise is up to 30% of total noise and it tends to become dominant under high speed running condition.[1,4] For even low speeds, the tire/pavement noise is significant portion of the pass-by noise for automobiles. For trucks, the tire/pavement noise typically becomes dominant at higher speeds, overcoming engine and exhaust noise that is greater when compared to automobiles. So the reduction of tire/pavement noise is essentially important for the abatement of traffic noise.

2.2 Pavement textures

Based on physical relations between texture and friction and noise, the concrete pavement surface can be divided into three general groups: microtexture comes primarily from exposing the sand particles in the mortar, macrotexture refers to grooves and channels formed in the plastic or the hardened concrete, megatexture is usually an undesirable characteristic or results of defects in the surface. The ISO standards define texture as the deviation of a pavement surface from a true planar surface, within the texture wavelength ranges defined as followings.[11]

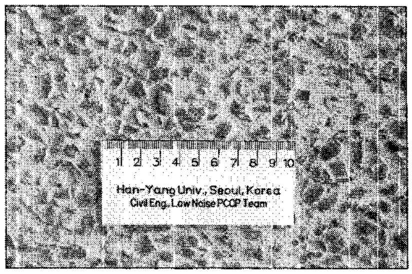
- Microtexture: deviation of a road surface from a true planar surface with the characteristic dimensions along the surface of less than 0.5mm, corresponding to texture wavelengths with one third octave bands with up to 0.5mm of center wavelengths.
- Macrotexture: deviation of a road surface from a true planar surface with the characteristic dimensions along the surface of 0.5mm to 50mm, corresponding to texture wavelengths with one third octave bands including the range 0.63mm to 50mm of center wavelengths.
- Megatexture: deviation of a road surface from a true planar surface with the characteristic dimensions along the surface of 50mm to 500mm, corresponding to texture wavelengths with one third octave bands including the range 63mm to 500mm of center wavelengths

Microtexture is important for safety but does not have a significant impact on noise generation. Macrotexture and megatexture play significant roles in noise generation and safety. Especially, when macrotexture wavelengths increase, tire noise decreases, primarily in the high frequency range. This is thought to be associated with air pumping as previously discussed. It is obvious that both the road surface and the tire are important when considering sound created by the tire/pavement interaction. This paper concerns a study of the effects of road surface texture on tire/pavement noise considering EAC pavement with large amount of macro-texture.

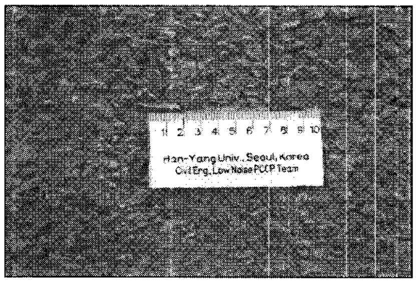
3. Methodology

3.1 Test pavements

It has been reported that smooth surface of pavement often causes high levels of air pumping noise which is major reason of tire/pavement noise. In fact, the most "noisy" pavement that has ever been measured was a smooth and polished cement concrete pavement (Sandberg and Ejsmont, 2000). There are several methods that can be used which practically eliminate the necessity for noisy textures. Exposed aggregate texturing considered in this paper is also suggested as one of them. This texturing is achieved by means of removing mortar between the aggregate before it hardens. The process includes spraying retarder on the finished surface of pavement but still fresh concrete and then brushing away the loose mortar that has not set. It has been found that exposing the aggregate can reduce noise level, but only if the aggregate sizes are small and uniform depth of mortar are removed. In order to remove proper and uniform depth of mortar layer, it is very important to decide the time of brushing for removal of mortar, and it also depend on properties and dosage of retarder. As the results of laboratory tests, it is possible that sound pressure level (SPL) at the exposed depth of 1~2mm is approximately reduced as 10dB(A) as than plain concrete pavement when adopted maximum size of aggregate is 13mm.[5,6] In conclusion, the exposed depth of 1~2mm and G_{max} of 13mm are suggested for texture optimization and this designed exposed depth of aggregate is acquired by means of removing of surface mortar at the hardness of 30~40.[6] Surface hardness test of concrete was performed as the method for measuring of retardation. Generally, exposed aggregate concrete has been achieved by using two-layer constructions with only small-size aggregate in the upper layer and conventional concrete in the lower layer wet on wet. Since sufficient ages are needed for hardening of base concrete, as the part of remaining by brushing away, without penetrating of retarder, it is supposed that proper hardness value of 30~40 could be acquired 12hours after retarder is added using the dosage of 200g/m^2. While the curing ages of concrete are elapsed more than 24hours, it would be impossible to expect effects of retarder. Fig. 1 shows the close-up view of surface textures of exposed aggregate concrete which are manufactured in both laboratory and field.



(a) Manufactured in the laboratory



(b) Manufactured in the field

Fig. 1 Close-up view of exposed aggregate concrete

Table 1 Overview of the equipment

Items	Description
Sound analyzer	Symphonie (01dB Ltd.) with 1/2" condenser microphone (40AF)
Analyze program	dBenv32: combine the features of a data logging integrating sound level meter, a digital tape recorder and a real-time frequency analyzer at the same time.
Tire	Dimensions: 195/70 R14 91T (Air pressure: 30psi) tread pattern featuring attributes of the most popular car "summer tread" tire.

3.2 Measuring methods

3.2.1 Pass-by noise measurement

The noise measurement procedure adopted in this study was based on the coast-by method standardised in ISO 13325.[3] Exterior noise levels were recorded with microphone mounted 1.2m above the pavement and positioned 7.5m from the centreline of the nearest traffic lane. A description of equipment and pass-by noise measurement are presented in Table 1 and Fig. 2 respectively.

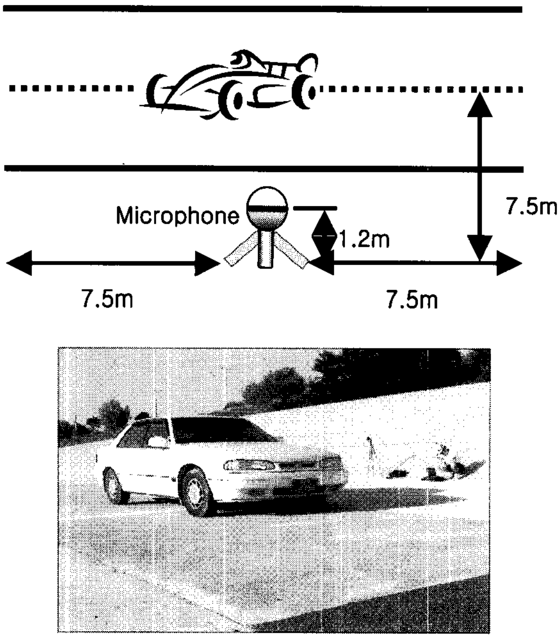


Fig. 2 Physical set-up for pass-by noise measurement

It is common to make a recording of the maximum A-weighted noise level and frequency spectrum at the moment of peak A-weighted noise. This method is often used to classify both the road surface and the tire influence on noise. All noise measurements were performed with the same car and tire, at operating speeds of 20, 40, 60 and 80 km/h in the right lane. A minimum of three valid runs was needed to collect enough data for each speed. All measurements were performed on dry pavements. Quality control of the measured data included review of the field notes and validation that the "pass-by peaks" exceeded the background noise levels by at least 15 dB(A).

3.2.2 Close-proximity method

All tyre/pavement noise measurement methods rely on certain assumptions and compromises are restricted by certain conditions. This means that one cannot expect to obtain exactly the same results when using different methods. The pass-by noise measurement is a sort of method not for pure tyre/pavement noise but for a mix of tyre/pavement noise and power unit noise. However, the close-proximity method has been rather extensively compared with pass-by noise measurement as the respect of characteristics of noise.

In searching for testing standards of the onboard tire/pavement noise measurement, it was determined that no test standard existed. Since then, a draft standard, ISO/CD 11819-2 "Method for measuring the influence of road surface on traffic noise-part 2: The close-proximity method" has been distributed for review and comment.[3] In the onboard method used, the setup is somewhat different from the pass-by noise measurement. The microphone setup of this method is shown in Fig. 3.

3.2.3 Interior noise measurement

In this study, the research was expanded to include an interior noise evaluation though this study aims the reduction of exterior noise. As can be seen from Fig. 4, the interior noise measurement was performed with microphone installed at the height of driver's ear.

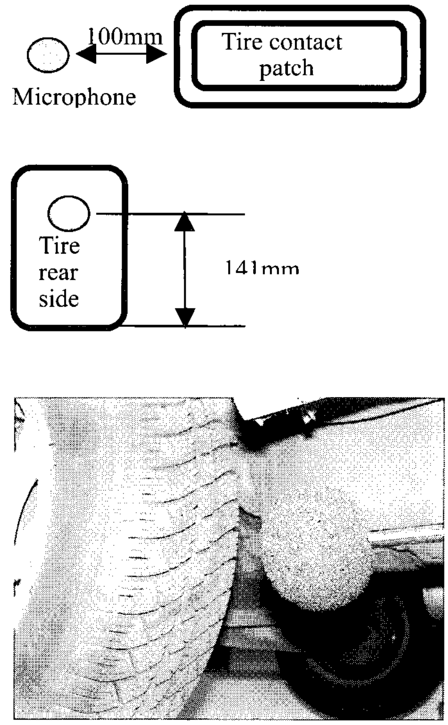


Fig. 3 Schematic of the onboard microphone setup

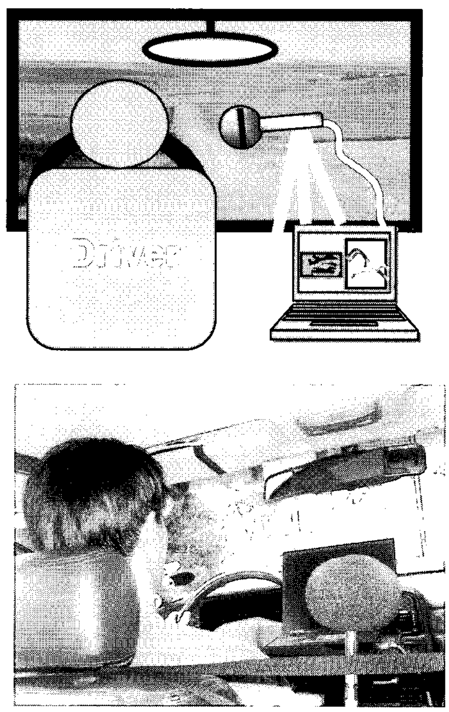


Fig. 4 View of the interior noise measurement facility

4. Construction

To evaluate application ability of exposed aggregate concrete for low noise pavement, pilot construction was performed as the condition shown in table 2. Construction was completed in June, 2002, and noise and texture measurements were completed within 1 month after placing concrete. At that time, temperature, humidity and wind velocity were 33.4 °C, 34% and 2.0m/s respectively. Because of the hot weather and high wind velocity, curing method and brushing time were considered with care.

Based on the preliminary results of laboratory test, polypropylene sheet curing was adopted for preventing rapid water evaporation and surface mortar was brushed away at the hardness of 30~40. As the methods for texture measurements, sand patching and peak searching were performed as shown in Fig. 5. In order to measure the exposed

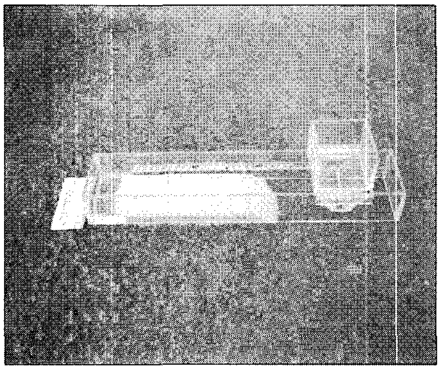
Table 2 Description of construction

Location	Length (m)	Width (m)	Section thickness (cm)		Applied methods
Kyunggi-do, Namyangju-shi, Suseok-dong	36	3.5 (1 lane)	Upper concrete	15	Exposed aggregate concrete (EAC) & Conventional concrete (Control)
			Lower concrete	15	
			Subgrade	100	

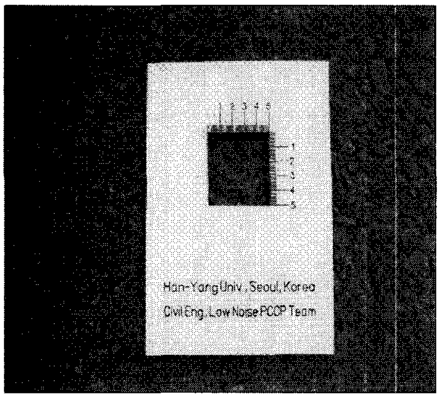
Mixture proportion

Specification					Unit weight (kg/m^3)					
Gmax (mm)	W/C (%)	S/a (%)	Air (%)	Slump (cm)	W	C	S	G	AEA*	WRA*
13	46.7	38	4.5	10±1	170	364	666	1,108	0.073	1.092

* AEA: Air Entrained Agent, WRA: Water Reduce Agent



(a) Sand patching test



(b) Peak searching test

Fig. 5 Texture measurements

depth of aggregate, the fine sands whose volume was already known were spread on the surface of concrete, and then the depth was calculated through volume of spread sands. It so called the sand patching test. The exposed aggregate depth of objective pavement was obtained as 1.7mm, which is satisfied within 1~2mm suggested for texture optimization. Peak searching test, counting the exposed aggregate within 5×5cm square, was also performed to visually find out the distribution of exposed aggregate. 28ea were counted through peak searching test in exposed aggregate concrete, this result was also satisfied to the optimum texture condition for expecting noise reduction

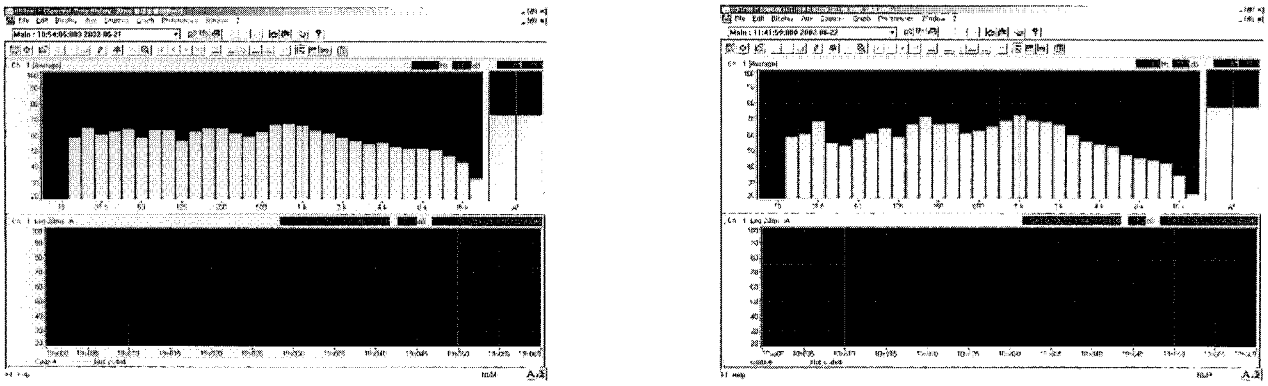
5. Results and discussion

5.1 Pass-by noise

The noise measurement using the pass-by method was adopted to analyze the characteristics of traffic noise emission according to texturing of pavement. Such measurements are performed with a test vehicle under real traffic conditions. The procedure which measure noise from a single car with the engine running is used in Europe for classification of different road surface. This method is independent of the type of vehicles or tires used and the acoustical results are only dependent on the road surface.[7] Furthermore, the influence of all other noise sources is not a significant factor because noise from test vehicle is much higher than any other noise sources. A-weighted sound pressure level measurements were recorded as well as one-third octave frequency bands between 50 and 10,000 Hz. The recorded data through the pass-by noise measurement are shown in Fig. 6 respectively. The bars represent A-weighted sound pressure level in one-third octave band at a vehicle speed of 80km/h.

Based on the recorded data of the exterior measurements, the analysis is presented graphically in Fig. 7 and Fig. 8. Fig. 7 presents A-weighted sound pressure level at a speed of 20~80km/h for the two different pavement conditions. Bars represent the average of more than three times tests. Generally, an increase in volume, speed, or vehicle size increases traffic noise levels. The results present that noise levels from traffic sources depend on vehicle running speed and exposed aggregate concrete is quieter than conventional pavement with regardless of speed.

Result of the noise level analysis at every frequency as shown in Fig. 8 indicate that the sound pressure spectrum is much varied for the difference of the pavement at higher frequencies. There is a distinct trend in the exposed aggregate concrete to have more attenuation in the frequency range above 1kHz, where the level difference between the highest and the lowest are 6dB(A). Because sound pressure



(a) EAC: exposed aggregate texturing

(b) Control: conventional concrete

Fig. 6 Data recorded by pass-by noise measurements (80km/h)

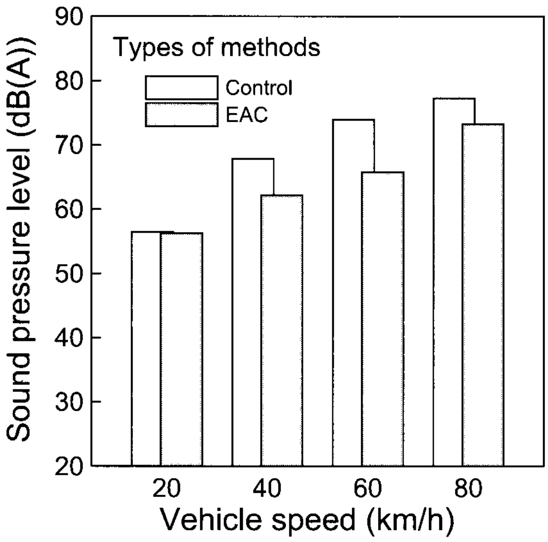


Fig. 7 A-weighted sound pressure level

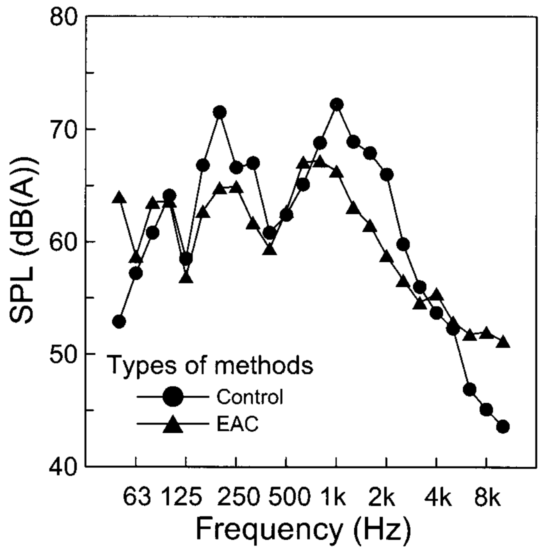


Fig. 8 Noise spectra (80km/h)

levels at high frequencies are decreased with texture amplitude when considering texture within the texture wavelength range 0.5~10mm. It means that the effects of texture on exterior noise are conflicting, depending on how the texture is composed.[3)]

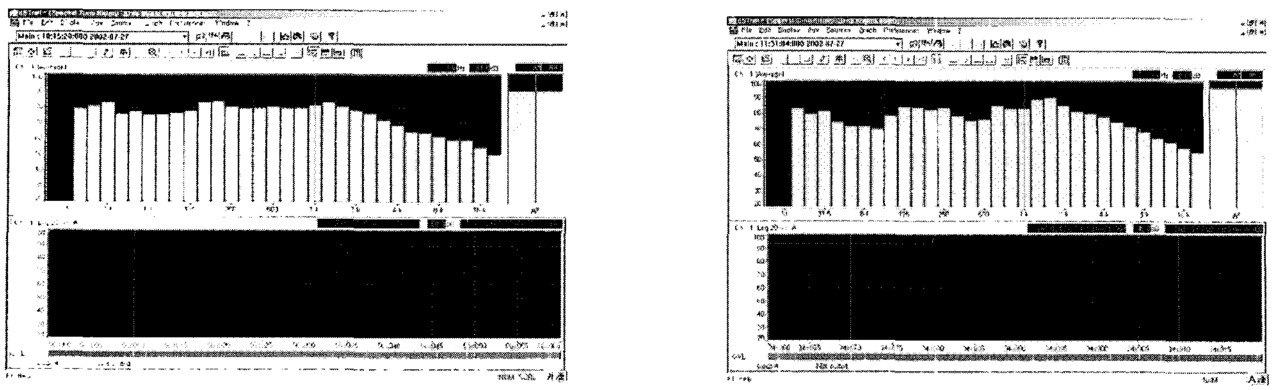
In conclusion, it is expected that tire/pavement noise represents significant portion of noise levels at higher frequencies and it would be reduced on special textures with large amount of macrotexture.

5.2 Close-proximity noise

Following results are collected by the close-proximity method. Generally, the onboard data from the microphones set on the near one of the tires was recorded to capture a noise signal that was predominately tire/pavement noise and less power unit noise or aerodynamic noise as compared to the pass-by noise measurement. Fig. 9 shows the recorded noise levels in the frequency range between 50 and 10,000 Hz through the close-proximity method.

As the result at a vehicle speed of 80km/h, there is the trend that the sound pressure spectrum of exposed aggregate concrete is lower than that of conventional concrete significantly at higher frequencies.

The sound pressure levels for all vehicle speed are shown in Fig. 10, and it shows that the trend of results is similar to that of pass-by noise measurement except that overall noise levels are higher. In all speed except 20km/h, sound pressure levels in exposed aggregate concrete are approximately 2~6dB(A) lower than those of conventional concrete. In addition, this trend is especially significant at higher running speed, and the reason is why tire/pavement noise tends to become more dominant under high speed running condition. The human ear is very effective at perceiving sounds with a frequency between approximately 1,000 and 5,000 Hz, with the efficiency decreasing outside this range.



(a) EAC: exposed aggregate texturing (b) Control: conventional concrete

Fig. 9 Data recorded by the close-proximity method (80km/h)

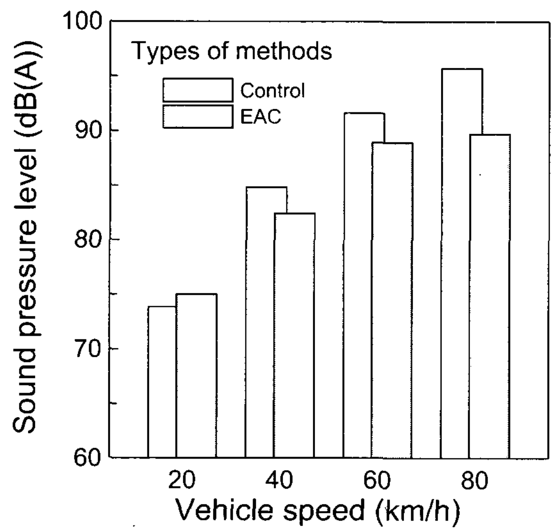


Fig. 10 A-weighted sound pressure level

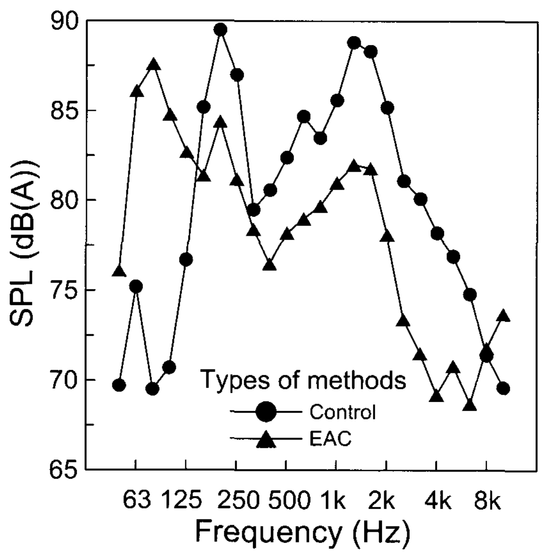


Fig. 11 Noise spectra (80km/h)

Fig. 11 shows the spectrum analysis conducted by the close-proximity method in one-third octave band at a speed of 80km/h. Compared to pass-by noise measurement, the onboard noise levels for adopted pavements represent overall higher sound pressure levels at all frequencies. When hearing sensitivity is considered, the frequency content below 500 Hz is not significant to human ear than the frequency content from 500 to 2,000 Hz. As the result of spectra analysis, the spectrum of exposed aggregate concrete are reduced by 5~10 dB(A) in the high frequency range compared to conventional concrete pavement. Conclusively, in the case of exposed aggregate concrete, distribution of sound pressure levels at high frequencies were much lower than those of conventional pavement as well as lower equivalent sound levels. It is expected according to these results that traffic noise levels are dominated by tire/pavement noise at highway speeds and surface treatment are able to reduce traffic noise with regard to human ear's perceiving.

5.3 The interior noise

Based on the preliminary results of the exterior measurements, the interior noise measurement was performed with microphone mounted at the same height of driver's ear in order to investigate the noise level which driver perceives.

Fig. 12 through 13 show the A-weighted sound pressure level at a speed of 20~80km/h and spectrum analysis in one-third octave band at a speed of 80km/h respectively. The results show that the trend of interior noise levels is totally different from that of exterior noise levels. Furthermore, there is no significant difference between exposed aggregate concrete and conventional concrete. As the result of this test, surface treatment such as exposed aggregate concrete is effective on reducing exterior noise more than interior noise. In addition, it is assumed that interior noise levels show a tendency to depend on power unit noise than noise source related to texturing of pavement.

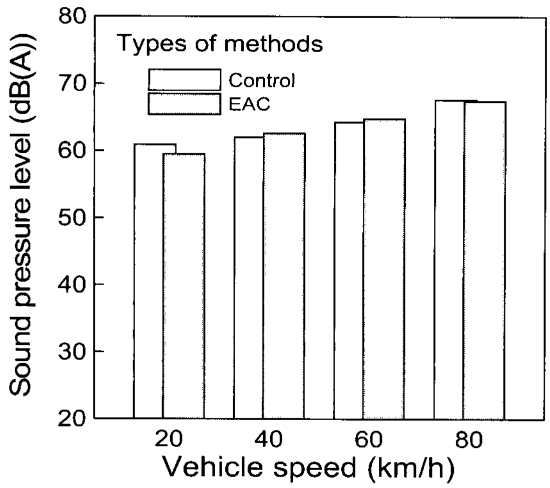


Fig. 12 A-weighted sound pressure level

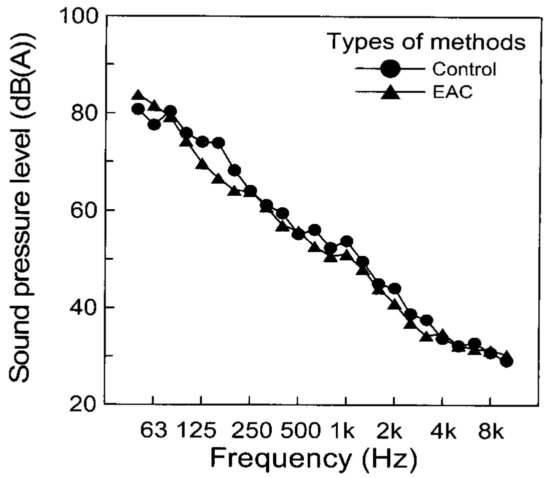


Fig. 13 Noise spectra (80km/h)

6. Conclusions

1) As the results of texture measurement of pilot construction, surface texture of exposed aggregate concrete was satisfactory with suggested texture optimization i.e. exposed aggregate depth of 1.7mm and peak number of 28ea.
2) Based on the results of the exterior measurement, noise levels from traffic sources depend on vehicle running speed, and the results from close-proximity method showed overall higher sound pressure levels than those of pass-by noise measurement at all frequencies, this can be seen that it significantly affected by the way of microphone set-up.
3) Sound pressure levels in exposed aggregate concrete were approximately 2~8 dB(A) lower than those of conventional concrete. This trend was especially significant at higher running speed where tire/pavement noise tends to become dominant.
4) In the case of exposed aggregate concrete, distribution of sound pressure levels at high frequencies were much lower than those of conventional pavement as well as lower equivalent sound levels. It is expected that tire/pavement noise which is represented much noise levels at higher frequencies would be significantly reduced on special textures of pavement with large amount of macrotexture.

Acknowledgements

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