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Noise Performance of Drainage Asphalt Pavement

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Abstract: In this paper, the noise-reducing characteristics of open graded drainage asphalt mixture pavement were investigated. Based on the prevailing theory of the Pumping Effect between tire and pavement, tire-pavement noise was evaluated. The Standing Wave Tube (SWT) method and the Roadside Pass-by (RPB) method were used. The acoustic properties of the five types of asphalt mixtures typically used in the Beijing region were determined. Properties studied in the laboratory included the noise reduction coefficient and sound absorption coefficient. In situ noise levels and noise frequency spectrums were obtained and compared using these methods. Also, the relationships between the noise reducing coefficient and the percentage of air voids (Va), nominal maximum aggregate size (NMAS), and texture depth (TD) were also analyzed. Analysis of the frequency spectrum of the pavement noise indicated that the open graded drainage asphalt pavement mixture had outstanding performance in reducing the noise level compared with that of dense-grade mixtures. Its noise reducing coefficient was twice as large, and it reduced the pavement equivalent continuous sound level (Leq) by 3.4 to 6.7dB(A).

***Key words**: Asphalt pavement; Drainage asphalt mixture; Frequency spectrum analysis; Pavement noise; Reducing-noise performance.*

Introduction

Noise generated by highway traffic is a growing concern to residents worldwide, especially in urban areas with high population densities, often near major roadways. Many sources contribute to the overall sound level generated in the highway environment, which can be separated into three categories, pure vehicles sources, aerodynamic effects, and tire-road interaction [1]. According to Sandberg and Ejsmont [2], in a standard drive-by test, the relative contribution from tire-road interaction to overall noise is 41%. Further, at speed above 55*km/hr*, tire-pavement interaction becomes the principal source of pavement noise [3].

Because of the increasing awareness of the traffic noise issues, in addition to sufficient structural strength, better surface texture characteristics to provide environmental friendly performance of pavements for riding comfort and safety have been under study in recent years. Open graded drainage asphalt pavement is a low-noise pavement that also reduces hydroplaning. In a study of acoustics between the tire and pavement surfaces, Richard [4] indicated that porous pavement materials, such as open-graded asphalt mixtures, would help absorb the noise energy, and thus reduce the pavement noise level. Michael et al. [5] determined the noise levels on Portland cement concrete (PCC) and asphalt concrete (AC) pavements by taking field measurements. By conducting laboratory tests using Tire Falling method (TF), Sen et al. [6] concluded that PCC pavement with a rough and porous surface, such as exposed aggregate concrete surface, would generate less tire-pavement noise. It is indicated that rough and porous surface could weaken the air dynamic effects between the tire and pavement, and therefore reduce the noise level. Cao and Lv [7] developed a prediction model for tire pavement noise. Douglas et al. [8] measured noise levels of many different types of asphalt mixtures using Statistical Pass-by (SPB) and Close-Proximity (CPX) methods [9]. However, most of studies concentrated on performing field measurements of tire-pavement induced traffic noise [10], and few have evaluated acoustical characteristics of the pavement surfaces and pavement materials.

The objective of this study was to investigate the noise reduction effects of open graded drainage asphalt mixtures using both field and laboratory measurements. Five types of asphalt mixtures, dense graded hot mix asphalt (HMA), stone matrix asphalt (SMA), crumb rubber asphalt mix, asphalt drainage mix (DAM), and small-size DAM, were evaluated. The Standing Wave Tube (SWT) method and the Roadside Pass-By (RPB) methods were used. Noise levels and acoustical characteristics for different materials and pavement surfaces were determined. Efforts were also made to study the effects of various material parameters and pavement surface characteristics, such as percentage of air voids (Va), nominal maximum aggregate size (NMAS), and texture depth (TD), on the measured noise reduction characteristics.

Research Approach

There are several mechanisms in the tire-pavement interaction that generate sound. Rolling contact made between the tire tread block and the pavement texture induces radial vibrations of the tire, which in turn, generate sound or noise. Pumping of air through the tire treads and pavement texture can produce high-frequency sound. This air-pumping noise is due to sound waves generated by the differences in air pressures between the front and the rear of a rolling

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Table 1. Volumetric Properties of the Samples.

Specimen Code	Average Height *mm*	Bulk Specific Density, g/cm^3	Air Voids %
FDA-8	65.93	2.065	18.0
DA-13	65.15	1.958	19.5
CRA-10	65.88	2.315	7.0
AC-10	62.95	2.442	4.1
SMA-13	64.65	2.342	4.9

tire treads. Both laboratory and field test methods were used in this study to measure pavement noise and acoustic characteristics; they are the SWT method and RPB method, respectively. The SWT method measures the pavement acoustic property and the RPB method measures field noise levels.

Determination of the Sound Absorption Coefficient by SWT Method

Sound absorption is a phenomenon of energy loss after a sound wave impacts on the surface of a material. The phenomenon can be quantified using the Sound Absorption Coefficient, α, which is defined as the ratio of the absorbed sound energy to the emitted sound energy. Because α is influenced by a material's absorption of sound at different frequencies, the characteristic frequency curve for α is used to describe the sound absorption properties. According to International Standards Organization (ISO), only those values of α within frequencies between 100 and 5,000*Hz* need to be evaluated.

In this study, α was determined by the SWT method. The sample was placed at one end of the tube, while microphone and sensor were placed at the other end. A single frequency sound wave is used in the test. The wave emitted in the tube is regarded as a plane wave, and forms a standing wave because of interference. The intensity of the sound is determined by the sensor, and α is calculated. Another parameter, Noise Reducing Coefficient (NRC) was also used in this study to evaluate the noise-reducing effects of the material. The NRC is the arithmetic average of the values of α obtained at frequencies of 0.25, 0.5, 1, and 2*kHz*.

Measurement of Pavement Noise Level by RPB Method

At present, there is a concern throughout the world regarding how to reliably study and quantify the acoustic properties of pavement surfaces. Different methods have been referred to in the literature, but no universally acceptable specifications exist for pavement noise measurement. In this investigation, to measure pavement noise, a sound sensor was installed on the road side at 1.2*m* above the pavement surface, and 7.5*m* from the pavement center. Vehicles pass by the sensor at a uniform speed in the range of 50*m* linear distance with the engine of the vehicle turned off. The peak value and the spectral distribution of the noise are recorded by the sensor.

Laboratory and Field Experiments

Five types of asphalt mixtures were studied, including a dense-graded hot mix asphalt (AC-10), a drainage asphalt mix (DA-13), a small-size drainage asphalt mix (FDA-8), a dense-graded rubber-asphalt mix (CRA-10), and a stone matrix asphalt mix (SMA-13).

Table 2. Sound Absorption Coefficients.

Frequency, *Hz*	125	250	500	1,000	2,000	4,000
AC-10	0.03	0.09	0.10	0.18	0.10	0.21
FDA-8	0.04	0.06	0.39	0.27	0.40	0.50
SMA-13	0.05	0.09	0.04	0.42	0.21	0.34
DA-13	0.03	0.04	0.36	0.20	0.44	0.38
CRA-10	0.03	0.03	0.09	0.38	0.36	0.27

Table 3. Results Determined for TD, α, and Va.

Mix Types	CRA-10	FDA-8	SMA-13	DA-13	AC-10
$\bar{\alpha}$, Arith-Average	0.19	0.28	0.19	0.24	0.12
Va, %	7.0	18.0	4.9	19.5	4.1
TD, *mm*	0.72	1.02	0.95	1.16	0.59
NRC	0.22	0.28	0.19	0.26	0.12

To determine their values of α, five specimens were prepared for each mixture in the laboratory at their optimum asphalt content using a Superpave gyratory compactor (SGC). The volumetric properties of the mixtures are presented in Table 1. The saturated surface density (SSD) method was used to determine the bulk density for the dense grade mixes CRA-10, AC-10, and SMA-13; and the Volume method was used for the open graded mixes FDA-8 and DA-13. The maximum theoretical density (MT Density) was measured using the Vacuum method.

The field evaluation of the pavement noise levels on three pavement test sections was conducted by using the RPB method. Low wind speeds and medium temperatures were chosen for all tests to ensure reliable and precise data. Vehicle speeds used in the study were 60 and 80*km/hr*. Each section was tested eight times at the same speed, and the data were averaged.

Results and Discussion

The measured Sound Absorption Coefficient values for the five different asphalt mixes are presented in Table 2. As can be observed from this table, the values of α for the AC-10 and SMA-13 mixtures ranged from 0.03 to 0.21 and from 0.05 to 0.34, respectively. For the frequencies of 125 and 250*Hz*, the differences of α among the mixtures are not noticeable; but, as the frequencies increased, significant differences in α between open-grade drainage asphalt mixtures (FDA-8 and DA-13), and dense-grade mixtures (AC-10, SMA-13 and CRA-10) become noticeable.

Table 3 shows the TD values, the average values of α and Va for five different asphalt mixtures. For the dense-graded mixture, the TD was measured by the sand patch method; while, for the open-graded mixture, the laser TD meter was used. The results indicate that the values of α and TD generally increased with the increase of Va. However, no linear correlation between α and TD can be observed. The compact surface of a dense graded mix cannot absorb noise, and in addition, the texture depth is difficult to measure precisely.

Effects of Percent Air Voids on the NRC

The NRC is usually used for evaluating the sound absorption characteristic of pavement materials in the appropriate acoustical

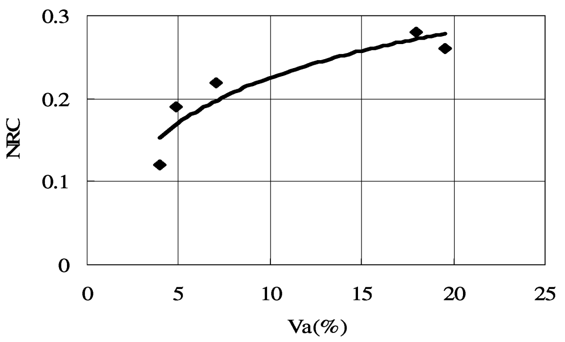

Fig. 1. The Relation between Va and NRC.

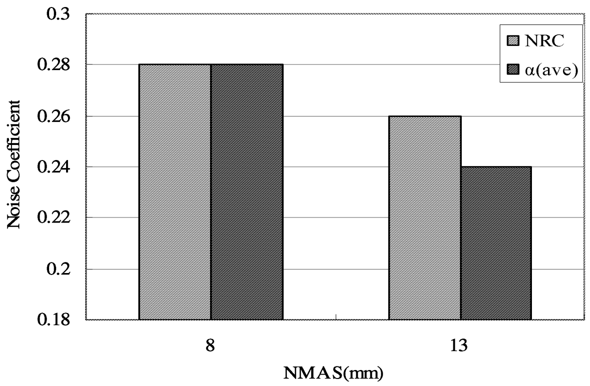

Fig. 2. Variations of the NRC and α with NMAS.

frequency range since a simple average of α values measured at different frequencies cannot accurately describe the noise properties of the materials. For each mixture, the NRC value was obtained by averaging the values of α at frequencies of 250, 500, 1,000, and 2,000*Hz*; the average values were rounded off to 0.01. The calculated NRC values for the five asphalt mixtures studied are also summarized in Table 3.

As can be noted from Fig. 1, the NRC value increases with the increasing values of Va. This study showed that the values of the NRC for mixtures FDA-8 and DA-13 were 0.28 and 0.26, respectively. These values are higher than that of other dense-graded asphalt mixtures. As a result, it was concluded that open-graded asphalt mixtures can absorb more sound energy, and thus, have better performance than the dense-graded mixtures for reducing pavement noise pollution.

Effects of NMAS on the NRC

The effects of the NMAS on the noise reducing characteristics for asphalt mixtures FDA-8 and DA-13 are shown in Fig. 2. It can be seen from the figure that the values of the NRC and average α increase with decreasing NMAS. The NRC and α values of the FDA-8 mixture increase by 0.02 and 0.04 compared with the DA-13 mixture. The value of Va for FDA-8 is 18.0%, and for DA-13 is 19.5%. When the Va values of the two mixes are similar, the differences of the NRC and α will be significant. At one point, NMAS is smaller and NRC is higher at the same Va. This phenomenon is related to the inner pore structure of the mixtures, with the finer mixtures having more continuous and ample inner pore structure.

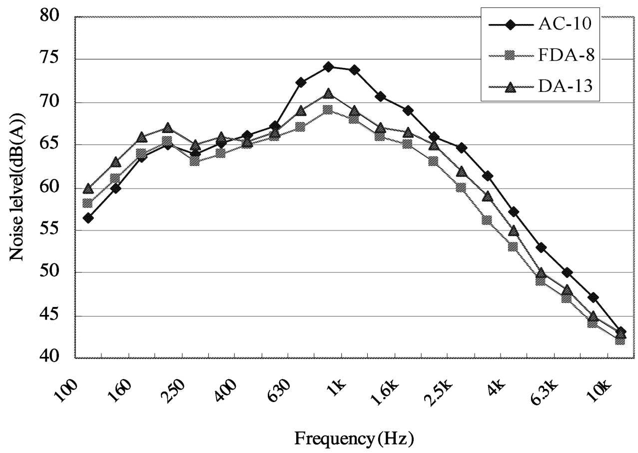

Fig. 3. 1/3 Octave Spectrum Analysis.

Table 4. Noise Levels of Field Sections, dB(A).

Speed *km/hr*	Open-Graded DA-13	Dense-Graded AC-10	Open-Graded FDA-8
60	68.7	72.1	65.4
80	71.0	74.9	69.5

One Third Octave Frequency Spectrum Analysis

In this study, 1/3 octave spectrum analysis was performed for the noise levels at a constant car speed of 80*km/hr*. The variations of the noise level with the frequency are shown in Fig. 3. It was found that the 1/3 octave noise level of the dense-graded AC-10 mix was higher than that of the open-graded DA-13 and FDA-8 mixtures at frequency ranges equal to or greater than 500*Hz*. At the same time, the smaller size mix has a 1/3 octave noise level between DA-13 and FDA-8. The spectrum analysis is the same for NRC.

Pavement Noise Level

Field evaluation of the equivalent continuous sound level (Leq) was performed on test sections by using the RPB method. The description of the mixtures used and the test results are listed in Table 4. As can be seen from the table, the equivalent continuous sound levels, Leq, of the open-graded sections are lower than that of dense-graded section. These results show that the decreases in noise level for the two open-graded sections are 3.9 and 5.4dB(A) at 80*km/hr*. This indicates that open grade drainage mixtures perform better in reducing pavement noise than that of dense-graded mixtures.

Summary and Conclusions

Based on the asphalt mixtures used, and within the limitations of tests performed in this study, the following conclusions are drawn:

1. The α and NRC values of asphalt concrete mixtures generally increase as the Va content increases, up to 15%. It is found that the inner pore structure is the most important factor in determining the NRC. The plentiful distribution of pores at the same Va is beneficial to the absorption of noise energy. This study also confirmed that greater values of Va and TD are also

effective in reducing pavement noise.

2. The open graded drainage asphalt mixture (DA) greatly reduced the noise induced by the pumping action of air and of tire vibrations. For open graded drainage mixtures, the use of smaller aggregate size also improves their noise reducing properties. Field evaluations of the reduction in noise levels by RPB method showed that the, by using the DA mixture, the equivalent continuous sound levels (Leq) were reduced up to 5.4dB at higher speeds.
3. It was also found that the 1/3 octave noise level for the dense-graded section was higher than that of the DA and the small-size FDA test sections at a frequency range up to 500Hz. Results show that flexible pavements with reduced noise pollution can be obtained by using open graded drainage asphalt mixtures.

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