MECHANISM OF THE NOISE REDUCTION OF DIFFERENT HMA BASED ON ACOUSTIC METHOD

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ABSTRACT

Small NMAS, porous structure and high elasticity of asphalt mixture were proved main measurements to reduce road/tire noise in past decades. However, the three measurements have different mechanism, which have been studied by many researches and engineering. Standing Wave Tube and Reverberation Chamber test were two typical methods for evaluating materials acoustic absorption.
The purpose of this paper was to analyze the mechanism of the noise reduction of different asphalt mixture, the influence factors were NMAS, air void level and visco-elastic characteristic of mixture. Further, this study focuses on demonstrating the reasonability and reliability of the two acoustic test methods evaluating the HMA reducing road/tire noise.

Keywords: road/tire noise, Standing Wave Tube, Reverberation Chamber

1. Background

The study of the noise reduction mechanism of asphalt pavement has developed decades. In china, low noise asphalt pavement has been studied and applied since late 90's last century. .

In the United States, the Federal Highway Administration has published the noise standards for highway projects as 23CFR772 (1). The FHWA Noise Abatement Criteria states that noise mitigation must be considered for residential areas when the A-weighted sound pressure levels approach or exceed 67 dB (A). To accomplish this, many areas in significant tire/pavement noise reductions. European highway agencies have found that the proper selection of the pavement surface can be an appropriate noise abatement procedure. Specifically, they have identified that a low noise road surface can be built at the same time considering safety, durability and cost using one of the following approaches (2):

1. A surface with a smooth surface texture using small maximum size aggregate
2. A porous surface, such as an open graded friction course (OGFC) with a high air void content
3. A pavement-wearing surface with an inherent low stiffness at the tire/pavement interface

In china, the upper three types of low noise asphalt pavement have been constructed on several applied project and the noise level on these road were tested by Statistical Pass-By Methods (SPB), and the effects are compared. The laboratory studies on this aspect are lack, the study object and method are focus on multi-porous asphalt concrete and standing wave tube, but the study for small () and high-elastic rubber asphalt concrete were few. In this paper, the upper three noise reduction measures (Small NMPS, multi-porous and high elastic asphalt concrete) are selected to compare through laboratory Acoustic Test.

2 Contents

The 7 gradations tested in this study are listed in table 1. The binders are: SBS modified asphalt、Pen 20/40 hare asphalt、Pen 80/100 base asphalt and rubber asphalt: AR1 and AR2.

1: Same aggregate proportion and same binder (SBS modified asphalt), but the different NMAS(4.75mm, 7.2mm, 9.5mm, 13.2mm and 16mm).

2: same gradation (the gradation is SAC-10), and various binder (Pen80/100、Pen20/40、SBS、AR1、AR2、AR3).

3: same NMAS, same binder and the various air voids (The NMAS is 10mm, and the passing rate of 4.75mm are 70%, 80% and 90% respectively)

Table 1 Gradations used in this paper

	Passing rate (%)											
	19	16	13.2	9.5	7.2	4.75	2.36	1.18	0.6	0.3	0.15	0.075
SAC16	100	97.5	80.9	58.8	44.9	30.0	23.5	18.4	14.5	11.4	8.9	7.0
SAC13		100	97.5	66.7	48.5	30.0	23.5	18.4	14.5	11.4	8.9	7.0
SAC10			100	97.5	60.8	30.0	24.0	19.2	15.5	12.4	10.0	8.0
SAC7.2				100	97.5	62.8	30.0	23.6	18.6	14.6	11.5	9.0
SAC4.75					100	97.5	30.0	24.1	19.4	15.6	12.5	10.0
SAC10-2			100	97.5	51.7	20.0	15.8	12.6	10.0	7.9	6.3	5.0
SAC10-3			100	97.5	39.2	10.0	7.6	5.8	4.5	3.4	2.6	2.0

The Marshall tests are carried before acoustic Test, measure the asphalt aggregate ratio and corresponding bulk gravity. And the air voids standards are 5% for type 1 and 2, and the air void standard for type 3 are 5%, 10% and 15%. The corresponding asphalt aggregate ratio and corresponding bulk gravity are listed on table 2.

Table 2 Bulk gravity of hot mix asphalt and air voids

Type	BINDER/MIXTURE	AIR VOIDS	Asphalt aggregate ratio (%)	Bulk gravity （g/cm^3）
Various binder (SAC10)	Pen 20/30	5%	5.35	2.4254
	Pen 80/100	5%	5.83	2.4316
	AR3	5%	6.99	2.3829
	AR2	5%	7.06	2.3881
	AR1	5%	6.84	2.4062
Various NMAS (SBS)	SAC16	5%	4.31	2.4798
	SAC13.2	5%	4.84	2.4564
	SAC10	5%	5.19	2.4529
	SAC7.2	5%	5.03	2.4395
	SAC4.75	5%	8	2.3625
Various Air voids (SBS)	SAC10	5%	5.19	2.4529
	SAC10-2	10%	4.11	2.3371
	SAC10-3	15%	3.25	2.2886

The upper specimens are formed as 10mm cylinder at the design air voids, and the

Absorption coefficient is measured by the standing wave tube.
The SAC7.2, SAC10 and SAC16 with 5% air voids are selected to measured by small Reverberation Chamber test. And this is another method to evaluate the noise absorption coefficient.

3 Introduction of Acoustic Test

The two important parameters for evaluating of noise absorption are noise absorption coefficient and acoustic impedance。
The noise absorption coefficient refers to the proportion of acoustic energy absorbed by surface and media。This parameter is affected by both orientation of noise wave and noise measure method. The noise reduction coefficient (NRC)：the average of the noise absorption coefficient measured at 250Hz,500Hz,1000Hz and 2000Hz.
The acoustic impedance on certain area is the complex ratio of acoustic pressure and volume speed for passing this area. The acoustic impedance ratio is the complex ratio of acoustic pressure and speed of one point.
The acoustic impedance can be expressed as:

$$Z_a = R + jZ \qquad (1)$$

where：

R —acoustic resistance；

Z —acoustic reactance；

The acoustic impedance is used to analyze the relationship between resistive leakage 、inertial、elastic and frequency. The acoustic resistance has no relationship with the frequency, but the frequency is a function of acoustic reactance, the acoustic reactance is an effective factor for frequency. As the acoustic reactance is positive,
Usually, There are two methods to evaluate noise absorption level, the one is standing wave tube and another is reverberation chamber. The noise absorption coefficient and noise absorption value can be measured by reverberation chamber. The characteristic of this method is that need a large size specimen for testing, and the two parameters can be used in Acoustic design directly. On the other hand, the standing wave method can be used to evaluate the noise absorption coefficient and acoustic impedance ratio. The testing is opposite with reverberation chamber, the dimension of specimen for testing is small, and convenient for setting, but the evaluation result can only be used to compare the noise absorption coefficient relatively between different material and same material under different condition, can not measure the resonant acoustic structure and the result can not be used for Acoustic design too.

3.1 Standing wave method

The maximum and minimum of acoustic pressure are measure by standing wave tube, the ratio to maximum and minimum is defined standing wave ratio, the standing wave ratio is the noise absorption coefficient under certain frequency and can be measured during testing directly, shown in the formula 2.

$$a = \frac{4S}{(S+1)^2} \qquad (2)$$

where：

a—noise absorption coefficient;

S—standing wave ratio;

At same time, the modulus of the acoustic impedance rate on normal direction（as formula 3）、amplitude angle of the acoustic impedance rate on normal direction（as formula 4） and corresponding (as formula 5) the acoustic reactance rate on normal direction and the specific acoustic resistance on normal direction.

$$|\xi| = \left[\frac{2 - \alpha - 2\sqrt{1-\alpha}\cos(2\pi b)}{2 - \alpha + 2\sqrt{1-\alpha}\cos(2\pi b)}\right]^{\frac{1}{2}} \quad (3)$$

$$\phi = tg^{-1}\left\{-2\sqrt{1-\alpha}\sin(2\pi b)/c\right\} \quad (4)$$

$$\mu = |\xi|\cos\phi \quad (5)$$

$$v = |\xi|\sin\phi \quad (6)$$

where： $|\xi|$——the modulus of the acoustic impedance rate on normal direction；

ϕ——amplitude angle of the acoustic impedance rate on normal direction；

v——acoustic reactance rate on normal direction；

μ——specific acoustic resistance on normal direction；

b and c are testing parameters.

3.2 Resonant Column Test

The noise absorption coefficient and noise absorption capacity can be calculated base on the reverberation time on various frequency, by the following formula (7):

$$a_s = \frac{55.3V}{cS}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \quad (7)$$

where：

a_s —noise absorption coefficient;

V—volume of reverberation chamber;

S —area of specimen;

T_1 —reverberation time without specimen（s）

T_2 —reverberation time with specimen（s）

c —sound velocity（m/s）

4 Data analysis

4.1 Result of standing wave tube

By standing wave tube testing, the noise reduction coefficient under different frequency are listed in table 3. the NRC refer to the average of noise reduction coefficient under 250、500、1000 and 2000Hz.

Table 3. Noise reduction coefficient of different NMAS

Materials	Frequency（Hz）	200	250	400	500	630	800	1000	1250	1600	2000	NRC
Different NMAS	SAC4.75	0.13	0.09	0.09	0.13	0.14	0.29	0.88	0.41	0.46	0.14	0.310
	SAC7.2	0.12	0.09	0.10	0.13	0.13	0.23	0.69	0.53	0.43	0.28	0.296
	SAC10	0.12	0.10	0.09	0.07	0.12	0.40	0.49	0.30	0.27	0.19	0.214
	SAC13	0.10	0.07	0.09	0.04	0.11	0.24	0.57	0.60	0.60	0.13	0.199
	SAC16	0.05	0.05	0.07	0.08	0.18	0.66	0.35	0.12	0.19	0.15	0.158
Different Air viods	SAC10-3	0.13	0.12	0.21	0.29	0.50	0.69	0.57	0.45	0.47	0.32	0.326
	SAC10-2	0.14	0.12	0.14	0.18	0.31	0.76	0.58	0.35	0.38	0.25	0.283
	SAC10	0.12	0.10	0.09	0.07	0.12	0.40	0.49	0.30	0.27	0.19	0.214
Different binders	PEN 20/40	0.11	0.09	0.09	0.11	0.20	0.31	0.42	0.46	0.42	0.18	0.199
	PEN 80/100	0.10	0.07	0.07	0.06	0.14	0.57	0.47	0.37	0.35	0.23	0.205
	AR1	0.12	0.07	0.07	0.06	0.10	0.51	0.58	0.23	0.25	0.18	0.221
	AR2	0.07	0.05	0.06	0.04	0.10	0.32	0.76	0.29	0.44	0.13	0.244
	AR3	0.06	0.05	0.06	0.04	0.10	0.26	0.83	0.40	0.37	0.29	0.303

The upper results illustrated:

1. the noise reduction coefficient of HMA decrease with the increasing of NMAS (shown in figure1)
2. the noise reduction coefficient of HMA increase with the increasing of air voids (shown in figure 2)

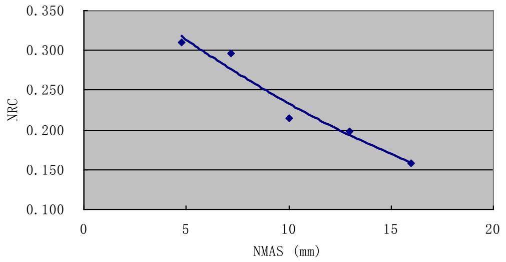

Figure 1: NMAS versus NRC

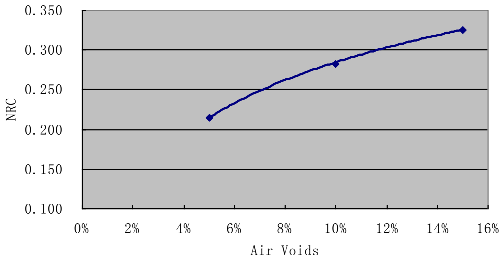

Figure 2: air voids versus NRC

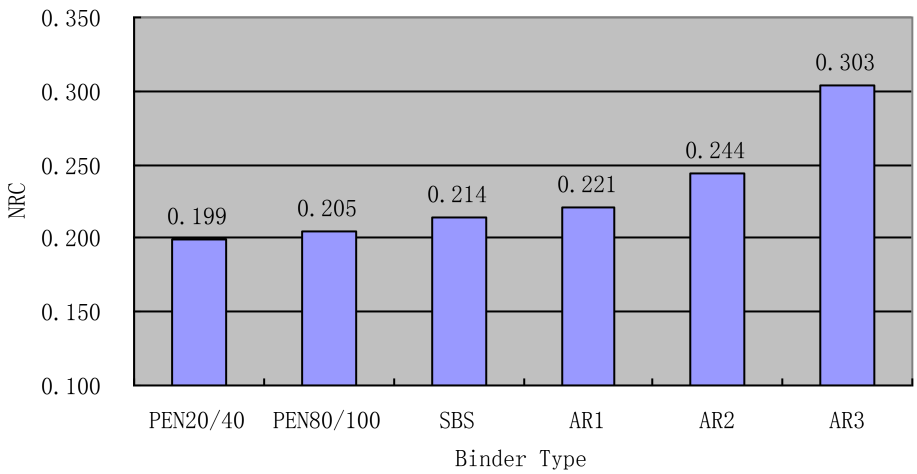

Figure 3. The NRC for mixtures with various binder

4.3 Reverberation chamber testing result

The results of testing result for SAC7.2, SAC10 and SAC16 are listed in table 4. the T1 is r reverberation time without specimen and the T2 is corresponding reverberation time with specimen, the α_S is the calculation result of noise reduction coefficient.

Table 4. Results of Reverberation Chamber for HMA With Various NMAS

materials	SAC16			SAC10			SAC7.2		
frequency	T_1	T_2	α_S	T_1	T_2	α_S	T_1	T_2	α_S
200	0.85	0.73	0.21	0.85	0.72	0.22	0.85	0.77	0.12
250	0.75	0.81	-0.1	0.75	0.83	-0.13	0.75	0.87	-0.17
315	1.17	1.14	0.02	1.17	1.14	0.02	1.17	1.15	0.01
400	1.42	1.12	0.2	1.42	1.22	0.12	1.42	1.21	0.12
500	2.02	1.47	0.2	2.02	1.46	0.2	2.02	1.48	0.17
630	2.17	1.46	0.23	2.17	1.45	0.24	2.17	1.47	0.21
800	2.15	1.28	0.33	2.15	1.28	0.33	2.15	1.27	0.31
1000	2	1.14	0.4	2	1.12	0.41	2	1.11	0.38
1250	1.92	1.02	0.48	1.92	1.03	0.47	1.92	1.03	0.42
1600	1.53	0.88	0.51	1.53	0.86	0.53	1.53	0.78	0.6
2000	1.07	0.74	0.42	1.07	0.72	0.47	1.07	0.69	0.49
2500	1.13	0.84	0.32	1.13	0.83	0.34	1.13	0.79	0.36
NRC			0.23			0.24			0.22

The results show, there are difference between the testing result measured by standing wave tube and reverberation chamber method. Shown in figure 4, the noise reduction absorption of these three materials are equivalent, but on various frequency phase, the rules exist difference. On low frequency (500~1250 Hz)， the HMA with large NMAS has larger noise reduction coefficient; and on high frequency(1600~2500Hz), the noise reduction coefficient will increase with the decreasing of NMAS.

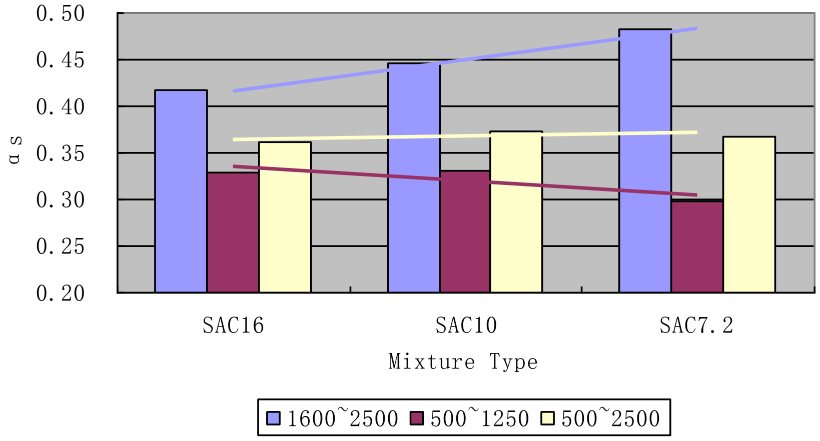

Figure 4. Noise absorption coefficient of various mixtures under various frequencies (reverberation chamber testing)

5. Conclusion

In this paper, two classical acoustic Test standing wave tube and reverberation chamber method are attempted, the noise absorption coefficient of asphalt concrete with different NMAS, air voids and binders are compared. The results show:

1. For mixtures has same binder and air voids, the noise absorption coefficient will increase with the decreasing of NMAS, and the better noise reduction performance under high frequency.
2. For the mixture has same NMAS and binder, The noise absorption coefficient will increase with the increasing of air voids.
3. For the mixture has same NMAS and air voids, the noise reduction coefficient will increase with the viscosity of binder, and this character is more remarkable for rubber asphalt mixture.

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