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A Method for Evaluating Noise Reduction Effect of Low-noise Asphalt Pavements Based on Damping Characteristics

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Abstract. To find an alternative method to replace the reverberation chamber method and the standing wave tube method in evaluating noise reduction effect, the damping characteristics of several low-noise asphalt pavements were studied by uniaxial unconfined dynamic repeated loading test. The correlation between damping and sound absorption coefficient was established, and the influencing factors of damping characteristics were investigated. The results revealed a good correlation between the damping and the sound absorption coefficient of bituminous mixtures. As the damping value increased, the sound absorption coefficient also increased. Bituminous mixtures exhibited preferable noise reduction performance. The noise reduction effect of bituminous mixtures can be evaluated indirectly by damping. The major factors influencing damping were the static and dynamic moduli of bituminous mixture, as well as the viscosity and porosity of bitumen. The smaller the static and dynamic moduli of bituminous mixture, the higher the viscosity and porosity of bitumen, the greater the damping value, and the more prominent the noise reduction effect.

1. Introduction

In recent years, low-noise asphalt pavement construction technology has gained widespread attention of the road engineering industry at home and abroad, with noise reduction effect all along being the focus of R & D. At present, the indoor test methods for evaluating the noise reduction of low-noise asphalt pavements mainly include the reverberation chamber method [1] and the standing wave tube method [2], both of which can measure the sound absorption performance of materials. Reverberation chamber method requires the area of specimen to be large. It can measure the sound absorption coefficient under random sound wave incidence and the sound absorption of a single object. Standing wave tube method requires small specimen area. It is easy to install and convenient to use, which can measure the sound absorption coefficient and acoustic impedance under normal incidence of sound waves. Nonetheless, reverberation chamber method needs preparation of large-area pavement material specimen and is thus difficult to operate, while the standing wave tube method is not suitable for popularization in practical engineering because of high equipment cost. Therefore, it seems crucial to find a simple evaluation method that can be used in ordinary laboratories to replace the reverberation chamber and standing wave tube methods.

Existing research has shown that the elasticity and viscosity of pavement materials significantly influence their noise reduction effect; the greater the elasticity or viscosity, the more prominent the noise reduction effect [3]. Damping, on the other hand, can reflect the material's degree of energy loss under cyclic loads. The greater the damping, the higher the viscosity and deformability of material, the easier the dissipation of vehicle load's vibration on the asphalt pavement, and the easier the reduction of noise generated by tire-road friction. Clearly, it is feasible to evaluate the noise reduction effect of bituminous mixtures based on their damping characteristics.

As a typical viscoelastic material, the response strain of bituminous mixture is cyclically alternating when cyclic alternating stress is input, but hysteresis is common [4,5,6]. When cyclic alternating stress is input, the stress-strain curve of loading process and that of unloading process form an end-to-end loop, which is generally called the hysteretic curve, as shown in Fig.1.

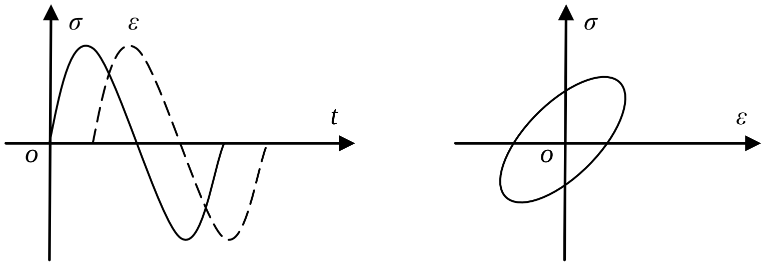

Fig.1 Hysteretic curves of viscoelastic materials

From the energy perspective, the work done by external force will accumulate a certain amount of energy within the material, so that its size can be expressed by the area of stress-strain curve [7]. For viscoelastic materials, the energy gained from loading process is not balanced with the energy released by the unloading process under dynamic loads, where the former is greater than the latter [8]. The area difference between the two, i.e. the area surrounded by the hysteresis curve, can be defined as the damping of material. Its numerical magnitude can reflect the degree of energy loss of material under cyclic loads. The greater the damping, the more viscous the material, and the more favorable to the noise reduction. This paper evaluates the noise reduction effect of low-noise asphalt pavements based on the damping characteristics of bituminous mixtures and analyzes the factors influencing noise reduction effect.

2. Experimental design

2.1 Test method for damping of bituminous mixtures

Stress-strain curves during loading and unloading processes can be obtained through the repeated loading test as shown in Fig.1, thereby enabling the calculation of damping parameter of materials. Thus, the repeated loading test can be employed as the main measure for studying the damping characteristics of low-noise bituminous mixtures. In this study, the MTS810 hydraulic servo system was utilized to conduct the uniaxial, unconfined dynamic repeated loading test on bituminous mixtures (Fig.2). Meanwhile, damping values were calculated based on the area of stress-strain hysteresis curves under different conditions. Test loads were delivered at a frequency of 15 Hz using a haversine wave form. The specimen used was Φ 100×100 mm cylindrical specimen, while the test temperature was 20 °C.

Fig.2 Uniaxial unconfined dynamic repeated loading test

2.2 Test materials

2.2.1 Gradation

Regarding the gradation of low-noise bituminous mixture, the small particle size mixture AC10 commonly used worldwide now was selected. During the gradation design, 7.2 mm-mesh coarse aggregate was introduced. Gradation compositions are listed in Table 1.

Table 1 Gradation compositions used in test

Mesh(mm) / Gradation	13.2	9.5	7.2	4.75	2.36	1.18	0.6	0.3	0.15	0.075
AC10	100	97.5	60.8	30.0	24.0	19.2	15.5	12.4	10.0	8.0

2.2.2 Bitumen

For low-noise bituminous mixtures, the viscosity of bitumen material is a key factor influencing their damping characteristics and noise reduction effect. Thus, the test bitumen materials were distinguished mainly by the viscosity index during material selection in this paper. During the test, two types of matrix bitumen were selected, namely AH-30# (a) and AH-90# (b); and three types of rubber powder modified bitumen (derived from AH-90#) were selected, whose rubber powder dosages were 17% (c), 20% (d) and 23% (e), respectively. The Brookfield viscosities at 175 °C of the five bitumen types are shown in Table 2.

Table 2 Types of bitumen used in test

Bitumen No.	a	b	c	d	e
No. of corresponding bituminous mixture	A	B	C	C	E
Type of bitumen	AH-30#	AH-90#	AH-90#+17%AR	AH-90#+20%AR	AH-90#+23%AR
175 °C Brookfield viscosity (Pa·s)	0.71	0.78	1.22	1.53	2.16

2.2.3 Preparation of bituminous mixtures

Mix proportion design of five bituminous mixtures was completed by volumetric method using the aforementioned AC10 gradation and five types of bitumen materials, and the bituminous mixture specimens used for studying the standing wave tube method and the damping characteristics were prepared. For ease of comparison, the five bituminous mixtures were numbered corresponding to the numbering of bitumen, which were A-E (corresponding bitumen numbering: a-e), respectively, as listed in Table 2.

3.Correlation between damping and sound absorption coefficient

Repeated loading test was conducted on bituminous mixtures A-E. The damping within one load cycle was calculated by the integral method. Meanwhile, standing wave tube method was employed to measure the sound absorption coefficients of these five bituminous mixtures. The results are shown in Table 3 and Fig.3.

Table 3 Damping and sound absorption coefficient test results for five bituminous mixtures

No. of bituminous mixture	A	B	C	D	E
Damping (N·mm)	64.11	68.94	89.87	93.05	105.94
Sound absorption coefficient	0.199	0.205	0.221	0.244	0.303

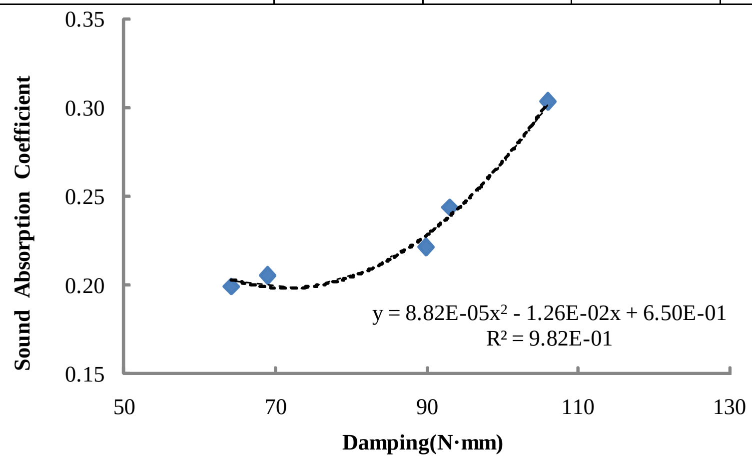

Fig.3 Correlation between damping and sound absorption coefficient

As can be seen from Fig.3, there was a good positive correlation between the damping and sound absorption coefficient of bituminous mixtures. With the increase of damping values, the sound absorption coefficients measured by standing wave tube method also increased, and the bituminous mixtures had better noise reduction effects. Since the damping was well correlated with the sound absorption coefficient, and the standing wave tube method can preferably evaluate the noise reduction performance of bituminous mixtures, the damping parameters obtained via the uniaxial unconfined dynamic loading test can be used to indirectly evaluate the noise reduction effect of bituminous mixtures.

4.Influencing factors of damping characteristics

4.1 Correlation between damping and resilient modulus of bituminous mixtures

Static and dynamic modulus tests were carried out on bituminous mixtures A-E, and the correlation curves between damping and modulus were plotted, as shown in Fig.s 4 and 5. As can be seen, damping of bituminous mixtures had good negative correlations with the static and dynamic moduli. With the increase of modulus, the damping of materials diminished. As that time, the energy loss of bituminous mixtures under dynamic loads was reduced. The greater the modulus, the higher the rigidity of bituminous mixture, the harder the material, and the worse the noise reduction effect.

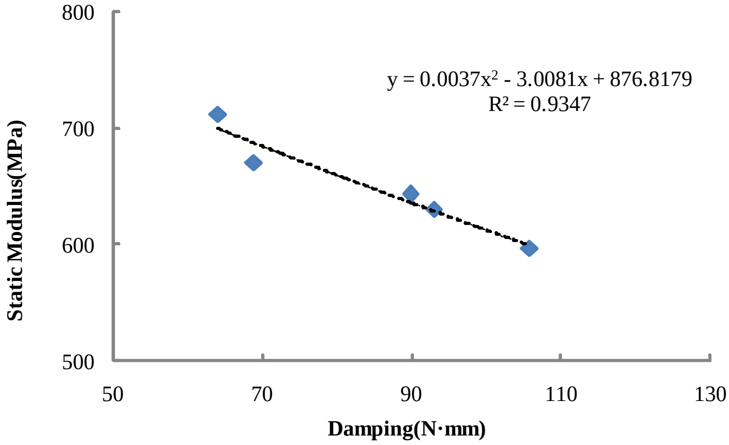

Fig.4 Correlation between damping and static modulus

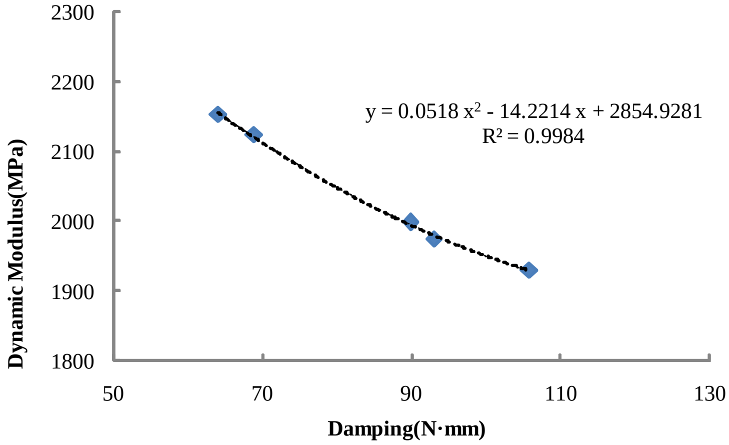

Fig.5 Correlation between damping and dynamic modulus

4.2 Correlation between damping and bitumen viscosity

As mentioned above, the five bituminous mixtures A-E corresponded separately to five types of bitumen with different viscosities a-e. The correlation curve between damping and bitumen viscosity was plotted, as shown in Fig.6. The result in Fig.6 indicated a good positive correlation between the bituminous mixture damping and the bitumen viscosity. With the increase of bitumen viscosity, the damping of bituminous mixtures increased gradually, the viscous property of materials became more remarkable, and the noise reduction effect got better.

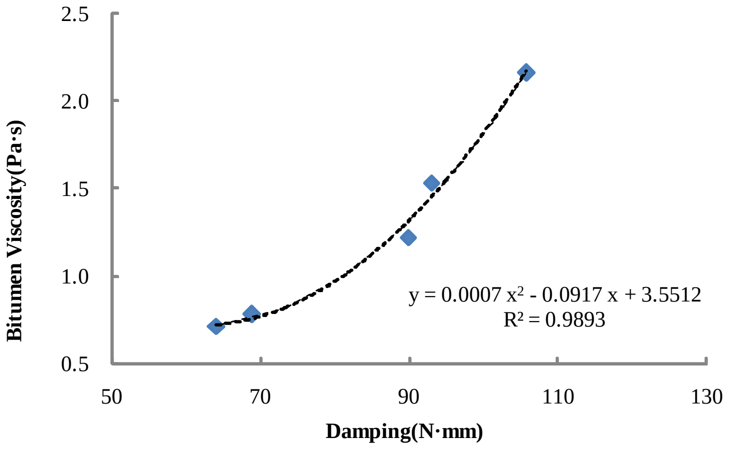

Fig.6 Correlation between damping and bitumen viscosity

4.3 Correlation between damping and bituminous mixture porosity

Using the aforementioned AC10 gradation and 90# bitumen, three types of bituminous mixture specimens with different porosities were prepared via the Marshall tests under varying compaction times. The prepared specimens were subjected to repeated loading test and standing wave tube method-based sound absorption coefficient test, and the correlation curves of porosity with sound absorption coefficient and damping were plotted, as shown in Fig.s 7 and 8. As can be seen, the porosity of bituminous mixtures was positively correlated with the sound absorption coefficient and damping. With the increase of porosity, the sound absorption coefficient and damping both increased, and the noise reduction effect was enhanced.

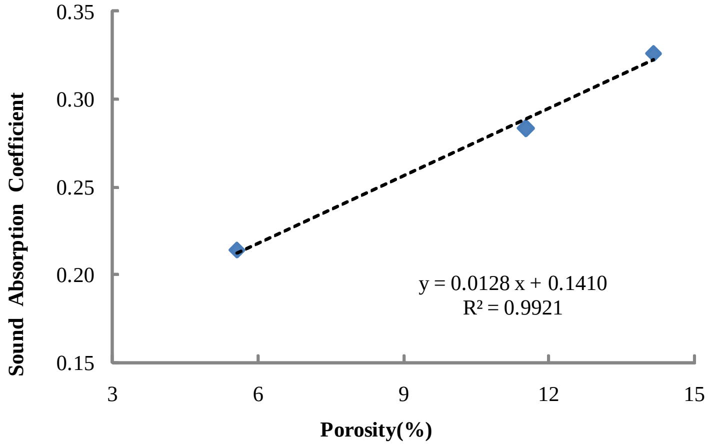

Fig.7 Correlation between porosity and sound absorption coefficient

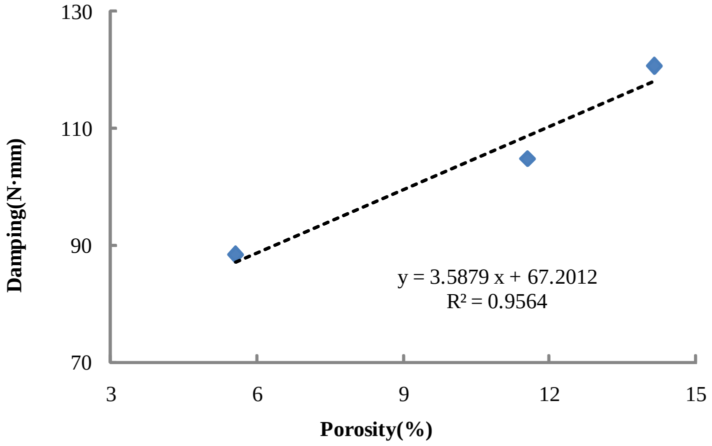

Fig.8 Correlation between porosity and damping

5.Conclusions

There is a good positive correlation between damping and sound absorption coefficient of bituminous mixtures. With the increase in damping value, the sound absorption coefficient measured by the standing wave tube method also increases, and the bituminous mixtures have better noise reduction effect. The damping parameter can be used for indirect evaluation of the noise reduction effect for bituminous mixtures.

Damping of bituminous mixtures has good negative correlation with the static and dynamic moduli. As the moduli of bituminous mixtures increase, the damping of materials diminishes. At this time, the energy loss of bituminous mixtures under dynamic loads is reduced, and the noise reduction effect worsens.

Damping of bituminous mixtures has a good positive correlation with the bitumen viscosity. With the increase of bitumen viscosity, the damping of bituminous mixtures increases gradually, the viscous property of materials becomes more remarkable, and the noise reduction effect improves.

Porosity of bituminous mixtures is positively correlated with the sound absorption coefficient and damping. The higher the porosity, the greater the absorption coefficient and damping, and the better the noise reduction effect.

6. References

[1]Ma Baoguo,Wei Dingbang,Li Xiangguo,et al. Primary Investigation on Sound-absorption Character of low- noise Asphalt Pavement. New Building Materials,2009,(8):18~20

[2]Ding Qingjun,Xu Min,Huang Shaolong,et al.Assessment and application on Noise-damping Performance of Antiskid and Fire-retarding Asphalt Pavement. Journal of Wuhan University of Technology(Transportation Science & Engineering),2010,34(5):1044~1048

[3]Hanson D I,James R S.Colorado DOT tire/pavement noise study.National Center for Asphalt Technology,Auburn University,April 2004

[4]Zhang Zhenli,Li Shiqi,Zhu Wenge. Temperature Spectrum Model of Dynamic Mechanical Properties for Viscoelastic Damping Materials.Journal of Mechanical Engineering,2011,47(20):135~140

[5]Wang Bing,Zhang Yongbing,Lin Xinzhi,et al. Analysis and Measurement Technologies Development of Dynamic Mechanical Properties for Viscoelastic Materials. Development and Application of Materials,2009,(6):77~80

[6]Lv Songtao, Tian Xiaoge, Zheng Jianlong. Test of Viscoelastic Parameters of Bituminous Mixture and Its Application in the Constitutive Model.Journal of Changsha Communications University,2005,21(1):37~42

[7]Zhang Hongliang,Hu Changshun,Xu Weiqing.Dynamic Response of Flexible Pavement under Moving Load.Journal of Chang'an University(Natural Science Edition),2005,25(5):6~10

[8]Shu Fumin,Qian Zhendong.Analysis on the Dynamic Response of Asphalt Pavement under Moving Load.Journal of Transportation Engineering and Information,2007,5(3):90~95