Construction and Building Materials 173 (2018) 801–810

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Prediction of tire-pavement noise of porous asphalt mixture based on mixture surface texture level and distributions

De Chen [a,b,c,*], Cheng Ling [d], Tingting Wang [e], Qian Su [a,b], Anjun Ye [c]

[a] School of Civil Engineering, Southwest Jiaotong University, 1545 Civil Building, No. 111, North 1st Section of Second Ring Road, Chengdu, Sichuan 610031, PR China
[b] Key Laboratory of High-Speed Railway Engineering of Ministry of Education, Southwest Jiaotong University, 1545 Civil Building, No. 111, North 1st Section of Second Ring Road, Chengdu, Sichuan 610031, PR China
[c] State Key Laboratory of Rail Transit Engineering Informatization (FSDI), China Railway First Survey and Design Institute Group Co. Ltd., No. 2, Xiying Road, Shaanxi, Xi'an 710043, PR China
[d] Oldcastle Materials, Inc., 15900 158th St West, Rosemount, MN 55068, USA
[e] State-Key Laboratory of Traction Power, Southwest Jiaotong University, 206 State-Key Laboratory Building, No. 111, North 1st Section of Second Ring Road, Chengdu, Sichuan 610031, PR China

HIGHLIGHTS

- A micro-structure sound absorption model of porous asphalt mixture was developed.
- Optimizing surface texture can reduce the level of tire-pavement noise.
- A tire-pavement noise prediction model of porous asphalt mixture was developed.

ARTICLE INFO

Article history:
Received 9 November 2017
Received in revised form 2 April 2018
Accepted 7 April 2018
Available online 24 April 2018

Keywords:
Porous asphalt pavement
Tire-pavement noise
Texture level and distributions
Image Texture Analysis Method
Prediction model

ABSTRACT

An accurate tire-pavement noise prediction model is highly needed by transportation agencies and pavement designers during the porous asphalt mixture design to reduce the tire-pavement noise which has been recognized as a dominant contributor to the overall traffic noise. In this paper, the surface texture level and distributions of porous asphalt mixture are acquired by a recently developed program named as 2-Dimensional Image Texture Analysis Method (2D-ITAM). The acoustic absorption coefficient of porous asphalt mixture is calculated using a proposed sound absorption model based on the micro-structure of porous asphalt mixture. Also, a prediction model correlating the tire-pavement noise level with macro-texture and short wavelength of mega-texture of pavement is established using a multivariate non-linear regression analysis. This prediction model is validated through laboratory experiment demonstrating its effectiveness of predicting the tire-pavement noise level. The model is anticipated to serve as an improved tool which could be considered by practitioners in an optimized porous asphalt mixture design incorporating the evaluation of noise produced by asphalt pavement.

1. Introduction

An exposure to noise levels above 70 dB (A) for longer than 24 h may cause hearing damage, general annoyance, induce adverse health effects according to the research of World Health Organization (WHO) [1]. With the increased volume of vehicles, noise from highway traffic is already one of the "city diseases" which significantly influences the quality of living and may cause discomforts [2]. Tire-pavement noise emissions are found much higher than those from other traffic noise sources even at low vehicle speeds [3].

According to a statistical analysis the tire manufacturers have developed over 16,000 types of tires in an effort to optimize ride safety, durability, and noise reduction [3]. However, it is not sufficient to merely focus on the improvement of the tire design to reduce the tire-pavement noise. Researchers have found that optimized design of pavement can also reduce the level of tire-pavement noise. Porous asphalt mixture pavement is one of effective type of quiet pavement, and already used in urban roads to reduce the traffic noise [4,5].

* Corresponding author at: School of Civil Engineering, Southwest Jiaotong University, 1545 Civil Building, No. 111, North 1st Section of Second Ring Road, Chengdu, Sichuan 610031, PR China.
E-mail address: chende@swjtu.edu.cn (D. Chen).

https://doi.org/10.1016/j.conbuildmat.2018.04.062
0950-0618/

An accurate tire-pavement noise prediction model is highly needed by transportation agencies and pavement designers during the stage of porous asphalt mixture (i.e. used in urban roads) design to reduce the tire-pavement noise. The generation of tire-pavement noise is a complex process with several generation mechanisms involved. The tire vibrations and air-flow related mechanisms such as air-pumping are the two main mechanisms among those generation mechanisms. According to the generation mechanisms of tire-pavement noise, several intrinsic properties of pavement influence the level of tire-pavement noise. Among these properties, pavement surface texture and acoustic absorption property are the two main influencing factors.

Nordic countries (i.e. Sweden, Norway, Finland, Denmark, and Iceland) introduced a common model in the 1970s for prediction of traffic noise, which gave more accurate noise prediction compared to other previous prediction models as it included road surface properties [6]. Researches have indicated that pavement surface texture significantly affected tire-pavement noise [7,8]. Reyes et al. developed a noise prediction model which obtained the one-third octave band frequency data. The input parameters of this noise prediction model are mean profile depth (MPD) and airflow resistivity [9].

However, the MPD, an indicator of the overall property of surface texture, cannot indicate the distributions of pavement surface texture which play a significantly role in tire-pavement noise reduction and skid resistance of pavement [2,10]. Liu et al. found texture amplitude, the shape (positive texture or negative texture) and distributions (texture spectrum) of pavement texture have strong impacts on pavement noise and friction [11]. The SPERoN and HyRoNE models predicted the pass-by tire-pavement noise of a passenger car based on the characteristics of the road surface (i.e. the spectral power of pavement surface texture) [12,13]. Meanwhile, some studies have been conducted and it was found that the mixture acoustic absorption property influenced the noise level generated by roads [14,15]. Additionally, Chen et al. found that there was good correlation between the design parameters and surface texture of asphalt mixture [16].

The primary objective of this study is to develop a prediction model of tire-pavement noise level based on level and distributions of surface texture and acoustic absorption properties of porous asphalt mixture. The prediction model is anticipated to serve as a useful tool for practitioners towards an optimized porous asphalt mixture design incorporating the evaluation of tire-pavement noise.

2. Data acquisition method

2.1. 2-Dimensional image texture analysis method (2D-ITAM)

To evaluate the level and distributions of macro-texture and micro-texture of asphalt pavement, a 2-Dimensional Image Texture Analysis Method (2D-ITAM) [2,10] was developed by Chang'an University and the University of Wisconsin-Madison based on the image analysis techniques and spectral theories, as shown in Fig. 1.

2D-ITAM acquires the surface profile of asphalt pavement from the scanned image of mixture cross section based on image analysis techniques [10]. The levels of surface texture at different wavelength (i.e. $L_{TX,m}$) are developed according to the standard ISO. 13473-4 [17]. The indicator of asphalt pavement surface texture level within the octave band from i to j (i.e. $L_{TX,i-j}$) is calculated according to Eq. (1).

$$L_{TX,i-j} = 10lg\left(\sum_{m=i}^{j} 10^{\frac{L_{TX,m}}{10}}\right) dB \quad (1)$$

where $L_{TX,m}$: surface texture level within the octave band m, in decibels; $L_{TX,i-j}$: surface texture level within the octave band from i to j, in decibels; i,j: octave band i and j.

Higher value of $L_{TX,i-j}$ represents a profile with coarser surface texture within the octave band from i to j. The details of 2D-ITAM can be found in another paper of authors [10].

2.2. Laboratory Tire Rolling-down (TR) method

The Laboratory Tire Rolling-down (TR) Method developed by Pavement Research Center of Chang'an University [2] uses a device to measure the tire-pavement noise of asphalt mixture specimen in laboratory, as shown in Fig. 2.

The hardware of TR is mainly constituted of test tire, rolling down guide apparatus, and safety shield device. During the measurement process of TR, the test tire freely rolls down from the slope rail with a pre-set angle (i.e. 15°, 30°, and 45°) and impacts the pavement specimen with certain horizontal and vertical velocities, which is considered to represent the actual tire-pavement interaction when vehicles are operated on road surface [2]. The velocity of the tire at the measuring point of tire-pavement noise is calculated with a simplified model that a tire freely rolls down from the top of an ideal slope (no thermal energy conversion) with an initial speed equaling to 0 km/h [2]. Metal mesh safety shields (Fig. 2) are applied to protect the wedge absorber and microphone from being impacted by the test tire. The distance between microphone and measured tire while passing by is 10 cm. The INV9206A high-precision ICP type acoustic pressure transducer is used, which meets the requirements of the standard IEC 61672-1:2002 [18]. The Data Translation DT9837-OEM is used as the data collector to acquire noise data. The DEWESoft7.0.6 software is adopted to collect and analyze the tire-pavement noise. To eliminate the influence of the background noise on test results, the measurement of tire-pavement noise is carried out in the hemi-anechoic chamber of Chang'an University, as shown in Fig. 2.

3. Experiment design

Pavement surface texture level and distributions and acoustic absorption play fundamental roles in the generation of tire-pavement noise [19]. For asphalt pavement, three components of asphalt mixture affect pavement surface texture including aggregate, permeable air voids, and asphalt mastic (i.e. mix of asphalt binder and aggregate particles finer than 0.075 mm) [2], as demonstrated in Fig. 3. Additionally, the effect of sound energy dissipation due to the viscosity of air in the voids of porous mixture is another major influencing factor on acoustic absorption of porous asphalt mixture [2].

Different types of asphalt mixture design parameters including material, design and construction were selected to provide reasonable range of surface texture and air voids levels. Open-Graded Friction Course (OGFC) mixture was chosen in this study as a porous asphalt mixture. Three Nominal Maximum Sizes of Aggregate (NMAS) (i.e. 16 mm, 12.5 mm, and 9.5 mm) were selected for OGFC mixtures. Three gradations (i.e. coarse, intermediate, and fine) were adopted for mixes with NMAS which were widely used in practice (i.e. 12.5 mm and 9.5 mm), while only two gradations (i.e. coarse and fine) were selected for mixes with NMAS of 16 mm. High-viscosity SBS modified asphalt binder was used in this experiment. The asphalt-aggregate ratio which was not the optimum asphalt content was determined based on the aggregate gradation and NMAS of mixture according to project experience. Besides, five compaction levels (number of roller passes) and three compaction temperatures were selected as the compaction effort and temperature are known to have a great influence on mechanical and volumetric properties of asphalt mixtures. The details of experimental design are shown in Table 1.