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Evaluation of wearing course mix designs on sound absorption improvement of porous asphalt pavement

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HIGHLIGHTS

- A laboratory test on noise reduction property of porous asphalt mixes is proposed.
- Noise reduction capability of the mixes is insensitive to design porosity value.
- Clogging of pores significantly reduced sound absorption coefficients of the mixes.
- Specimen thickness had negligible effect on measured sound absorption coefficient.
- A method to give approximate noise reduction capability of paving mixes is shown.

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ABSTRACT

This paper describes a laboratory procedure to study the sound absorption characteristics of porous asphalt pavement wearing course mix designs, and estimate their contributions to tire-pavement noise reduction. The effects of the following mixture properties were considered: percent porosity of mixture, degree of clogging occurred, and layer thickness. Four porosity levels of porous asphalt were studied: 12%, 16%, 20% and 25%. The mix design with 20% porosity was tested for the effects of clogging and specimen thickness respectively. A dense graded mix was included to serve as a reference for comparison. The effectiveness of the sound absorption and tire-pavement noise reducing capability of the mixtures were evaluated using the laboratory data and field measurements of trial sections. An approximate noise reduction calculation based on laboratory sound absorption measurements is proposed for comparison of different mix designs. The study found that changing the percent porosity from 25% to 12% caused some changes in the frequency characteristics of sound absorption, but made negligible changes in their contributions to tire-pavement noise reduction. On the other hand, clogging of the pores in the mixtures resulted in noticeable decreases in both the sound absorption coefficients and tire-pavement noise reductions. The analysis estimates that about 23–33% of the total tire-pavement noise reduction achieved by the porous asphalt mixtures can be attributed to their sound absorption capability. Finally, changing the thickness of the asphalt mixture tested from 63 mm to 200 mm had no significant effect on sound absorption and tire-pavement noise reduction.

1. Introduction

Road traffic noise is one of the major contributors to noise pollution in urban areas today. About 40% of the population in developed countries is exposed to high level of road traffic noise that causes health risks and disturbance of sleep [1]. Technological improvements in automobile have reduced exhaust system and engine noise substantially to make tire-pavement noise the most dominant contributor to road traffic noise [2–4]. Studies have shown that tire-pavement noise dominates traffic noise at speeds above 40 km/h for passenger cars and 60 km/h for trucks [4].

As an effort to reduce tire-pavement noise, pavement engineers and researchers have explored different pavement wearing course designs to mitigate noise generated from tire-pavement interaction. Studies have found porous asphalt pavements to be an effective form of quiet pavement, and they are today the most widely used pavement applications worldwide to reduce traffic noise [2,5–7]. Porous pavements are effective in reducing tire-pavement noise because of their porous structure. The connected pores in the porous asphalt structure reduce tire-pavement noise through its porous structure to dissipate sound energy, and its sur-

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face pores and macrotexture to weaken noise generation mechanisms (such as air sucking, air pumping, air resonant and horn effect) by acting as air channels to relieve air pressures [4,8].

In the mix design of porous asphalt mixture, a point of interest to pavement engineers is to determine how the choice of different mix designs would help to reduce tire-pavement noise and not to lose the sound absorption capacity when clogging occurs during service. Currently such quantitative information is unavailable to guide pavement engineers in the mix design of porous asphalt pavement mixtures. There are also no recommended laboratory procedures for assessing the tire-pavement noise reduction of a design mix of porous asphalt mixture. This paper presents an attempt to develop a laboratory procedure and a method of analysis to assist pavement engineers in estimating the contribution to tire-pavement noise reduction by the porous structure of a porous asphalt design mix, and assessing how the noise reduction capability of the mix would be affected by clogging during service.

2. Objective and scope of study

The main objective of this study is to demonstrate that during the mix design phase of an asphalt mixture, it is possible to conduct acoustic tests on laboratory specimens to determine the sound absorption characteristics of the material, and perform analysis on the measured acoustic properties of the specimens to estimate the tire-pavement noise reduction achievable. To achieve this objective, a laboratory test and an analysis procedure is proposed in this study. The proposed procedure is developed to provide useful information to pavement engineers for the selection of suitable materials and porosity level in the design of porous asphalt mixtures to meet tire-pavement noise reduction requirements.

The proposed laboratory evaluation procedure consists of two parts. In the first part, by means of acoustic impedance tubes, the sound absorption coefficients of laboratory specimens of a test mix and a reference dense graded mix are measured. In the second part, with the measured sound absorption coefficients, the tire-pavement noise reduction of the test mix is estimated using a simplified method. For illustration of the proposed procedure, four porous asphalt mix designs used in Singapore were tested. The sound absorption characteristics of the test mixtures with respect to the following properties were examined: percent porosity of mixture, degree of clogging, and thickness of specimen.

These three properties identified above are of interest to pavement engineers because besides pavement surface texture, they are the main pavement-related factors that affect the tire-pavement noise generated by traffic traveling on a porous pavement. Clogging was considered for the reason that it is a common phenomenon associated with porous asphalt pavement surface layers in service due to the presence of dust and debris on roads [9,10]. The values of the three properties tested in the experimental program were:

- Percent porosity of mixture: 12%, 16%, 20% and 25%.
- Degree of clogging: 0%, 28%, 53%, 76%, and 100%.
- Thickness of specimen: 63 mm, 100 mm, and 200 mm.

The range of porosity tested encompasses the porosity levels of open-graded asphalt mixes and porous asphalt mixes normally constructed in practice. The thicknesses of specimen examined cover the range of common porous asphalt surface layer thicknesses used. The effects of clogging and specimen thickness were tested for the porous asphalt mixture with 20% porosity.

In addition to the porous mixtures, a dense graded mix was also tested in the study. The dense graded mix had an air void content of about 4%. It served to provide a basis of reference to facilitate the effectiveness assessment of the sound absorption and tire-pavement noise reduction capability of the porous asphalt mixtures tested.

Following the acoustic testing of the test mixtures, the test results were analyzed to show how each of the three properties studied affects the sound absorption properties of the test mixtures, and to estimate the effectiveness of the sound absorption and tire-pavement noise reduction capability of the porous asphalt mixtures studied. An approximate simplified calculation method was proposed to estimate the magnitude of noise reduction based on the sound absorption properties measured. A field trial of the test mixtures were laid to provide actual tire-pavement noise measurements for comparison with the calculated values.

3. Laboratory test program

3.1. Preparation of test specimens

Specimens of five different mixtures were prepared for the laboratory tests program, namely four porous asphalt mixes designated as PA-13, PA-16, PA-20 and PA-25, and a dense graded asphalt mix designated as DG. The gradations of these mixtures are shown in Table 1. The test mixes were selected for the purpose of the present study so that the porosity (i.e. percent air voids) covers a range from 4 to 25%. The porosity of a mix can be varied by adjusting its asphalt binder content and compaction effort. As shown in Table 1, an asphalt content of 5% was used for all the mix designs tested in this study. Marshall size test specimens of 102 mm in diameter and about 63 mm in height [11] were used for the study. Following the local practice in Singapore, drop hammer compaction in accordance with the ASTM standard procedure D6926-10 [11] was adopted. Three replicate specimens were prepared for each specific test. The porosity level of the test specimens are summarized in Table 2.

3.2. Laboratory clogging procedure

To study the effect of clogging, a laboratory clogging procedure developed by Fwa et al. [12] was adopted to produce clogged specimens with the following target degrees of clogging: 25%, 50%, 75%, and 100%. The procedure used a local residual soil in Singapore as the clogging agent. The residual soil was applied to a test specimen in stages, with an amount of 5.3 g added at every stage. At the end of each stage of clogging, the permeability coefficient of the specimen was measured. The clogging procedure developed by Fwa et al. [12] permitted clogging treatment and permeability measurements to be made in sequence in the same test setup.

The percent clogging achieved is calculated according to the following definition,

$$\%\ \text{clogged after clogging stage n} = \frac{\text{Permeability coefficient after clogging stagen}}{\text{Permeability coefficient before clogging treatment}} \quad (1)$$

An alternative definition of percent clogged is to take the ratio of porosity after clogging stage n and the initial porosity before clogging treatment. Eq. (1) is considered to be a more practical definition as it is relatively easy to perform permeability measurements both in the laboratory and in the field [13]. In comparison, it is practically impossible to measure changes in porosity in the field in a nondestructive manner.

3.3. Acoustic absorption measurements

The acoustic absorption coefficients of test specimens were measured using an acoustic impedance tube following the ASTM