Construction and Building Materials 191 (2018) 281–289

Contents lists available at ScienceDirect

Construction and Building Materials

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

Evaluation of functional characteristics of laboratory mix design of porous pavement materials

L. Chu [a], B. Tang [a], T.F. Fwa [b,c,*]

[a] School of Highway, Chang'an University, South Erhuan Middle Section, Xi'an 710064, China
[b] Chang'an University, China
[c] National University of Singapore, Singapore

HIGHLIGHTS

- Current pavement mix design methods inadequately address functional requirements.
- Laboratory tests are proposed to address functional requirements during mix design.
- The proposed tests address drainage, skid resistance and noise related properties.
- Test data allow evaluation of drainage capacity and skid resistance of mix design.
- Test data also allow prediction of tire-pavement noise of mix design.

ARTICLE INFO

Article history:
Received 11 April 2018
Received in revised form 14 August 2018
Accepted 1 October 2018

Keywords:
Porous pavement
Porosity
Permeability
Skid resistance
Sound absorption
Tire-pavement noise

ABSTRACT

Porous pavements are designed and constructed today to provide one or more of the following functional benefits: lower traffic noise, improved wet-weather driving safety, lower stormwater peak load, and replenishment of groundwater supplies. However, depending on the mix design and material properties of a porous pavement, not all these benefits can be achieved fully by the porous pavement. The factors that affect such functional benefits include the porosity, the properties of binder and aggregates, and the binder content and aggregate gradation of the porous mixture. Currently no agencies have specified any laboratory test procedure for pavement engineers to evaluate the functional characteristics during the mix design phase. Such laboratory procedures are useful in practice for porous pavement design. This study demonstrates that a set of laboratory tests based on currently available equipment and methods, along with related functional assessment analysis, can be performed to meet the purpose. The following laboratory tests on the design mix are proposed in this study: (i) Permeability test. (ii) 3-dimensional scanning of surface texture, (iii) Skid resistance test, and (iv) Sound absorption test. The test data may then be used for drainage capacity analysis, wet-weather skid resistance assessment, and tire-pavement noise analysis. The proposed laboratory test procedures are illustrated using two porous pavement materials. The test results show that practically useful information on functional characteristics of a design porous mix can be obtained using the proposed procedures.

1. Introduction

Porous pavements consist of one or more layers of high porosity to provide one or more of the following functional benefits: lower traffic-generated noise [1–3], improved wet-weather pavement skid resistance [4–6], lower peak flow load of stormwater runoff [7,8], and replenishment of groundwater supplies [9,10]. Other associated benefits include reduced splash and spray, and improved visibility of pavement markings on rainy days, as well as higher average traffic flow speeds during wet weather [10,11]. However, depending on the mix design and properties of the porous materials, not all of the above-mentioned benefits can be achieved in a given porous pavement.

As will be shown later in the review of current porous mixture mix design practices, the standard laboratory mix design procedures today do not adequately evaluate the functional characteristics of a porous mixture design during the mix design phase. The present study was motivated by the fact that there already exist

* Corresponding author at: School of Highway, Chang'an University, South Erhuan Middle Section, Xi'an 710064, China.
E-mail address: ceefwatf@nus.edu.sg (T.F. Fwa).

https://doi.org/10.1016/j.conbuildmat.2018.10.003
0950-0618/

in the literature sufficient knowledge and available test methods and analysis techniques to obtain the required data that can be used to estimate the desired functional characteristics of a porous pavement constructed with a given design mix. It is demonstrated in this study that using currently available test equipment and analysis methods, data can be generated to predict the functional performance of a porous pavement in the following three aspects: its drainage capacity, its wet-weather skid resistance, and the tire-pavement noise generated under traffic.

The following laboratory tests on a design mix are proposed: (i) Permeability test (ii) 3-dimensional scanning of surface texture, (iii) Skid resistance test, and (iv) Sound absorption test. The test procedure, the measured data obtained from each test, and how the measured data can be used to predict the desired functional performance are explained in this paper. To illustrate the concept and working of the proposed laboratory test procedures, the results of tests performed on two porous asphalt design mixes are presented and explained. The test data produced from the tests serve to demonstrate that the proposed tests were able to differentiate different functional performances of different porous mix designs.

2. Review of current porous mixture mix design practices

Various forms and designs of porous pavement have been used in North America and Europe for more than 50 years [12–14]. Two important aspects of the mix design of a porous pavement material are that the high-porosity mixture should be (i) structural sound and durable, and (ii) able to maintain its functional benefits over the entire design life. The National Center for Asphalt Technology, a leading asphalt research center in North America, has developed a mix design procedure for OGFC (open-graded friction course) mixes which are a common form of high-porosity mixture used in North America [12]. The mix design procedure consisted of 5 steps: materials selection, formulate trial aggregate gradations, determination of optimum gradation, determination of optimum binder content, and moisture susceptibility evaluation.

In the Texas PFC (porous friction course) mix design method, specimens at the selected optimum binder content were evaluated for draindown, moisture susceptibility and durability [15]. In Alabama, a minimum tensile strength ratio (TSR) was also specified in addition to draindown test [16]. More recently, an improved OGFC mix design procedure was recommended to the California Department of Transportation (Caltrans) [17]. The mix design procedure included two primary components: Volumetric design and performance testing. The first component was similar to the first 4 steps of the NCAT procedure. The performance testing in the second component comprised Cantabro, draindown, and Hamburg wheel tracking testing [16].

In Europe, the mix design of porous asphalt is governed by the European standard EN 13108-7:2016 [18]. The European standard specifies requirements for the constituent materials as well as the porous mixture. In its latest 2016 edition, the standard has included the following test requirements for the mix design: (i) Water sensitivity assessed using either indirect tensile strength ratio or compression strength ratio [19]; (ii) Resistance to abrasion by the Cantabro wear test [20]; (iii) Resistance to permanent deformation by wheel-tracking test [21]; (iv) Polishing resistance by the Wehner and Schulze method [22]; (v) Binder drainage by either the basket or beaker method [23]; (v) Permeability by a constant-head permeameter [24].

It is significant to note that, in contrast with North American practices, the latest European standard has incorporated some functional performance requirements into the mix design of porous pavement. This is reflected by requirements (iv) and (v) in the preceding paragraph. These additional functional requirements represent a recognition of the need to incorporate functional requirements into porous pavement mix design. However, the tests in requirements (iv) and (v) alone are inadequate to address the main functional benefits of porous pavements. A more complete set of tests and analysis is proposed in the present study, as explained in the next section, to cover the functional requirements of porous pavements.

3. Concept and scope of study

The main objective of the present study was to develop a set of laboratory procedures to test a mix design for the purpose of obtaining the material properties required for evaluating pavement functional characteristics based on mechanistic methods. Compared with predictions using empirical statistical regression models, improved and more accurate predictions of functional performance of pavement mix designs can be achieved with the proposed procedure. This is because mechanistic prediction models for skid resistance and tire-pavement noise are now available. Specifically, the proposed laboratory tests would be used for the prediction of the following three functional properties of a porous pavement:

- Surface runoff drainage capacity of the porous pavement layer;
- Wet-weather skid resistance properties of the porous pavement; and
- Tire-pavement noise.

Fig. 1 presents a flow diagram that shows the proposed additional laboratory tests (i.e. Phase II in the figure) to be included during the mix design phase of a porous pavement mixture. With these data, analyses can be performed to estimate the expected functional performance of the mix design.

To estimate the drainage capacity of a porous pavement layer, one needs to determine the permeability coefficient of the porous mix considered. This drainage property, together with pavement surface texture characteristics (both microtexture and macrotexture of the porous pavement surface), are required for assessing the wet-weather skid resistance performance of the porous pavement. Finally, by measuring the sound absorption coefficient of the porous pavement material, the expected tire-pavement noise can be predicted by means of a computer simulation model using the sound absorption coefficient and pavement surface texture data as input. The rationale and test procedures for the various laboratory tests proposed in this study are explained in the next section.

4. Proposed laboratory tests: Rationale and test procedures

4.1. Permeability test of porous mixture

The current standard permeability tests for testing cohesive or cohesionless materials are not suitable for measuring the permeability coefficients of porous pavement materials. For instance, ASTM D5084-16 [25] is applicable only for materials with permeability coefficients less than 10^{-5} m/s, which is much lower than those of common porous pavement materials; while ASTM D2434-68(2006) [26] and AASHTO T215-14 [27] both assume laminar flow that follows Darcy's Law as follows,

$$v = ki \tag{1}$$

where