Construction and Building Materials 126 (2016) 426–433

Contents lists available at ScienceDirect

Construction and Building Materials

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

Development of a predictive model to estimate permeability of dense-graded asphalt mixture based on volumetrics

Yu Yan [a],[*], John P. Zaniewski [b], David Hernando [a]

[a] Engineering School of Sustainable Infrastructure and Environment, Department of Civil and Coastal Engineering, University of Florida, 365 Weil Hall, PO Box 116580, Gainesville, FL 32611, USA

[b] College of Engineering and Mineral Resources, Department of Civil and Environmental Engineering, West Virginia University, ESB 651C, Morgantown, WV 26506, USA

HIGHLIGHTS

- Effective film thickness defined gradation coarseness more effectively than primary control sieve point.
- VFA appeared to help predict permeability by serving as a surrogate for the coarseness of the gradation.
- Predictive models proposed can be adopted as an effectively tool to validate mixtures at design state.

ARTICLE INFO

Article history:
Received 24 June 2016
Received in revised form 12 August 2016
Accepted 18 September 2016
Available online 22 September 2016

Keywords:
Permeability
Volumetrics
Dense-graded
Air voids

ABSTRACT

Asphalt mixtures with a coarser gradation typically provide greater rutting resistance due to a better structural network to resist shear, but they may present other issues, such as higher permeability. Increased permeability can facilitate water intrusion, which makes the pavement more vulnerable to moisture damage, stripping and erosion of unbound bases. Also, higher permeability promotes oxidation of asphalt binder, which may result in increased brittleness and susceptibility to cracking. The objective of this study was to develop a predictive model to estimate permeability of dense-graded asphalt mixture based on volumetrics. Eight Superpave mixtures were prepared: 9.5-mm fine and coarse graded, 12.5-mm coarse, 19-mm fine and coarse, 25-mm fine and 37.5-mm fine and coarse. Four target air void contents were defined for each mixture: 4%, 7%, 9% and 11%. Permeability tests were conducted using a falling head device according to the Florida Department of Transportation (FDOT) procedure FM 5-565. Permeability increased with air void content and nominal maximum aggregate size (NMAS); however, the effect of gradation was not conclusive as the primary control sieve point insufficiently defined gradation coarseness. In addition, voids filled with asphalt (VFA) exhibited a great correlation with permeability. Furthermore, two separate predictive models for 37.5-mm and 9.5 to 25-mm NMAS mixes were successfully developed based on regression analyses. These models provide a valuable decision tool to validate mixtures at a design stage on the basis of maximum permeability thresholds established by highway agencies.

1. Introduction

Asphalt mixtures with a coarser gradation typically provide greater rutting resistance due to a better aggregate structural network to resist shear, but they may present other issues, such as higher permeability. Increased permeability can facilitate water intrusion, which makes the pavement more vulnerable to moisture damage, stripping and erosion of unbound bases. Also, higher permeability promotes oxidation of asphalt binder, which may result in increased brittleness and susceptibility to cracking.

Permeability is defined as the ability of a material to transmit fluids through its pores when subjected to a difference in hydraulic head [1]. Hudson and Davis [2] stated that permeability depends not only on air void content, but also on air void size. Kanitpong et al. [3] reported that at the same air void content, coarser mixes are more permeable due to larger individual air voids. As air void size increases, the potential for individual air voids to be interconnected also increases. Thus, asphalt mixture permeability is directly related to the amount of interconnected air voids. Early work by Zube [4] concluded that asphalt pavements may become

---

[*] Corresponding author.
E-mail address: sayme@ufl.edu (Y. Yan).

http://dx.doi.org/10.1016/j.conbuildmat.2016.09.071
0950-0618/

excessively permeable to water at an air void content of 8%. However, Cooley and Brown [5] asserted that coarse-graded Superpave mixtures can be excessively permeable even at an air void content below 8%. Research by the Florida Department of Transportation (FDOT) suggested an air void content threshold of 6% [6].

Many models based on laboratory tests have been published to predict permeability of asphalt mixture [3,7–14]. Most of them include air void content as the main predictor of permeability in the form of an exponential, hyperbolic or, mostly, a power function. Limitations of these models relate to the factors considered in the experimental design. For example, some models focused on gradation parameters and the effect of binder content but compaction level was not assessed. Others are applicable only to a narrow air void content range or limited nominal maximum aggregate sizes (NMASs). Therefore, there is still the need for a permeability predictive model that can be used as a decision tool at a mixture design stage.

2. Objectives and scope

The main objective of this research was to develop a predictive model to estimate permeability of dense-graded asphalt mixture based on volumetrics. Detailed objectives were as follows:

- Evaluate permeability of fine and coarse-graded asphalt mixtures with different NMAS and air void content.
- Achieve a better understanding on the effects of volumetrics, e.g., voids in mineral aggregate (VMA), voids filled with asphalt (VFA), etc., on mixture permeability.

Eight Superpave asphalt mixtures including 9.5-mm fine and coarse graded, 12.5-mm coarse, 19-mm fine and coarse, 25-mm fine, 37.5-mm fine and coarse were produced for permeability testing in the laboratory. Coarse mixtures were defined as those passing below the corresponding primary control sieve (PCS) point. Gradations of the eight mixtures are presented in Fig. 1.

3. Materials and testing program

Mix designs were provided by the aggregate supplier, except for 9.5-mm fine and 37.5-mm coarse mixtures. A crushed limestone aggregate from Elkins (West Virginia) was employed for all mixtures. The asphalt binder for 9.5-mm and 12.5-mm mixtures was PG 70-22, while a PG 64-22 was used for 19-mm, 25-mm and 37.5-mm mixtures. Volumetrics were verified and 150-mm Superpave testing samples were prepared. Of note, the initial design binder content (P_b) for the 37.5-mm coarse mixture (4.9% by mass of total mixture) led to excessive binder draindown, so after consultation with the contractor's mix design technician, a binder content of 3.6% was selected.

Mixture volumetrics for a 4% target air void content at 75 gyrations are summarized in Table 1. Four target air void contents were selected for each mix: 4%, 7%, 9% and 11% (±0.5% tolerance was defined for 4% and 7% air void target contents, and ±1% tolerance for 9% and 11% contents). Air void contents above the maximum 8% suggested by conventional wisdom were included in the experimental design after cores from interstate highways I-79 and I-64 showed numerous samples exceeding 8%, particularly near the longitudinal joint. The number of gyrations was adjusted to produce specimens at target air void contents. Two replicates were prepared for permeability testing at each air void content.

A laboratory falling head device was used to evaluate permeability (Fig. 2). The Florida Department of Transportation (FDOT) procedure FM 5-565 [15] for falling head permeability test was followed. Before permeability testing, Superpave specimens were soaked in water to reach saturation. Petroleum jelly was used to fill the large void pockets around the specimen that were not representative of the compaction level inside the specimen. A lateral membrane was pressurized at 68.9 ± 3.4 kPa (10 ± 0.5 psi) to ensure water would not flow laterally. Water from a graduated cylinder was allowed to flow through a saturated asphalt sample and time taken to reach a known change in head was recorded. The coefficient of permeability was calculated using Eq. (1), which is based on Darcy's law for one-dimensional laminar flow through a porous medium. For each replicate, permeability tests were conducted three times to report an average permeability value. Permeability values for the first and third test did not vary by more than 4%.

$$K = \frac{a \cdot L}{A \cdot t} \cdot ln\left(\frac{h_1}{h_2}\right) \cdot t_c \tag{1}$$

where

K, permeability (cm/s);
a, inside cross-sectional area of graduated cylinder (7.9 cm^2);
L, length of test specimen (7.5 cm);
A, cross-sectional area of test specimen (176.7 cm^2);
t, elapsed time of flow between heads (s);
h_1, initial head of water (85.5 cm);

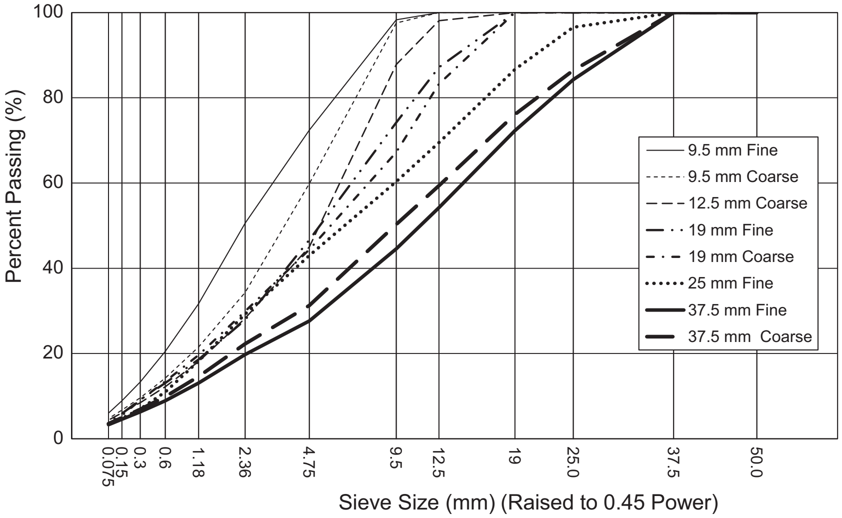

Fig. 1. Gradation of eight Superpave mixes selected for study.