Construction and Building Materials 114 (2016) 851–863

Contents lists available at ScienceDirect

Construction and Building Materials

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

Design and skid resistance evaluation of skeleton-dense epoxy asphalt mixture for steel bridge deck pavement

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HIGHLIGHTS

- One skeleton-dense epoxy asphalt mixture was designed and evaluated.
- The designed mixture meets the operating requirements of steel bridge pavement.
- The designed mixture has superior rutting resistance and anti-fatigue performance.
- The designed mixture could significantly improve the pavement skid-resistance.

ARTICLE INFO

Article history:
Received 7 December 2015
Received in revised form 16 March 2016
Accepted 29 March 2016
Available online 7 April 2016

Keywords:
Skid-resistance
Epoxy asphalt mixture
Steel bridge deck pavement
Skeleton-dense structure
V-S volume design method

ABSTRACT

To improve the skid-resistance of epoxy asphalt concrete pavement for the steel bridge deck, an epoxy asphalt mixture with skeleton-dense structure was proposed. This paper carries out a laboratory study on the design and performance evaluation of skeleton-dense epoxy asphalt mixture. Firstly, the mixture was designed through a volume design method, and the pavement performance was investigated to evaluate the applicability of the skeleton-dense epoxy asphalt mixture for the steel bridge pavement. Secondly, the skid-resistance of the skeleton-dense epoxy asphalt mixture was evaluated, including the initial skid-resistance, long-term skid-resistance and skid-resistance under the inclement weather condition. The long-term skid-resistance attenuation law was simulated by the small traffic load simulation system MMLS3, and the skid-resistance life was predicted. The skid-resistance attenuation law under the rainy and freezing weather was investigated in the laboratory, and the influence of water film thickness, different ice situations on the pavement skid-resistance was analyzed. Finally, gray correlation analysis method was applied to the comprehensive evaluation of pavement skid-resistance. Results indicate that the proposed mixture could meet the operating requirements of steel bridge pavement and dramatically improve the skid-resistance of epoxy asphalt concrete pavement.

1. Introduction

Epoxy asphalt mixture (EAM) has been proven to be a superior material and has been widely used in the steel deck pavement [1,2]. In general, EAM is made of suspended-dense structure, which could ensure the excellent physical and mechanical properties, such as watertightness and anti-fatigue performance [1,3]. Nevertheless, the suspended-dense EAM with insufficient pavement structure depth, tends to cause the shortage of skid-resistance on the epoxy asphalt pavement, especially under the conditions of inclement weather or large longitudinal slope [3,4].

Currently, materials for skid-resistance asphalt pavement are skeleton-dense structure [5,6], which could reinforce the skid-resistance of asphalt mixture through increasing the maximum size and proportion of coarse aggregates. However, influenced by the design thickness of asphalt pavement for the steel bridge deck, the NMAS of EAM is generally restricted to 9.5 mm (the so-called EA-10). In addition, excessive coarse aggregates would sacrifice the watertightness and anti-fatigue performance of EA-10. Therefore, this paper designed the skeleton-dense EAM, to improve the skid-resistance while balancing it with the physical-mechanical properties.

The common design methods of asphalt mixture, the Marshall and SUPERPAVE design method [7,8], are mainly based on the empirical method and laboratory tests. The SUPERPAVE method is usually used for the traditional dense-graded asphalt mixture, and demands a higher level of experimental facilities and

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http://dx.doi.org/10.1016/j.conbuildmat.2016.03.210

professional skills. The Marshall method is easily performed, but the volumetric characteristics of asphalt mixture are hard to predetermine. To make the aggregates form a skeleton structure, Zhang et al. [4] developed the coarse aggregate void filling method (CAVF method), and Zhao et al. [9] developed the volume design method (V-S method) based on multi-point supported skeleton theory. The experiment processes of CAVF method and V-S method are similar to the Marshall method, and the design concept is that the coarse aggregates form the skeleton, and the fine aggregate and asphalt fill in the void of skeleton, which could ensure the good skeleton structure and waterproof performance of asphalt mixture. In the CAVF method and V-S method, the material components could be determined by calculating, but the CAVF method could only determine the proportions of coarse aggregate and fine aggregate, and the minute aggregate grading is not defined, while the V-S method proposes the minute aggregate grading design method. Therefore, the V-S design method has better practicability for the design of skeleton-dense asphalt mixture.

The objective of this study is to design the skeleton-dense EAM, to improve the skid-resistance while balancing it with the physical-mechanical properties. In this paper, the skeleton-dense EAM was designed by V-S design method, and the skid-resistance of the novel EAM was evaluated, including the initial skid-resistance, long-term skid-resistance and skid-resistance under the inclement weather condition, and gray correlation analysis was applied to evaluate the comprehensive pavement skid-resistance.

2. Design of skeleton-dense EAM

2.1. V-S design method

The V-S design method depends on the mechanical and volumetric characteristics of skeleton-dense asphalt mixture, and is comprised of three parts: coarse aggregate gradation design, fine aggregate gradation design and mixture volumetric design. The V-S design method is proposed based on the idea that coarse aggregates ($\geqslant$4.75 mm) form the skeleton of compacted mixture, fine aggregates (<4.75 mm) fill in the voids of skeleton, and asphalt binder fills in the voids of mineral aggregate, and the design equations could be presented as

$$\begin{cases} M_C + M_F = 100\% \\ \frac{M_F}{\rho_F} = \frac{M_C}{\rho_C}\left(\frac{VCA-VMA}{100}\right) \\ \frac{P_a}{\rho_a} = \left(\frac{VMA-VV}{100}\right)\frac{M_C}{\rho_C} \end{cases} \quad (1)$$

where M_C is the proportion of coarse aggregates; M_F is the proportion of fine aggregates; ρ_F is the synthesized density of fine aggregates mixed mineral powder; ρ_C and *VCA* are the stacking density and voids of coarse aggregates in the packing condition, respectively; *VMA* is the voids of the mineral aggregate; *VV* is air-void content of asphalt mixture; P_a is the asphalt-aggregate ratio; ρ_a is the density of asphalt binder.

In the V-S method, the volume parameters, *VMA* and *VV*, are firstly determined according to the design requirement, and ρ_F, ρ_C, ρ_a, *VCA* could be obtained by tests. Naturally, the rest parameters, M_C, M_F, and P_a could be calculated by Eq. (1).

According to the design concept of V-S method, the bigger aggregate particle should be densely surrounded by smaller particles, forming the multi-point supported skeleton, which could ensure the stability of aggregate skeleton, as shown in Fig. 1.

Based on the model in Fig. 1, the coarse aggregate gradation is determined as

$$V_i = \frac{V_0}{\left(1+\frac{D_{i+1}}{D_i}\right)^3} \quad (2)$$

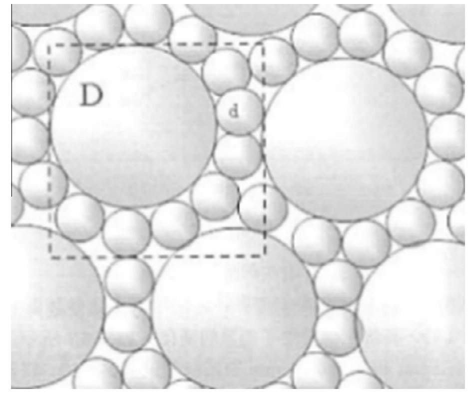

Fig. 1. Plane model of multi-point supported skeleton.

$$a_i = V_i \Big/ \sum_i V_i \quad (3)$$

where V_0 is the volume filling rate of coarse aggregates, which is defined as the bulk density divided by the apparent density of coarse aggregates [10]; V_i is the volume percent of the aggregates with the size of D_i, D_{i+1} is the aggregate with smaller size than D_i, and a_i is the volume percent of aggregates. It is noted that the volume of aggregates with the size of D_i should be deducted when calculating the volume percent of aggregates with the size of D_{i+1}.

The higher compactness of fine aggregate gradation could decrease the air-void content of asphalt mixture, and form the skeleton-dense structure of asphalt mixture. Therefore, the design of fine aggregate gradation refers to the Fuller's curve, as shown in Eq. (4)

$$P_i = (d_i/\overline{D})^n \times 100\% \quad (4)$$

where P_i is the percentage passing of aggregates with the size of d_i; $\overline{D}$ is the maximum size of fine aggregates; n is the exponent of the curve, which ranges from 0.2 to 0.45.

The procedures for the V-S design method are summarized and described below.

(1) Measure the bulk density and apparent density of coarse aggregates, and calculate the volume filling rate of coarse aggregates, V_0.
(2) Determine the coarse aggregate gradation using Eqs. (2) and (3).
(3) Determine the fine aggregate gradation using Eq. (4).
(4) Predetermine the *VMA* and *VV* of mixture, and measure the ρ_F, ρ_C, ρ_a, and *VCA* by the laboratory experiments, then calculate the proportion of coarse aggregates (M_C), the proportion of fine aggregates (M_F), and the asphalt-aggregate ratio (P_a) by Eq. (1).
(5) Acquire the composite gradation of mixture according to the coarse aggregate gradation, fine aggregate gradation, and the proportion of coarse aggregate and fine aggregate.

2.2. Design of VS-EA10

The EAM used in this study was mixed by basalt aggregate and epoxy asphalt binder. The technique indices of basalt aggregate and epoxy asphalt binder are list in Table 1.

The coarse aggregate gradation was determined using Eqs. (2) and (3). Because aggregate particles with the size between 2.36 mm and 4.75 mm would undermine the skeleton-dense structure of asphalt mixture [14], these particles were rejected. The design process of coarse aggregate gradation is given in Table 2.