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Evaluation and design of fiber-reinforced asphalt mixtures

Huaxin Chen [a,1], Qinwu Xu [b,*], Shuanfa Chen [a,1], Zhengqi Zhang [c]

[a] School of Materials Science and Engineering, Chang'an University, Xi'an 710064, China
[b] Pavement and Materials Research, The Transtec Group Inc., 6111, Balcones Dr., Austin, TX 78731, USA
[c] Highway College, Chang'an University, Xi'an 710064, China

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ABSTRACT

This paper investigated the volumetric and mechanical properties, and design method of fiber-reinforced asphalt mixtures. Four different fiber were used: polyester, polyacrylonitrile, lignin, and asbestos fibers. Marshall tests were performed to measure the volumetric and mechanical properties of asphalt mixtures. Performance tests were also conducted to examine moisture susceptibility and dynamic stability. Results show that the optimum asphalt content, air void, void in mineral aggregate and Marshall stability increase, while bulk specific gravity decreases after adding fibers into asphalt mixtures. Optimum asphalt content, Marshall stability, and dynamic stability increase initially and then decrease with increasing fiber content. It also shows that the polyester and polyacrylonitrile fibers have higher stability due to their higher networking effect, while the lignin and asbestos fibers result in higher optimum asphalt content and VFA (asphalt filled in the voids of mineral aggregates) due to their higher absorption of asphalts. A design procedure for fiber-reinforced asphalt mixture is proposed, which elects the fiber type based on the characteristics of both fiber and asphalt mixture, designs the optimum asphalt content following the Marshall method, and then determines the optimum fiber content in terms of performance test results. Based on the test results, a fiber content of 0.35% by mass of mixture is recommended for the polyester fiber used in this study.

1. Introduction

Fibers have been used in asphalt mixtures to improve performances of pavements. Previous researchers have reported fiber's reinforcing effects in asphalt mixtures and pavements. Fiber can stabilize asphalts to prevent asphalt leakage especially for the open-graded-friction-course (OGFC) and stone–mastic–asphalt (SMA) mixtures during the material transportation and paving [1–3]. Fiber changes the viscoelasticity of mixture [4]; improves dynamic modulus [5], moisture susceptibility [6], creep compliance and rutting resistance [7,8]; while reduces the reflective cracking of asphalt mixtures and pavements [9,10].

However, it shows that not much study is performed on the design method of fiber-reinforced asphalt mixture based on the literature review. The design methods of ordinary asphlat mixture primarily include the well-known Marshall design method and Superpave design method. In the design procedure asphalt content plays a key role in determining the engineering properties of mixture, which is determined in terms of the volumetric properties of mixture (specific gravity, air void, etc.) in both the Marshall and Superpave mixture design procedures. However, the volumetric properties of fiber-reinforced asphalt mixture are different from that of the ordinary asphalt mixture [2]. Therefore, it is regarded essential to investigate the volumetric properties of fiber-reinforced asphalt mixtures in order to design more reliable materials. Likewise, fiber content also plays an important role in determining the volumetric and engineering properties of asphalt mixture. It was reported that there exists some optimum fiber contents to achieve the maximum tensile strength and toughness [11]. Unfortunately, at many cases, fiber content is determined only according to engineering practice or manufacturer recommendation. E.g., a fiber content of 0.3% was used to study the performance of mixtures [6]. Therefore, it would be necessary to study the optimum fiber content toward a more effective mixture design. In addition, different fiber types would have different characteristics and reinforcing mechanisms. Thus, it is meaningful to identify their different reinforcing effects and mechanisms in order to elect appropriate fiber types for mixture design.

Accordingly, the primary objective of this paper is to study the volumetric properties and design method of fiber-reinforced asphalt mixtures. The volumetric and mechanical properties of asphalt mixtures using four different fibers were measured and evaluated through laboratory tests. Moisture susceptibility and

* Corresponding author. Tel.: +1 512 709 4155; fax: +1 512 451 6234.
E-mail addresses: chx92070@163.com (H. Chen), qinwu.xu@yahoo.com (Q. Xu), Zhqzhangchensf@263.com (Z. Zhang).
[1] Tel./fax: +86 29 82337340.

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Table 1
Physical properties of asphalt binder

Test items	Unit	Value	Specification
Original asphalt binder			
25 °C penetration	0.1 mm	85	ASTM D5
15 °C ductility	cm	117	ASTM D113
10 °C ductility	cm	75.6	ASTM D113
Softening point	°C	48.2	ASTM D36
Wax content	%	1.82	ASTM D 3344
Flash point	°C	268	ASTM D56
Specific gravity	Non	1.015	ASTM D 2041
RTFO			ASTM D2872
Mass loss	%	0.489	ASTM D2872
25 °C penetration ratio	%	60.25	ASTM D5
15 °C ductility	cm	37	ASTM D113
10 °C ductility	cm	13	ASTM D113

dynamic stability of mixtures were also examined to evaluate fiber's effects on the critical performances of pavements. A design procedure is proposed to design fiber-reinforced asphalt mixture.

2. Materials

2.1. Asphalt

The asphalt type of AH-90 produced by the Panjin Petrochemical Industry was used for all mixtures in the experiments. The basic physical properties of asphalts are measured following the ASTM standards, and are presented in Table 1.

2.2. Fibers

Four fibers that are frequently used in China were studied in this research according to the project requirement, including one polyester fiber (BoniFiber®) produced by the Kapejo Inc., one polyacrylonitrile fiber (Dolanit®AC) produced by the Kelheim Fibers Inc., one lignin fiber produced by the Beijing Pan China Municipal Tec. CO., and one asbestos fiber produced by the Sichuan Yitong Asbestos Products Inc., as shown in Fig. 1. The basic physical properties of these fibers are presented in Table 2 (provided by the manufacturers).

2.3. Aggregate

The coarse aggregates and mineral powders are made from limestone, and the fine aggregates are used from natural sands. The basic physical properties of coarse aggregate, fine aggregate and mineral power are presented in Tables 3–5, respectively.

2.4. Asphalt mixture

The aggregate gradation for AC-16 mixture – a frequently used mixture in China – is designed following the specification [12], as detailed in Table 6.

The manufacturers have recommended the fiber contents (by mass of mixture) for mixture design, as shown in Table 7, which have been used in the controlled mixtures. However, in order to study the influence of fiber content on the volumetric and engineering properties of asphalt mixture, four different fiber contents – 0%, 0.2%, 0.35% and 0.5% – were used for the polyester fiber in comparison with the controlled mixture.

The optimum asphalt contents for different fiber mixtures were determined using the Marshall design method [12,13]. In this method, the asphalt contents at the maximum density, lowest air void, and maximum Marshall stability are determined, and the average value is used as the optimum asphalt content.

3. Experimental program

3.1. Specimen preparation

Fibers were mixed with aggregates thoroughly for 15–25 s, and then heated in an oven at 175 °C which is about 10–20 °C higher than that for ordinary asphalt mixture (i.e., 155 °C). Consequently, the melted asphalt binder at 160 °C was added into fiber aggregate mixes and mixed thoroughly till resulting in a well coated and evenly distributed mixture. Subsequently, the hot mixtures were placed in a steel frame and compacted under 75 blows at 145 °C to attain a Marshall specimen measuring 101.6 mm (diameter) by 63.5 mm (height) according to the specification [13]. These specimens will be used for the laboratory tests of volumetric properties as discussed later.

3.2. Mechanical testing

3.2.1. Volumetric properties

The bulk specific gravity (G_{mb}) and air void of asphalt mixture were measured following the specification [12].

Consequently, the void in mineral aggregate (VMA) can be calculated as follows:

$$\mathrm{VMA} = 100\left(1 - \frac{G_{mb}}{G_{mm}} P_s\right) \tag{1}$$

where G_{mm} is the maximum theoretical specific gravity of asphalt mixture, P_s is the aggregate percentage by mass of mixture.The volume percentage of asphalt filled in the voids of mineral aggregate (VFA) is determined as follows:

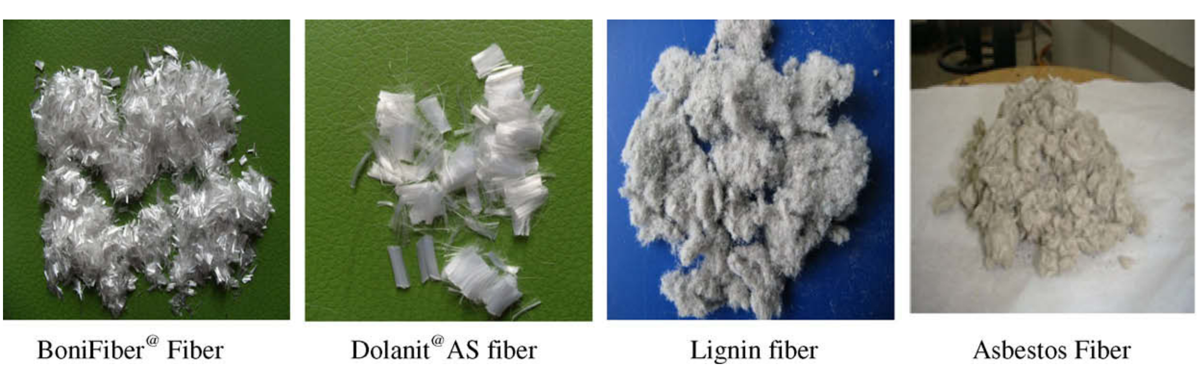

Fig. 1. Fibers.