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Characterization of asphalt mastics reinforced with basalt fibers

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HIGHLIGHTS

- Effects of basalt fibers of varied lengths and contents on asphalt mastic were studied.
- Cone penetration test and strip-tensile test were designed in this research.
- Excessive content of fiber may decrease the crack resistance and rheology.
- The reinforcement mechanism of basalt fiber on asphalt mastic was analyzed.
- The optimal length and content of basalt fiber were recommended.

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ABSTRACT

This paper examined the effect of basalt fibers of varied lengths (6 mm, 9 mm and 15 mm) and contents (3–10%) on the properties of asphalt mastics. For comparison, three asphalt mastics reinforced with basalt fiber, lignin fiber or polyester fiber were investigated. The asphalt adsorptivity, shear behavior, crack resistance and high-temperature rheological property were evaluated by leakage test, cone penetration test, strip-tensile test and dynamic shear rheometer test, respectively. In order to understand the reinforcement mechanism, the microstructure and morphology of basalt fiber-asphalt mastics were studied through using scanning electron microscopy (SEM). It was shown that the addition of basalt fibers generally improved the properties of asphalt mastics especially the crack resistance. The asphalt adsorption and strength behavior of asphalt mastic with 6 mm basalt fiber excelled that with 9 mm or 15 mm due to its largest contact area with asphalt mastic. The crack resistance and high-temperature rheological property of asphalt mastics were influenced by the adsorption and content of fibers. The asphalt mastic with basalt fiber showed the best comprehensive performance among all types of fiber-reinforced asphalt mastics. Basalt fibers could form a stable three-dimensional network in the asphalt mastic, which was able to disperse the stress and suppress the development of cracks of asphalt mastic effectively.

1. Introduction

Asphalt pavement occupies a growing percentage of freeways in China [1]. Asphalt concrete has good flexibility, good stress dispersion capability and the ability to adapt to the subgrade deformation [2]. On the other hand, it has temperature-dependent susceptibility and weak shear behavior due to the typical viscoelasticity of asphalt mastic that consists of asphalt binder and mineral filler, which constitutes the effective adhesive film in asphalt concrete [3,4]. These conditions may lead to rutting and cracking distresses of asphalt pavements. Therefore, asphalt mastic is nearly always reinforced with different modifiers (e.g., polymer) or fibers to help resist the temperature effect and load effect on asphalt pavement [5]. Previously, the compatibility between polymer modifiers and asphalt mastic has been questioned for satisfactory road performance, especially high-temperature stability and low-temperature property [6–8], and these modified techniques could be expensive and complex. In addition, fiber reinforcement technology is easy to implement into asphalt concrete, which can not only improve the high-temperature properties (dynamic viscosity and softening point) and low-temperature properties (ductility and bending strength), but also improve the elasticity modulus and the homogeneity of force distribution [9–11].

In recent years, several kinds of fibers, such as lignin fiber, polyester fiber, asbestos fiber and glass fiber, have been commonly used for asphalt pavement construction. Nevertheless, different types of fibers have different advantages and shortcomings. For

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lignin fiber, poor corrosion resistance and tensile strength make it difficult to ensure good long-term performance of asphalt pavement [12]. Although polyester fiber has excellent tensile strength and elasticity deformation restorability, it is combustible and easy to absorb dusts, which could result in reinforcement degradation [13]. Asbestos fiber and glass fiber have obvious disadvantages. For example, they are prone to be affected by moisture and aggressive substances, and release carcinogens in the process of application, especially under high-temperature conditions [14].

As a new type of environmentally friendly material, basalt fiber is made from basalt via the wire drawing technique between 1450 °C and 1500 °C, and it mainly consists of SiO_2, Al_2O_3, CaO, K_2O, MgO and TiO_2. Its operating temperature and tensile strength range from −269 to −960 °C and from 4000 to 4850 MPa, respectively. Furthermore, basalt fiber has excellent corrosion resistance, ultraviolet resistance, chemical stability and flame resistance [15]. Previously, research mainly focused on the physical properties of basalt fiber-asphalt mastic, such as penetration, softening, ductility and viscosity [16–20]. Based on extensive literature review, no substantive research has been conducted on the improvement mechanism of basalt fiber on asphalt mastic [21]. In addition, determining how to use basalt fiber for full production and solving relevant technical challenges in design require further research and investigation. Therefore, the effect of basalt fiber on both the physical and mechanical properties of asphalt mastic needs comprehensive investigation to elucidate how basalt fiber incorporation affects the stability, strength and rheological properties of asphalt mastic.

The main objective of this paper is to investigate the impact of basalt fiber on the physical and mechanical properties of asphalt mastic. Asphalt mastics with varied lengths and contents of basalt fiber were prepared in this study, and two types of commonly used fibers (lignin fiber and polyester fiber) were selected as the control experiments. A leakage test, cone penetration test, strip-tensile test and dynamic shear rheometer test were carried out to evaluate the asphalt adsorptivity, shear behavior, crack resistance and rheology of asphalt mastics, respectively. Furthermore, the reinforcement mechanisms of basalt fiber on asphalt mastic were studied through using SEM.

2. Test materials and mixing

2.1. Raw materials

2.1.1. Asphalt binder

A-70 petroleum asphalt was used in this study, which is suitable for hot and humid regions. Table 1 presents the physical properties of the asphalt according to the ASTM standards.

2.1.2. Fiber

Basalt fiber, lignin fiber and polyester fiber were selected for the performance test in this paper. Here, the basalt fibers used in this paper contained three different lengths of 6 mm, 9 mm and 15 mm, and the lengths of lignin fiber and polyester fiber were chosen based on engineering experiences. The physical and mechanical indices of these fibers are detailed in Table 2. In addition, it should be noted that the samples with lignin fiber or polyester fiber were set up as control groups to compare with that of basalt fiber.

2.1.3. Mineral filler

Levigated limestone was used as mineral filler with a density of 2.683 g/cm^3, whose maximum size was smaller than 0.6 mm.

2.2. Preparation of fiber modified hot asphalt mastic

Asphalt mastic was prepared by mixing the asphalt binder, mineral filler or fiber together, and the procedures of the preparation are shown as follows:

a. The fiber and mineral filler were oven dried at 60 °C for 1 h and the asphalt binder was heated to 160 ± 5 °C.
b. Asphalt binder and mineral filler were put into the MCM-01 colloid grinder. After 3 min of mixing, fibers were added steadily and the mixture was mixed for additional 5 min. The rotational speed was kept constant at 2000 rpm during the mixing process. The ratio of mineral filler to asphalt binder was 2:5, while various contents of fibers were added.
c. Immediately after mixing, specimens were sampled and cast in molds at 25 ± 2 °C.

3. Experimental testing

3.1. Leakage test

Asphalt binder is mainly composed of asphaltenes, saturates, aromatics and resins. These components could be selectively adsorbed by fiber during the mixing process of fiber-reinforced asphalt masitc, and the existence form and quantity of part of the components would be changed attributed to the interface effect between asphalt binder and fiber, which could affects the rheological property and stability of asphalt mastic significantly. Thus, leakage testing was carried out to evaluate the adsorption effect of fiber on asphalt mastic.

Here, fiber types (e.g., basalt fiber, lignin fiber and polyester fiber) were used at a constant percentage of 10 wt% of asphalt binder (approximately 0.4 wt% fiber of AC-16 asphalt mixture). Basalt fibers of different lengths (6 mm, 9 mm and 15 mm) were used into asphalt mastic to investigate the impact of fiber length on the performance of asphalt mastic. According to the engineering verification, the lengths of lignin fiber and polyester fiber were selected as 3 mm and 6 mm, respectively. The results of asphalt mastic reinforced by basalt fiber were also compared with the control sample with no fiber. The details of the test procedures are presented as follows.

Initially, the asphalt mastic sample (approximately 50 g) was molded naturally and placed in a stainless-steel mesh basket (sieve size: 0.6 mm), as illustrated in Fig. 1(a), and then the prepared sample was stored at 25 °C for 1 h. When cooled completely, the sample with mesh basket was oven heated at 140 °C for 1.5 h (see Fig. 1(b)). By measuring the weight of the asphalt mastic that

Table 1
Physical properties of asphalt binder.

Test item	Value	Standard value	Standard method
Penetration (25 °C, 100 g, 5 s) (0.1 mm)	72	60–80	ASTM D5-97 [22]
Softening point (°C)	59	≥46	ASTM D36-95 [23]
Kinematic viscosity (60 °C) (Pa·s)	193	≥180	ASTM 2170-01 [24]
Ductility (10 °C) (cm)	27	≥20	ASTM D113-99 [25]
Density (15 °C) (g·cm^{-3})	1.036	1.00–1.05	ASTM D70-09 [26]