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Laboratory investigation on the brucite fiber reinforced asphalt binder and asphalt concrete

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HIGHLIGHTS

- We modified the asphalt binder with brucite, lignin fiber, basalt fiber and polyester fibers.
- The water absorption and thermostability of fibers affect the asphalt binder modification.
- Brucite fiber reinforced asphalt concrete obtains a desirable engineering performance.

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ABSTRACT

To investigate the modification of brucite fiber, fiber reinforced asphalt binder and asphalt mixtures were prepared and tested. Lignin fiber, basalt fiber and polyester fiber were used for comparative studies. Water absorption, oven heating, mesh-basket draindown were designed to evaluate the fiber wettability, thermostability, asphalt absorption and stabilization. Cone penetration test and dynamic shear rheometer test were applied to research the shear resistance rheological property and rutting resistance of fiber reinforced asphalt. In addition, the microstructure of fibers and reinforced asphalt binders were analyzed via scanning electron microscopy. Moreover, the engineering properties, containing high temperature stability, low temperature cracking resistance and moisture susceptibility, were conducted. Results show that brucite fiber has a better state of preservation in humid environment and thermostability than lignin fiber. It obtains a better effect on asphalt absorption and stabilization than basalt fiber and polyester fiber. Besides, the brucite fiber can effectively improve the rutting resistance and shear prevention of asphalt binders. The brucite fiber obtains a spatial networking to enhance the adhesion and stabilization of asphalt binders. The results also indicate that the asphalt mixture mixed with brucite fiber shows great high temperature stability, low temperature cracking resistance and moisture susceptibility.

1. Introduction

Asphalt pavements are the main paving type of highway because of its advantages such as low noise, good skid resistance, improved comfort, convenience of maintenance and recyclability. Asphalt mixtures have been widely used in road pavements. However, asphalt pavements are subjected to distresses of cracking and rutting (permanent deformation) under the effects of repeated vehicle loading and freeze–thaw cycles [1–4]. Accordingly, fibers have been used in asphalt mixtures to improve performance of pavement while the fiber reinforced asphalt concrete is described as FRAC [5]. Previous researchers have reported fibers' reinforcing effects in asphalt mixture and pavement [6–8]. Fibers can not only modify asphalt binder just like organic polymers, such as Styrene–Butadiene–Styrene (SBS), Styrene–Butadiene Rubber (SBR), and Polyethylene (PE), to prevent asphalt leakage in asphalt mixtures, especially for the Open Graded Friction Course (OGFC) and Stone Matrix Asphalt (SMA) mixtures effectively, but also improve the engineering performances of asphalt mixtures including viscoelasticity, dynamic modulus, moisture susceptibility, creep compliance, rutting resistance, anti-reflective cracking. These benifits can prolong the service life of asphalt pavement [9–15], obviously.

At present, several fibers are usually added into the asphalt mixtures, such as lignin fiber, basalt fiber, polyester fiber.

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However, lignin fiber has objective shortcomings because it is prone to be affected with damp which results in poor dispersion property in the asphalt mixtures, as well as low tensile strength. Although the basalt fiber and polyester fiber can improve the road performance of asphalt mixtures, their prices are so high that they cannot be applied widely. Therefore, it is important to find appropriate fiber to overcome these shortcomings and it is really an innovative way to satisfy the asphalt pavement engineering needs.

As a naturally fibrous mineral abundant in world, brucite fibers are widely existed in China, United States, Italy, Russia and so on. It is quite different from asbestos in chemical compositions, crystal structures, and chemical properties [16]. Brucite fiber is a magnesium hydroxide mineral, $Mg(OH)_2$, crystallizing in the trigonal system. Its tensile strength and Young's modulus can reach more than 900 MPa and 13.8 GPa, respectively [17]. After a series of the systematic tests, including animal test, investigation of people's epidemics, solubility of the mineral, and the organism durability, etc., it has been proved that brucite fiber does no harm to human body [18]. So far, as a kind of reinforced material, application of brucite fiber in asphalt mixtures has not been studied. This paper aims to investigate the brucite fiber's properties, stabilizing and reinforcing effect and corresponding mechanism for asphalt mixtures. Many tests including water absorption test, oven heating test, mesh-basket draindown test are conducted to evaluate the properties of fibers, and Scanning Electron Microscope (SEM) is used to observe the microstructure of fiber and its spatial network in asphalt binder in order to provide a deeper insight into the fiber reinforcing mechanism. Mechanical tests for brucite fiber modified asphalt are conducted to evaluate its reinforcing effect. Besides, effects of fibers on high temperature stability, low-temperature cracking resistance property and moisture susceptibility were investigated through rutting test, low-temperature flexural test and freeze–thaw splitting test. Based on the comparative experiment, the feasibility and applicability of brucite fiber used in asphalt mixture is assessed compared with control specimens and the other fibers (lignin fiber, basalt fiber and polyester fiber).

2. Raw materials

2.1. Asphalt

The asphalt used in this research is A-90 (Kelamayi Petrochemical industry, Xinjiang Province, P.R. China) whose needle penetration is between 80 and 100 (0.1 mm) to be applied in cold regions. Here, the research background is to solve the problems faced in Qinghai-Tibet Plateau. Table 1 shows the physical properties of asphalt binder following ASTM standards.

2.2. Fibers

Brucite fiber (Deli Inc., China), lignin fiber (Beijing Tiancheng Kentelai Tec. Co., Ltd., China),basalt fiber (Dacheng Advanced Material Tec. Co., China) and polyester fiber (Beimeifu New Material Tec. Co., China) were used to modify the asphalt. Table 2 detailed the basic physical properties of these four fibers (provided by the manufacturers).

2.3. Aggregate and mineral filler

The coarse and fine aggregates were crushed basalt, with a density of 2.830 g/cm^3 and maximal size of 16 mm. Table 3 presents the gradation of mixed aggregate used in this paper which is generally applied on asphalt pavement surface in western China. Mineral filler is levigated limestone with a density of 2.795 g/cm^3, whose particle size ranges from 0 to 0.3 mm, with a passing range (75 μm) of 79.7% by weight.

Table 1
Physical properties of asphalt binder.

Material	Test items	Unit	Value	Specification
Original asphalt binder	Penetration at 25 °C	0.1 mm	83.1	ASTM D5-97
	Ductility at 15 °C	cm	120	ASTM D113-99
	Softening point	°C	47.4	ASTM D36-06
	Wax content	%	1.86	ASTM D3344-90
	Flash point	°C	271	ASTM D92-02
	Specific gravity	Non	0.982	ASTM D70-76
RTFO binder*	Mass loss	%	−0.05	ASTM D2872-04
	Penetration ratio at 25 °C	%	82.7	ASTM D5-97
	Ductility at 15 °C	cm	29.3	ASTM D113-99

* Rolling thin film oven (RTFO) aged, according to ASTM D2872-04.

Table 2
Physical properties of fibers (provided by manufactures).

Items	Brucite fiber	Lignin fiber	Basalt fiber	Polyester fiber	Specification
Diameter (mm)	0.020*	0.045*	0.013	0.020	ASTM D2130
Length (mm)	2.50*	1.10	6.00	6.00	ASTM D204
Aspect ratio (mean)	125	24	462	300	N/A
Specific surface area (10^{-3} m^2/g)	150.3	118.1	74.7	14.8	N/A
Density (g/cm^3)	2.440	1.280	2.817	1.360	ASTM D3800
Tensile strength (MPa)	932	N/A	2000	531	ASTM D2256
Melt temperature (°C)	>400	>200	1500	>250	ASTM D276

* Mean value.

3. Test methods

Before the investigation on the fiber modified asphalt binder, it is necessary to understand the properties of fibers primarily. Firstly, the microstructure of fibers was observed via SEM before the modification. Concerning that the water absorption (when storing) and moisture releasing (when mixing) will affect the stability of modified asphalt, water absorption test and oven heating test were conducted, after which the adhesion between fiber and asphalt binder was measured via mesh-basket draindown test. To understand the effects of fibers contents and temperatures, cone penetration and dynamic shear rheometer test were carried out. In applications, the engineering performance contains high-temperature stability, low-temperature cracking resistance and water stability. So, the FRACs were analyzed with high temperature rutting test, low temperature bending test and freezing–thaw splitting test.

3.1. Testing physical properties of fibers

3.1.1. Water absorption test

During the water absorption test (WAT), a fiber sample weighting 30 g was prepared and placed in a dry beaker. Then, the beaker with fibers was exposed in air in a curing chamber for 5 days while the relative humidity is 90% at 20 °C. Afterwards, the total weight was continuously measured at 5-h intervals. The absorbed water can be calculated from the weight changes. This procedure was continued for 5 days and three samples were tested for each fiber.

3.1.2. Oven heating test

The thermostability of fibers will be evaluated via a simple laboratory Oven heating test (OHT). In this measurement, fibers