Effect of basalt fiber on properties of asphalt and asphalt mixture

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Abstract. Asphalt mixture is the surface material of flexible pavement and semi-rigid pavement. It directly bears the influence of climate conditions and traffic load, and is prone to aging and fatigue damage. Therefore, using reinforcing agent to improve the performance of asphalt mixture is the long-term goal of researchers.This paper aims to study the effect of basalt fiber on asphalt viscosity and mechanical properties of asphalt mixture. Firstly, by testing the basic properties of asphalt binder with different fiber content, the viscosity characteristics of fiber + asphalt composites are analyzed by using the modified Einstein viscosity equation. The research shows that basalt fiber has obvious toughening effect on asphalt, and the penetration and softening point indexes are suitable to evaluate the viscosity properties of fiber + asphalt composites.Secondly, the effects of different fiber content on the water stability and splitting tensile strength of asphalt mixture are analyzed. The results show that the maximum content of basalt fiber should not be greater than 0.4%; With the increase of fiber content, the splitting strength of asphalt mixture increases, but the increase is not obvious when the content is > 0.30%, while the stiffness modulus continues to increase, indicating that the deformation resistance of asphalt mixture is enhanced after adding fiber. Based on the micromechanics theory of composite materials, the basic principle of basalt mineral fiber improving the strength performance of asphalt mixture is explained. The research shows that basalt mineral fiber can significantly improve the performance of asphalt mixture.

Keywords: Asphalt mixture, basalt fiber, asphalt viscosity, splitting strength.

1. Introduction

Asphalt pavement has become the most important form of pavement with driving comfort, but the poor durability of asphalt mixture has brought great maintenance burden to the staff. Focusing on how to reduce road diseases and enhance the service life of the road has become an important topic concerned by the majority of researchers[1,2]. In recent years, the application research of fiber in asphalt mixture has become more and more extensive. The prominent feature of fiber asphalt mixture is that it can prevent the expansion of cracks in asphalt pavement, reduce the occurrence of high-temperature rutting, make up for the deficiency of high low-temperature brittleness, and play a significant role in prolonging the service life of asphalt pavement [3,4].

There are many research achievements in strengthening the performance of asphalt mixture such as lignin fiber, asbestos fiber and polymer fiber, which have been widely used in overlay and crack repair [5,6]. Chopped basalt fiber is a kind of mineral fiber, which can make up for the shortcomings of organic fibers such as low strength and elastic modulus and poor high temperature resistance, and can be reused. At the same time, it also makes up for the defects of asbestos and other mineral fibers that threaten the environment and human body [7,8]. In the 1990s, the United States paved the first asphalt concrete pavement mixed with basalt fiber in Georgia and achieved good road performance. However, the performance of fiber reinforced asphalt mixture is very different under different combination conditions, so it is necessary to further study its improvement effect and mechanism.

From the current research situation, the current research work is mainly to study the road performance and meso mechanism of asphalt mixture after adding fiber from the macro and meso perspectives and taking the test as the main means. This paper based on the experiment, the mechanism of basalt fiber improving asphalt viscosity is analyzed by using the generalized mixing rate theory of rheology; The basic properties of asphalt mixture are analyzed through immersion

Marshall test and splitting strength test. The basic principle of basalt fiber improving the strength properties of asphalt mixture is explained by using the micromechanics theory of composite materials.

2. Viscosity properties of basalt fiber asphalt binder

2.1. Generalized mixing rate theory

The mathematical expression of the generalized mixing law [9] of composites is as follows:

$$M^{j} = \sum_{i=1}^{N} (V_i M_i^{j}) \tag{1}$$

Where "*M*" is a mechanical property, like Young modulus(E), shear modulus(G), volume modulus(K) or ductility flow intensity(σ_f); "*j*" is microstructure modulus with regard to two-phase form made up with strong phase and weak phase, when strong phase supports structure, *j> 0*; when weak phase supports structure, *j< 0;*"*V"* is volume fraction.

For the solid-liquid suspension system supported by weak phase, formula (1) can be reduced to:

$$M = \left[(1-V_S)M_w^{j} + V_S M_s^{j}\right]^{1/j} = M_w\left[1+V_S\left(\left(\frac{M_S}{M_w}\right)^{j}-1\right)\right]^{1/j} \tag{2}$$

Where "s" stands for solid granule, subscript "w" stands for weak solid granule. Einstein（1906）described liquid viscosity increase because of stream surface curved and then energy dissipated when solid granule existed in his classical thesis "Discussing about determine of numerators' sized"[10]. Batchelor and Green described energy dissipate because of mutual reciprocity of suspension granule (just like collision, reciprocity, attraction or exclusion) leads to the increase of liquid viscosity[11]. Jones et al[12] and Patankar and Hu[13] described suspension granules displacement in shear surface during the course of shear flowing which leads to liquid viscosity varying. The theory above can be shown with function (2). Einstein made some supposition and then deduced the famous viscosity formula of mixture of solid and liquid as shown in function (3):

$$M = M_w\left(1+K_E V_S\right) \tag{3}$$

M stands for the viscosity of mixture; Mw stands for the viscosity of original liquid, KE is Einstein coefficient, which is relative to the ratio of length to diameter(L/D); Vs is volume fraction of solid granule. Function (3) was inferred by Einstein based on some hypothesis. Though real suspending liquid is hard to satisfied ideal condition, plenty of dilute suspending liquid proved this function's value.

2.2. Study on properties of fiber asphalt binder

The experiment chose 90# road asphalt and short-cut basalt mineral fiber exclusive used for road asphalt mixture , and the technical index was shown in table 1. The content of mineral fiber is 0%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% of the mass of asphalt. After mixing with a small mixer, further mixing shall be carried out manually to ensure that the mineral fibers are well dispersed in the asphalt. After mixing evenly, the penetration, softening point and ductility tests of asphalt binder are carried out according to the experimental procedures [14]. The test results are shown in Table 2.

Table 1. Property of basalt fiber

Technique Data	Technical parameter	Chemical constituent	Percentage composition （%）
Fiber length（mm）	6	SiO_2	57.6
Fiber diameter（μm）	15	Al_2O_3	18.1
Rate of absorbent oil（%）	68	CaO	5.1
Maximum moisture content	0.45	MgO	5.2
Relative density (g/cm^3)	2.471	Na_2O+kO	4.4
Tensile strength（MPa）	3200-4800	TiO	1
Modulus (GPa)	93-110	Fe_2O_3+FeO	8.1
Moisture absorption (%)	0.4	Others	0.4

Table 2. Property of asphalt binder

Test index Unit		Penetration（25℃，100g，5s）0.1mm				softening point（ball and ring method）℃				ductility（5cm/min,25℃）cm	
		1dkp		2dkp		1dkp		2dkp		A	B
Fiber content（%）	0	89.3	90.1	88.3	89.6	51.8	51.4	52.0	52.3	117.8	131.6
	0.2	86.5	85.7	85.7	85.4	54.3	54.9	56.4	55.8	35.2	23.9
	0.3	82.2	80.4	81.5	81.4	56.8	56.2	57.8	58.2	17.3	19.4
	0.4	74.1	73.3	71.2	72.3	59.1	58.8	60.4	60.4	18.6	20.1
	0.5	62.5	63.2	63.6	62.7	60.7	61.3	62.3	61.9	20.8	15.1
	0.6	56.3	51.6	54.5	53.3	63.3	63.6	64.2	63.7	14.2	28.8

From the above experimental data, it can be seen that after adding fiber, the penetration, ductility and softening point of asphalt binder have changed. The penetration and softening point show obvious linear law with the increase of fiber content, as shown in Fig. 1 and Fig. 2. Penetration and softening point are indirect expressions of asphalt viscosity, which are widely used because of their simple experiment.

Asphalt binder is a two-phase composite composed of asphalt and fiber. Its viscosity performance can be analyzed by the generalized mixing law of the composite. For asphalt binder, it is obvious that weak phase asphalt accounts for a large proportion and is in a supporting position. Therefore, J < 0 in equation (2), because $(M_S/M_w)\to\infty$, therefore $(M_S/M_w)^j\to 0$, equation (2)is further simplified as:

$$M = M_w(1-V_S)^{1/j} \tag{4}$$

Where, *M* means needle penetration(or softening point) of asphalt mixture, *Mw* means needle penetration(or softening point) of asphalt, *Vs* means mass fraction of fiber, we can easily get the general function（5）from fig.1 and fig.2. More significant conclusion is that it is suited to use needle penetration and softening point to appraise the viscosity of asphalt mixture with basalt fiber.

$$M = M_a(1+m_S+C) \tag{5}$$

In function (5), *M* means fiber asphalt mixture's needle penetration (P) and softening point ($T_{R\&B}$), *Ma* means asphalt's *P* or $T_{R\&B}$, m_s means fiber's mass fraction , *C* means constant.

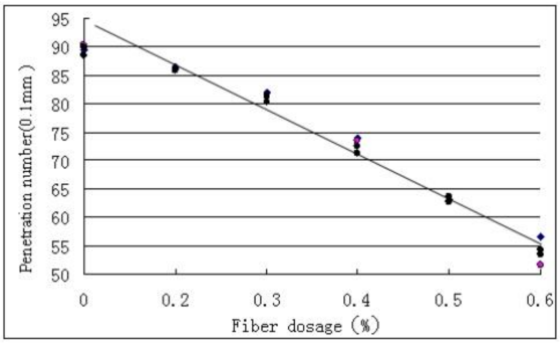

Figure 1. relation curves between Fiber content and needle penetration

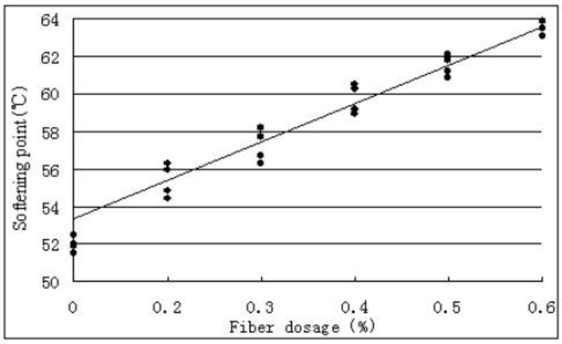

Figure 2.. relation curves between Fiber content and softening point

After adding fiber, the ductility of asphalt binder decreases sharply, because the fiber itself has no viscosity, and the adhesion between asphalt and fiber is much smaller than that of asphalt itself. Therefore, in the ductility test, the interface between asphalt and fiber is broken, and the ductility index is invalid to evaluate the viscosity performance of asphalt binder mixed with fiber.

3. Performance of basalt fiber asphalt mixture

3.1. Aggregate and Gradation

The coarse aggregate (19~2.36mm) used in the experiment is limestone, the fine aggregate (0.075~ 2.36mm) is clean river sand, and the filler is limestone powder. The technical indexes of the aggregate meet the requirements of the experimental specification [14], and the gradation of the aggregate is the median value of AC-16C recommended in the specification. As shown in table 3.

Table 3. Gradation of AC-16C dense-graded asphalt mixture

Mesh size（mm）	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Passing rate（%）	98	84	67	54	43	31	20	16	11	5

3.2. Marshall test analysis

Based on the optimal oil-stone ratio from Marshall asphalt mixture testing, six standard samples were molded for Marshall test and divided into two groups, one group was soaked in water with constant temperature 60 ℃ for 30-40 minutes, another was soaked in water with constant temperature 60 ℃ for 48 hours. Marshall stability were tested under the different curing conditions to calculate the Marshall residual stability MS0. Experimental results are presented in table 4.

Table 4. Marshall stability of AC-16C dense-graded asphalt mixture

Fiber content（%）	0	0.2	0.3	0.4	0.5
Optimum proportion of asphalt（%）	5.1	5.5	5.6	5.4	5.3
Marshall stability（KN）	17.1	17.6	15.2	14.2	8.3
residual stability（%）	76.2	77.8	86.3	91.8	87.4

Based on the test, the analysis of experimental results is below:

With the increase of fiber content, the optimal oil-stone ratio increased first the decreased, which indicate that when fiber content≥0.4%, the existing mixing process is difficult to disperse the fiber uniformly, resulting into the following groups of fiber specific surface area did not increase and effective fiber fraction did not enhance.

The maximal Marshall stability is 17.7kN when the fiber content is 0.20%. From the results of Marshall stability, there is a reasonable content of basalt mineral fibers in the asphalt concrete.

Admixture fibers can improve the water stability of asphalt mixture, but when fiber content>0.40% residual stability declined slightly. It indicates that there is also a optimal content of basalt mineral fibers for water stability of asphalt concrete.

3.3. Splitting test analysis

Splitting test was used to determine the mechanical properties of asphalt mixture at a specified temperature and loading rate. The experiment uses the standard Marshall test sample with temperature 15℃, the asphalt concrete splitting test results with different fiber content were shown in table 5.

Table 5. Splitting strength of AC-16C dense-graded asphalt mixture

fiber content（%）	0	0.2	0.3	0.4	0.5
breaking load（KN）	7.3	8.6	9.7	9.9	10.1
splitting strength（MPa）	0.741	0.841	0.957	0.975	0.996
Stiffness modulus（MPa）	151	207	248	287	319

Form the test results of table.5, we can see that fibers can increase the asphalt mixture splitting strength and stiffness modulus. It can prove that basalt mineral fibers can enhance the anti-cracking performance of asphalt mixture, and fiber asphalt mixture increased the capacity of resisting deformation.

Increasing of splitting strength of fiber asphalt mixture reflect the fiber tensile strength of asphalt mixture of "reinforced" effect. According to the theory of composite micromechanics strength[15], splitting tensile strength of fiber asphalt mixture can be functioned:

$$f_s = f_{sfp}\rho_{fp}\left(1-K_a\rho_a\right)+f_{ab}\left(S_a/V_a\right) \qquad (6)$$

Where, f_{sfp} is the tensile strength of fiber asphalt; ρ_{fp} is the percent by volume of fiber asphalt; K_a is the biggest stress concentration factor of aggregate embedding and crowding, and for AC mixture, $K_a = 0$; ρ_a is aggregate's percent by volume; f_{ab} is aggregates-asphalt interface bonding strength; S_a/V_a is unit volume within the aggregate ratio of surface area and volume.

Mixing fiber improved the value of f_{sfp}, because the skeleton structure network of random distributed fibers, on the one hand, increased the viscosity of asphalt; on other hand, this space net structure can be across of the inner pore and crack of asphalt mixture and form a "bridge fibers", making crack propagation of the energy release rate decrease, which play the role of delaying or stopping the asphalt mixture crack. Mixing fiber increased the value of S_a/V_a, because the fiber diameter is only 15μm, which will greatly increase the surface area of aggregates. From the analysis above, the strength of compositemicro-mechanics theory proved the basic principles that adding fibers can improve splitting strength of asphalt mixture.

4. Conclusions

Through the analysis of test results of the admixture of basalt mineral fiber asphalt and asphalt mixture, some valuable conclusions were obtained:

(1) Based on generalized composite rate analysis theory for fiber modified asphalt viscosity, it is applicable that the index of needle penetration and softening point evaluate asphalt mixture fibers viscosity.

(2) The changes of optimal asphalt content reflect the dispersion of fiber of asphalt mixture, and adding appropriate amount of fiber causes the increase of fiber optimal asphalt content of asphalt mixture.

(3) Marshall stability and residual stability results indicate that the basalt mineral fibers in the asphalt mixture should not be greater than 0.4%. The issue that fibers in the asphalt mixture improve the low-temperature behavior, high temperature behavior and fatigue performance remains to be studied further.

(4) Asphalt concrete splitting strength increased with the admixture of fiber, but the dosage higher than 0.30%, the increase was not obvious, and the ability to resist deformation increases with the fiber increase.

(5) According to composite materials micromechanics strength theory analysis, fiber increased splitting strength of asphalt mixture is the result that fiber increased asphalt cement strength and interface strength between aggregate and Asphalt.

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