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Research on Basalt Fiber Oil/Asphalt Absorption Performance and Test Methods Suitable for Asphalt Mixture with Different Structures

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Abstract: A basalt fiber asphalt mixture could improve the road performance of pavements and prolong the service life. The oil/asphalt absorption capacity of basalt fiber affects the road performance of asphalt mixtures to a certain extent. However, using kerosene as the medium to measure the oil absorption rate of bundle fibers by the vibration method, as the Chinese specifications recommends, is unreasonable. Therefore, the aim of this paper is to study the effect of the basalt fiber morphology on the oil absorption rate and the oil/asphalt absorption test methods suitable for asphalt mixtures with different structures (dense-graded and gap-graded), and to also explore the appropriate method to determine the oil/asphalt absorption rate of fiber to kerosene and asphalt. The results showed that the filamentous basalt fiber (FBF) was easier to disperse uniformly in asphalt than the bundled basalt fiber (BBF), and the oil absorption capacity of the FBF could more accurately characterize the actual working state of the fiber in the asphalt mixture. For the gap-graded asphalt mixture, the appropriate method to measure the fiber oil absorption rate is the combination of the vibration and centrifugation methods, while the fiber asphalt absorption rate is measured by the vibration method. For the dense-graded asphalt mixture, the combination of the extrusion and centrifugation methods are more reasonable to determine the fiber oil absorption rate, while the extrusion method is suitable for determining the fiber asphalt absorption rate. The concept of an effective fiber oil absorption rate is proposed to characterize the ability of fiber to adsorb kerosene in asphalt mixtures with different structures. A temperature of 160 °C is recommended as the test temperature to determine the fiber asphalt absorption rate. Kerosene as the asphalt absorption test medium could not directly reflect the ability of fiber to adsorb asphalt.

Keywords: basalt fiber morphology; asphalt mixture with different structures; oil/asphalt absorption test methods; effective fiber oil absorption rate; asphalt absorption test medium

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Citation: Shi, C.; Wang, J.; Sun, S.; Guan, C. Research on Basalt Fiber Oil/Asphalt Absorption Performance and Test Methods Suitable for Asphalt Mixture with Different Structures. *Coatings* **2024**, *14*, 204. https://doi.org/10.3390/coatings14020204

Academic Editor: Valeria Vignali

Received: 8 January 2024
Revised: 31 January 2024
Accepted: 2 February 2024
Published: 5 February 2024

1. Introduction

Asphalt pavement has the advantages of driving comfort, a smooth surface, wear resistance, construction period, etc., and holds advantages in high-grade highways. With the rapid development of the economy, there are higher requirements for the functionality of asphalt pavement. The incorporation of fiber materials could improve the road performance of the asphalt mixture [1–8]. Stone Mastic Asphalt (SMA) is a typical gap-graded asphalt mixture, which is widely used because of its excellent high-temperature stability, low-temperature crack resistance and water stability [9–13]. In order to solve the problem of asphalt drainage and fine material segregation in gap-graded asphalt mixtures, lignin fiber (LF) with a good asphalt absorption capacity was incorporated in an asphalt mixture [14]. The fiber had a good asphalt absorption capacity and could also change the sensitivity of asphalt to the temperature. The addition of basalt fiber can significantly improve the high-temperature and low-temperature performance of the modified dense-graded asphalt [15].

For the determination of the fiber oil/asphalt absorption rate, the Fibers for Asphalt Pavement of Chinese specification JT/T 533-2020 [16] proposed that bundled basalt fiber (BBF) could directly be used for the determination of the basalt fiber oil absorption rate. The test medium is kerosene. In the process of wetting kerosene, there is no need to stir it, while the fiber asphalt absorption rate tester provides the vibration function to remove the unadsorbed kerosene. However, this test method has the following problems: (1) the influence of the fiber morphology on the oil absorption rate is not considered, (2) the stress state of fibers in an asphalt mixture with different structures is different, which leads to changes in the test method, and (3) whether kerosene as the medium could characterize the ability of fiber to absorb asphalt. At present, researchers have been aware of these problems, and pay more attention to exploring the appropriate test methods.

Lv analyzed the mechanical properties of asphalt mixtures with different structures and concluded that the main function of fibers in gap-graded asphalt mixtures was to adsorb asphalt [17]. By comparing the microscopic characteristics of the cross-sections of fiber asphalt mixtures with different structures, it showed that the fibers mainly played the role of a reinforcement in dense-graded asphalt mixtures, while in gap-graded asphalt mixtures, the fiber had a better adhesion to the asphalt [18]. Due to the characteristics of gap-graded asphalt mixtures, the coarse aggregates were well embedded to form a skeleton, which bore the main compressive load and the fiber bore little pressure. The incorporation of fiber in asphalt mixtures mainly adsorbed asphalt and filled voids [19–21]. In dense-graded asphalt mixtures, the coarse aggregates were not embedded in each other to form a skeleton, while the fibers in the asphalt mixture played the role of the reinforcement, bridging and crack resistance, and the fibers needed to bear greater pressure [22]. That was to say, the fiber oil/asphalt absorption capacity cannot be measured by the same test method for asphalt mixtures with different structures. Meanwhile, the composition of kerosene was not exactly the same as that of asphalt, so it was not a reasonable method to reflect the asphalt adsorption ability of fiber [23]. In order to directly study the fiber asphalt adsorption capacity, Huang [14] designed a fiber asphalt adsorption test to obtain the ability of fiber to absorb asphalt at various temperatures. On this basis, the method of precipitation of mesh baskets is mostly used in China to measure the ability of fiber to absorb asphalt, but the test methods are various. The test temperature, the pore size of the mesh basket and asphalt viscosity all have great influence on the test results.

During the application of basalt fiber in gap-graded asphalt mixtures, the volume index such as the void ratio and voids in mineral aggregate (VMA) did not meet the requirements of the specification. It was necessary to change the gradation and reduce the oil–stone ratio to meet the requirements of the volume index and form a new type of gap-graded asphalt mixture [24]. Using BBF for tests will inevitably result in a low oil absorption rate, but this was not consistent with reality. It is necessary to explore new test methods to further analyze the effect of the fiber oil absorption rate in asphalt mixtures with different structures.

Based on the above, the basalt fiber morphology has a significant effect on the oil absorption rate, so the oil absorption rate is calculated through vibration, extrusion and centrifugation methods to find which morphology is consistent with reality. Then, the methods for determining the effective fiber oil absorption rate of asphalt mixtures with different structures is compared and analyzed. Meanwhile, according to the volume indexes of asphalt mixtures with different structures calculated by the test data and the actual application, the rationality of the test method is verified. Finally, the oil/asphalt absorption rate of fiber to absorb kerosene and asphalt under different test methods is studied, and whether kerosene as a medium could characterize the ability of fiber to absorb asphalt is explored.

2. Materials and Methods

2.1. Materials

2.1.1. Asphalt

The asphalt used in this paper is SBS-modified asphalt from Panjin Northern Asphalt Co., Ltd., (Panjin, China), located in the Liaoning province of China. The technical indexes are shown in Table 1.

Table 1. Technical indexes and test data of SBS-modified asphalt.

Test Item	Specification Requirement	Test Result	Test Method
Penetration (25°C)/0.1 mm	60~80	66.70	T0604
Softening point/°C	≥55	55.90	T0606
Elongation (5 cm/min, 5 °C)/cm	≥30	40.80	T0605
Apparent viscosity (135 °C)/Pa·s	≤3	1.110	T0625
Flash point/°C	≥230	259	T0611
Asphalt density (15 °C)/g·cm^{-3}	Measured record	1.026	T0603
After RTFOT			
Quality change/%	≤1.0	−0.066	T0609
Residual penetration value ratio (25 °C)/%	≥60	66.9	T0604
Residual ductility (5 cm/min, 5 °C)	≥20	23.6	T0605

Table 1 indicates that the SBS-modified asphalt meets the requirements of the Standard Test Methods of Bitumen and Bituminous Mixture for Highway Engineering in China (JTG E20-2011) [25]. Furthermore, it meets the requirements of Class I-C in the specification.

2.1.2. Fibers

1. Bundled basalt fiber (BBF)

The BBF (Figure 1a) is produced by Jilin Tongxin Basalt Technology Co., Ltd. of Tonghua City in Jilin Province (China), which is generally brown and has a metallic luster; 200 to 400 filaments form a bundle. As a new type of environmentally friendly high-performance inorganic fiber material, basalt fiber has the advantages of high strength, low water absorption, acid and alkali resistance, high-temperature resistance and environmental protection.

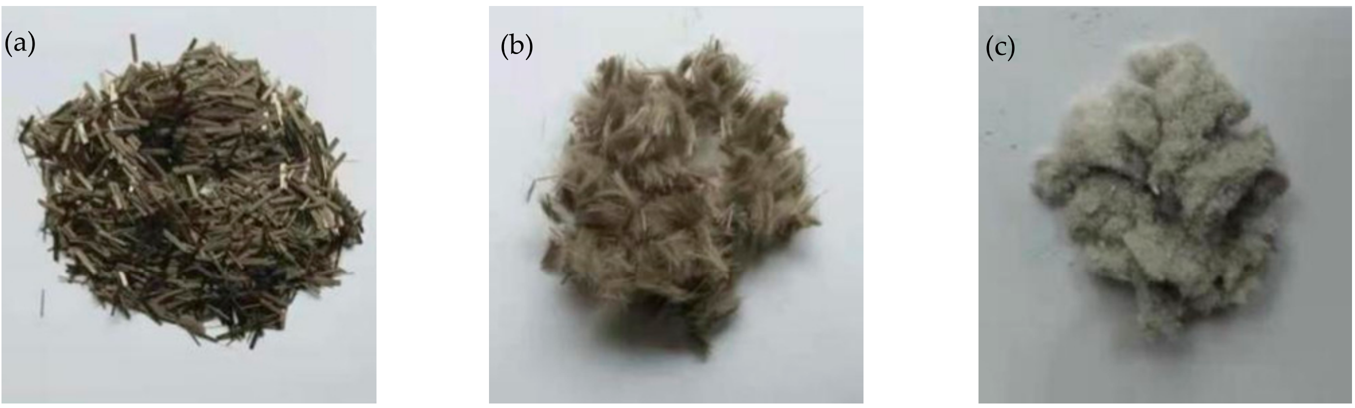

Figure 1. Comparison images of various fibers: (**a**) BBF, (**b**) FBF and (**c**) LF.

2. Preparation of Filamentous Basalt Fibers (FBFs)

In order to simulate the real dispersion state of basalt fiber in asphalt mixtures, the BBF is dispersed by dry mixing with aggregates to prepare the FBF (Figure 1b). The steps are as follows: (1) place the cleaning aggregates and BBF in an oven at 105 ± 5 °C to dry to constant weight, (2) weigh the dried coarse and fine aggregates according to the design gradation and mix them evenly in the tray, heat them in an oven with BBF to 160 °C for use, (3) preheat the asphalt mixer to 160 °C in advance, (4) mix the heated coarse and fine aggregates together with BBF in the mixer for 120 s, (5) after mixing, the coarse, fine aggregates and the scattered basalt fiber are placed in the tray, pick out the lumpy fibers with tweezers, and gently twist the scattered fibers by hand, shaking off the stone chips and stone powder to complete the preparation of the FBF.

3. Lignin fiber (LF)

LF (Figure 1c) is a plant fiber that is chemically or mechanically processed from wood as a raw material or processed from recycled wastepaper. The appearance of LF is cotton-like, white or off-white, with good dispersion and chemical stability, strong water absorption and excellent thickening properties.

In order to study the effect of the fiber morphology on the adsorption capacity of asphalt, BBF, FBF and LF are selected for comparative tests. The technical indexes of each fiber are shown in Table 2.

Table 2. Technical indexes of various fibers used in the test.

Fiber	Appearance	Diameter/µm	Length/mm	Density/g·cm^{-3}	Melting Point/°C	Asphalt Absorption Rate/Times
BBF	Golden brown, bunched	13	6	2.72	1450	0.774
FBF	Dark brown, monofilamentous	13	6	2.72	1450	4.339
LF	Light gray, loose and flocculent	43	0.8	1.23	230	6.206

2.2. Test Methods

The gap-graded asphalt mixture is well embedded and extruded between coarse aggregates to form a skeleton, and the fiber does not need to bear more compressive load, which mainly plays the role of adsorbing asphalt and filling voids. The vibration method recommended in Chinese specification JT/T 533-2020 [16] to determine the fiber oil/asphalt absorption rate in gap-graded asphalt mixtures is more reasonable. However, the vibration method does not consider the mechanism of fiber in dense-graded asphalt mixtures, where the fiber is closely connected with the aggregate and asphalt binder, plays the role of bridging and dispersing the concentrated load and is also subjected to greater pressure. The use of the vibration method to determine the fiber oil/asphalt absorption rate has a large deviation from the actual working state. Therefore, combined with the stress state of fiber in asphalt mixtures with different structures, the vibration method is used to simulate the oil/asphalt state of fiber in the gap-graded asphalt mixture, and the extrusion method is proposed to simulate the oil/asphalt absorption state of fiber in the dense-graded asphalt mixture.

2.2.1. Fiber Adsorbtion Kerosene Test

Fibers have different stress states in asphalt mixtures with different structures. Figure 2 shows the stress states and test methods of fibers in the asphalt mixture. Because of the hollow structure inside of the LF, part of the asphalt is absorbed in the fiber during the application process. In order to measure the oil absorption rate of this part, the centrifugal method is proposed to explore the effective oil absorption capacity of the LF and FBF. Therefore, three methods were used in the test to determine the fiber oil absorption rate in fiber to adsorb kerosene, namely the vibration method, extrusion method and centrifugal method, respectively.

The vibration test is realized by fiber oil absorption rate tester JJYMX-I (Figure 2), the vibration frequency is 240 times/min and the amplitude is 32 mm. The extrusion method to test the fiber oil absorption rate is that the fibers are laid flat on the mesh basket with a radius of 5 cm. The fibers are extruded by a test hammer with a circular base with a custom weight of 5500 g. Excess kerosene is absorbed by a custom collection device under the basket. The centrifugation test uses an asphalt extractor to provide centrifugal function, the rotation speed is 3000 r/min and the test time set as 10 min.

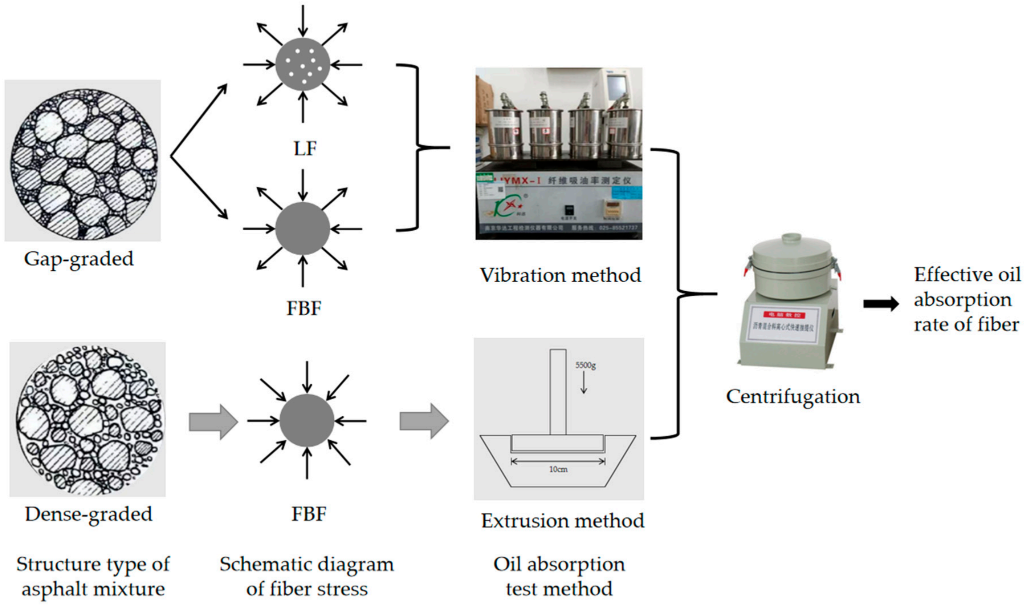

Figure 2. Schematic diagram for the determination of effective fiber asphalt absorption capacity in asphalt mixture.

2.2.2. Fiber Absorption Asphalt Test

In order to study the difference in the ability of fiber to adsorb kerosene and asphalt, the standing, extrusion and vibration methods are used to determine the fiber adsorption capacity for SBS-modified asphalt at different test temperatures (130~190 °C, with a temperature interval of 10 °C), as Figures 3–5 show.

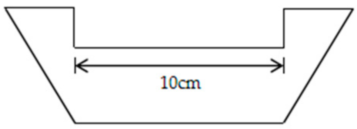

Figure 3. Standing method.

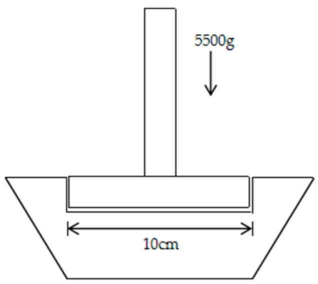

Figure 4. Extrusion method.

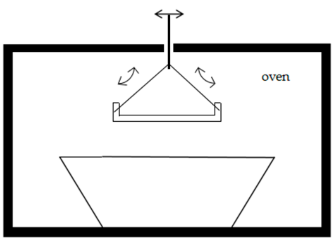

Figure 5. Vibration method.

The preparation process of fiber asphalt is to first heat the asphalt in an oven with the same test temperature for 1.5 h, then place the dried fiber (5 ± 0.1 g) on the mesh basket. After, slowly pour the preheated asphalt into the mesh basket and stir with a glass rod until the fibers fully absorb the asphalt. The standing method is to place the mesh basket in an oven, which reaches the test temperature, until the asphalt is not precipitated, and the fiber absorption asphalt capacity is determined. The vibration method is to fix the mesh basket in the oven by tying wires and rings, vibrating for 10 min every 5 min. The extrusion method of fiber to absorb asphalt is the same as that of fiber to absorb kerosene.

3. Results and Discussions

3.1. Effect of Basalt Fiber Morphology on Oil Absorption Rate

3.1.1. Oil Absorption Rate of Basalt Fiber in Different Morphology

Basalt fiber has a different morphology before and after breaking up, while the oil absorption rates are also different. The ability of basalt fiber in two different morphologies to absorb kerosene is measured by three different methods: vibration, extrusion and centrifugation. The fiber oil absorption rate under the vibration method can be obtained by Equation (1).

$$X = (m_3 - m_2 - m_1)/m_1 \tag{1}$$

where X is the fiber oil absorption rate, times; m_1 is the mass of fiber, g; m_2 is the mass of the sample sieve, g; and m_3 is the total mass of fiber after kerosene absorption and the sample sieve, g.

The fiber oil absorption rate under the extrusion and centrifugation methods can be obtained by Equation (2).

$$X = (m_2 - m_1)/m_1 \tag{2}$$

where X is the fiber oil absorption rate, times; m_1 is the mass of fiber, g; and m_2 is the mass of fiber after kerosene absorption, g.

From Figure 6, it can be seen that under the vibration condition, the oil absorption rates of the FBF and BBF are 4.337 and 0.774 times, respectively. The reason is that the FBF has an excellent dispersion state and the surface area is extremely increased, which could absorb more kerosene, so it increases the oil absorption rate. Under the extrusion condition, the oil absorption rates of the FBF and BBF are 0.293 and 0.227 times, respectively. The fiber oil absorption rates in the two morphologies are similar. When fibers are extruded, the dispersion degree of the FBF is reduced, resulting in limited oil absorption. However, under the centrifugal condition, the oil absorption rates of the FBF and BBF are 0.052 and 0.038 times, respectively. The oil absorption rate is smallest in the centrifugal condition, indicating that the surface of the FBF and BBF absorbs a very small amount of kerosene, while the main form is surface adhesion.

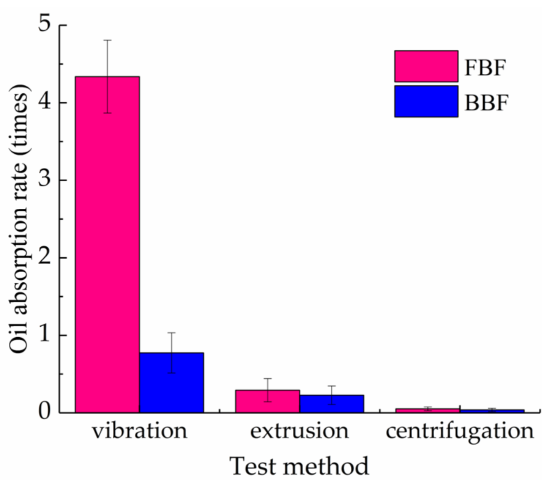

Figure 6. Oil absorption rate of basalt fiber in different test methods.

The above phenomenon indicates that the oil absorption rate obtained by different test methods is very different. The test method should be selected according to the actual stress state and mechanism of fibers in the asphalt mixture. The fiber has a different oil absorption capacity under different conditions. The FBF is consistent with the actual working state; thus, the FBF should be selected when determining the fiber oil absorption rate.

3.1.2. The Dispersion Degree of Basalt Fiber in Asphalt

In order to observe the dispersion of fibers in different morphologies more intuitively, a 6% fiber content dense-graded fiber asphalt was prepared. From Figure 7, there are obvious differences in the fiber asphalt obtained by fiber with a different morphology. Under the same fiber content, the BBF asphalt is still flowing dynamically, and no fiber agglomeration phenomenon occurred. From Figure 7a, it can be seen that the BBF is not dispersed in the asphalt and still maintains a bundled morphology, which is not conducive to the determination of oil absorption. While the FBF asphalt has an obvious viscous agglomeration phenomenon and does not have a flowing trend (Figure 7b). After magnifying the surface of the FBF asphalt (Figure 7c), the FBF is completely dispersed in the asphalt, showing the morphology of monofilament. There is no fluid asphalt on the surface of the fiber, which fully reflects the good asphalt absorption capacity of the fiber.

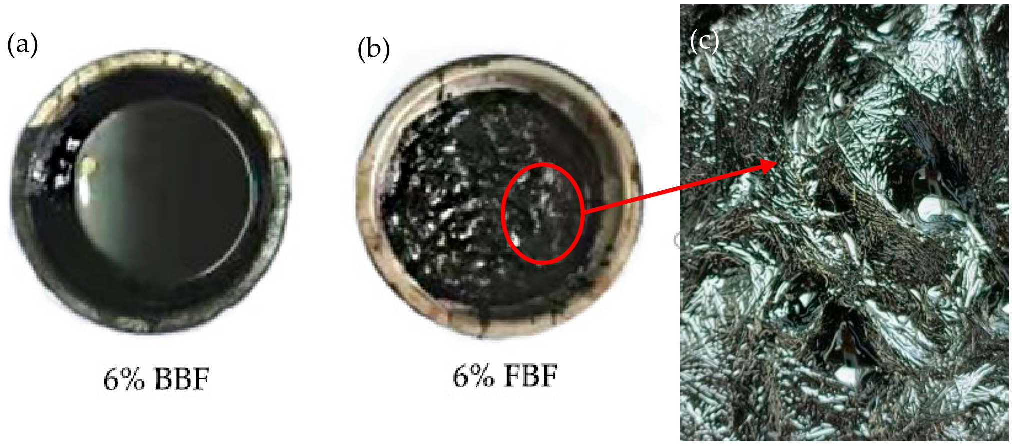

Figure 7. Comparison of basalt fiber asphalt mastic in different morphology: (**a**) dense-graded fiber asphalt with 6% BBF, (**b**) dense-graded fiber asphalt with 6% FBF and (**c**) partial enlarged image of (**b**).

The fiber morphology test shows that the dispersion of the FBF is more in line with the actual state in the asphalt mixture, and the determination of the oil absorption rate of the FBF is more practical; hence, the following test does not consider the BBF, and directly uses the FBF and LF for comparative analysis.

3.2. Research on Test Method of Fiber Oil Absorption Rate in Different Asphalt Mixture Structure

3.2.1. Test of Effective Fiber Oil Absorption Rate

In order to study the fiber oil absorption capacity in different asphalt mixture structures, a test to determine the ability of FBF and LF to absorb kerosene is carried out via three methods: vibration, extrusion and centrifugation, and the results are shown in Figure 8.

As Figure 8 shows, under the centrifugal condition, the difference in the oil absorption rate between the FBF and LF is the smallest. After being centrifuged, the surface of the fiber is dry, and no kerosene is adhered. The oil absorption rates of the FBF and LF in the centrifugal condition are 0.052 and 0.301 times, respectively. This means that a very small amount of kerosene is adsorbed on the surface of the FBF, and the main form is surface adhesion. The oil absorption rate of the LF is 5.9 times higher than that of the FBF; the reason is that, on the one hand, the kerosene absorbed by the LF comes from the adhesion of fiber surface, while on the other hand, the hollow structures inside it absorb kerosene. The centrifugal force provided by the asphalt extractor is very strong, and under the centrifugal action, the oil absorption rate of the LF is still high, showing that kerosene absorbed by LF will not be easily released, indicating that this part of the asphalt will not be released during usage, which results in the waste of asphalt. This part of the invalid asphalt must be subtracted to express the actual effective fiber oil absorption rate during the test. Therefore, the effective fiber oil absorption rates under the vibration and extrusion condition are shown in Table 3.

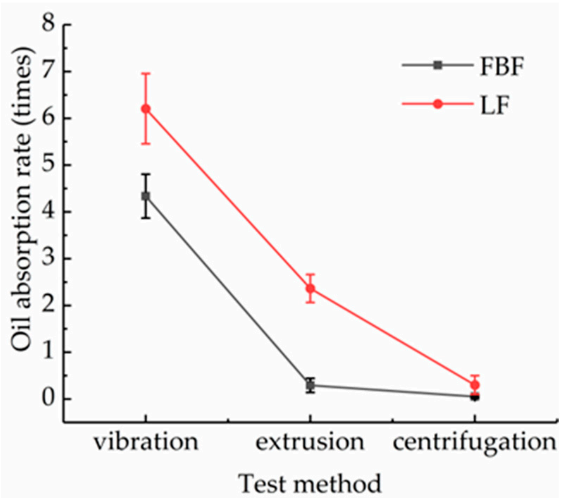

Figure 8. The ability of fiber to adsorb kerosene under different test methods.

Table 3. Effective fiber oil absorption rate under different test methods.

Test Method	FBF	LF
Vibration	4.285	6.905
Extrusion	0.241	2.063

3.2.2. Test Method for Fiber Oil Absorption Rate of Gap-Graded Asphalt Mixture

From Table 3, it can be seen that the oil absorption capacity of the LF is greater than that of the FBF under the vibration condition, indicating that the amount of oil absorption can be adjusted by the fiber type used in gap-graded structures. The effective oil absorption rates of the FBF and LF under the vibration method are 4.285 and 6.905 times, respectively. The optimal content of the FBF and LF in the gap-graded asphalt mixture is 0.4% and 0.3% [19,26], respectively, and the ability of fiber to absorb kerosene could characterize the ability to absorb asphalt in asphalt mixtures. Therefore, the converted effective fiber asphalt absorption rate is 1.714% and 2.072%, respectively. The asphalt absorption capacity of the two fibers in the asphalt mixture only differed by 0.358%, meaning that the effective asphalt absorption capacity of the two fibers is similar, and the test method used is correct.

In order to explain the increase in the voids in mineral aggregate (VMA) and oil flooding when basalt fiber is applied to gap-graded asphalt mixtures, consider the influence of the synthetic density on the volume index after the fiber has adsorbed the asphalt. The equation for calculating the synthetic density is as follows:

$$\gamma = \frac{P_x + P_x \times O_A}{\frac{P_x}{\gamma_x} + \frac{P_x \times O_A}{\gamma_A}} \tag{3}$$

where γ is the synthetic density of the fiber that has adsorbed the asphalt; P_x is the fiber content, replaced by the percentage of the total amount of the asphalt mixture, %; γ_x is the fiber density; O_A is the fiber oil absorption rate, times; and γ_A is the asphalt density.

$$m_x = \frac{\gamma_f \cdot V_f \cdot P_x}{100} \tag{4}$$

where m_x is the theoretical dosage of fiber in the asphalt mixture, g; γ_f is the asphalt mixture gross volume relative density, g/cm^3; and V_f is the theoretical volume of the asphalt mixture, calculated from the dimensions, cm^3.

$$V = \frac{m_x + m_x \cdot O_A}{\gamma} \quad (5)$$

$$K = \frac{V}{V_f} \quad (6)$$

where V is the synthetic volume after the fiber has absorbed the asphalt, and K is the ratio of the synthetic volume of the fiber asphalt to the volume of the asphalt mixture, %.

In order to better explain the FBF and LF in the case of similar oil absorption, the gap-graded FBF asphalt mixture needs to adjust the gradation and reduce the oil–stone ratio to meet the requirements of the volume index. The Marshall samples of the asphalt mixture with two fibers is used as the calculation basis. The basic indexes are shown in Table 4, and the calculation results are displayed in Table 5.

Table 4. Basic indexes of Marshall samples of fiber asphalt mixture.

Kinds of Mixture	V_f /cm^3	γ_f/g/cm^3	P_x /%	m_x /g
FBF asphalt mixture	514.55	2.521	0.4	5.19
LF asphalt mixture		2.487	0.3	3.84

Table 5. Calculation results of volume index.

Fiber Type	O_A/Times	γ_x/g/cm^3	γ/g/cm^3	V/cm^3	K/(%)
FBF	4.285	2.720	1.134	24.141	4.69
LF	6.905	1.000	1.000	30.348	5.90

As Table 5 shows, the K of the two fiber asphalt mixtures is 4.69% and 5.90%, respectively, with a difference of 1.21%. The difference in V is the reason why the basalt fiber asphalt mixture needs to reduce the VMA to adjust the gradation to meet the porosity index in the specification when the oil absorption capacity of FBF and LF is similar.

The results of the theoretical calculation, manifesting through the vibration and centrifugation method to determine the fiber oil absorption rate, could more accurately simulate the oil absorption capacity of fiber in gap-graded asphalt mixtures.

3.2.3. Test Method for Fiber Oil Absorption Rate of Dense-Graded Asphalt Mixture

From Table 3, it can be seen that under the extrusion condition, the oil absorption capacity of the LF is sharply decreased compared with the vibration condition but is still significantly higher than that of the FBF, indicating that the use of LF in dense-graded structures will cause a significant increase in the oil–stone ratio, which is not conducive to improving the high-temperature performance of asphalt mixtures. However, the oil absorption capacity of the FBF is greatly reduced, manifesting that FBF used in dense-graded structures can play the role of the reinforcement, bridging, crack resistance and enhance the high- and low-temperature performance of asphalt mixtures without significantly increasing the oil–stone ratio.

The effective oil absorption rate of the FBF under the extrusion method is 0.241 times of its own mass. The optimal ratio of fiber in AC is 0.3% [27], so the converted effective fiber asphalt absorption rate is about 0.07%, which is a good explanation for a small increase in the oil–stone ratio of basalt fiber into AC asphalt mixtures. The fiber oil absorption rate measured by the extrusion and centrifugation method can simulate the oil absorption capacity of fiber in dense-graded asphalt mixtures.

3.3. Experimental Study on Fiber Asphalt Absorption

3.3.1. Research on the Test Method of Fiber to Absorb Asphalt

Basalt fiber shows a different oil absorption capacity in different morphologies. FBF is more in line with the actual application state of basalt fiber in asphalt mixtures, and it is more practical to measure the oil absorption rate of FBF. Therefore, for the test on the fiber to adsorb asphalt, the asphalt absorption rate of FBF is also more in line with the actual asphalt absorption capacity of basalt fiber in asphalt mixtures. Hence, FBF and LF are selected for the test on the fiber to absorb asphalt.

Figure 9 shows the ability of fiber to absorb asphalt via the three methods of standing, extrusion and vibration. The fiber asphalt absorption capacity gradually decreased with the increase in the temperature. Because with the increasing temperature, the asphalt viscosity gradually decreased, the adhesion of asphalt on the fiber surface became worse, resulting in the decrease in the fiber asphalt absorption rate.

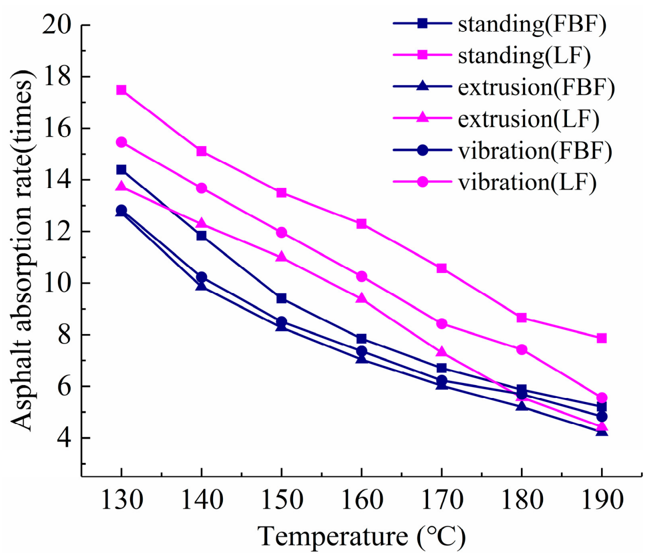

Figure 9. The ability of fibers to adsorb modified asphalt.

Comparing the three asphalt absorption rate test methods, the fiber asphalt absorption rate measured under the standing condition is significantly higher than the other two methods because of the weak precipitate asphalt capacity, resulting in excess asphalt, which is not precipitated and remains on the mesh basket. This part of the asphalt is also considered to be absorbed by fiber. So, this method can evaluate the ability of fiber to absorb asphalt, but it is not suitable for the determination of the fiber asphalt absorption rate for asphalt mixtures.

Table 6 shows the ability of FBF and LF to absorb asphalt at various temperatures under the vibration condition. In order to further analyze whether the vibration method is suitable for determining the fiber asphalt absorption rate for gap-graded asphalt mixtures, the volume ratio difference in the LF and FBF asphalt mixture is calculated. The calculation method is the same as in Section 3.2.1. The difference in the volume ratio of the two fibers at each temperature is shown in Table 7.

Table 6. The ability of fiber to absorb asphalt at different temperatures under the vibration method.

Fiber Type	130 °C	140 °C	150 °C	160 °C	170 °C	180 °C	190 °C
FBF	12.83	10.23	8.51	7.36	6.22	5.7	4.83
LF	15.46	13.67	11.96	11.26	8.43	7.42	5.56

Table 7. The volume ratio difference between FBF asphalt mixture and LF asphalt mixture.

Test Temperature/°C	130	140	150	160	170	180	190
Volume ratio difference/%	−1.03	0.26	0.72	1.35	0.39	0.16	−3.05

As Table 7 shows, the volume ratio difference at 160 °C is 1.35%, which corresponds to the difference in the VMA of the two fiber asphalt mixtures, indicating that the vibration method is reasonable as the determination of the fiber asphalt absorption rate in gap-graded asphalt mixtures. Meanwhile, the volume ratio difference in fiber to adsorb asphalt is similar to that of adsorbing kerosene. Hence, the test temperature for fiber to absorb asphalt is recommended to be 160 °C, which is the temperature of asphalt mixtures for paving and rolling, making the indexes of the fiber asphalt absorption rate more practical and corresponding to Chinese specification JT/T 533-2020 [16].

For the dense-graded asphalt mixture, the incorporation of basalt fiber has little effect on the oil–stone ratio, because the fiber is subjected to greater pressure in it, so the pores are compacted. Table 8 shows that the fiber asphalt absorption capacity in the extrusion condition is much higher than in the fiber to absorb kerosene. The reason is that the asphalt viscosity is high, and the pressure value is small, so that the excess asphalt cannot be completely precipitated. As a result, the measurement result of the asphalt absorption rate is too large. Meanwhile, in the extrusion method, because of the problem of asphalt viscosity, a lot of asphalt and fibers adhere to the test hammer, which causes the complexity of the test method. However, the viscosity of kerosene is lower, and the fibers will not be adhered to it, so the test results are more accurate. Therefore, kerosene could be used instead of asphalt and the extrusion method could be selected for the determination of the fiber asphalt absorption capacity for dense-graded asphalt mixtures.

Table 8. The ability of fiber to absorb asphalt at different temperatures under the extrusion method.

Fiber Type	130 °C	140 °C	150 °C	160 °C	170 °C	180 °C	190 °C
FBF	12.72	9.86	8.28	7.03	6.02	5.2	4.22
LF	13.71	12.28	10.99	9.38	7.3	5.57	4.42

3.3.2. The Influence of Medium Viscosity on Fiber Asphalt Absorption Rate

The fiber asphalt absorption rate test needs to consider the influence of the medium viscosity on the results, so the apparent viscosity of the SBS-modified asphalt at various temperatures is measured, as Table 9 shows. Furthermore, the ability of FBF and LF to absorb kerosene at room temperature is compared to analyze the influence of the medium viscosity on the fiber asphalt absorption capacity, as Figures 10 and 11 display, respectively.

Table 9. The apparent viscosity of SBS-modified asphalt at different temperatures.

Temperature/°C	130 °C	140 °C	150 °C	160 °C	170 °C	180 °C	190 °C
Apparent viscosity/Pa·s	1.35	0.87	0.55	0.37	0.26	0.19	0.14

Table 9 shows that the asphalt viscosity decreases with the increase in the temperature. Figures 10 and 11 illustrate that the fiber asphalt absorption rate increases gradually with the asphalt viscosity, indicating that the fiber asphalt absorption rate decreases with the temperature and the fiber asphalt absorption rate has a great relationship with the medium viscosity. The viscosity of kerosene at room temperature is much smaller than that of asphalt, meaning that using kerosene as a medium to measure the fiber asphalt absorption rate will make it smaller.

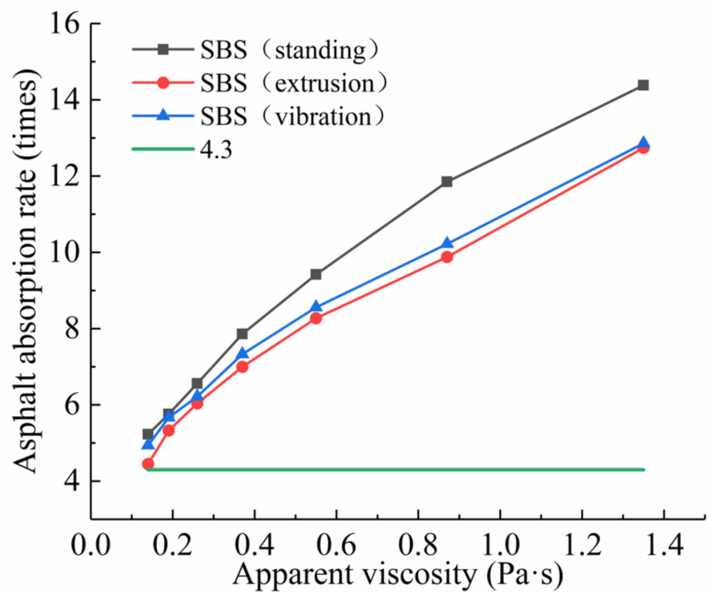

Figure 10. Relationship between asphalt absorption rate of FBF and viscosity.

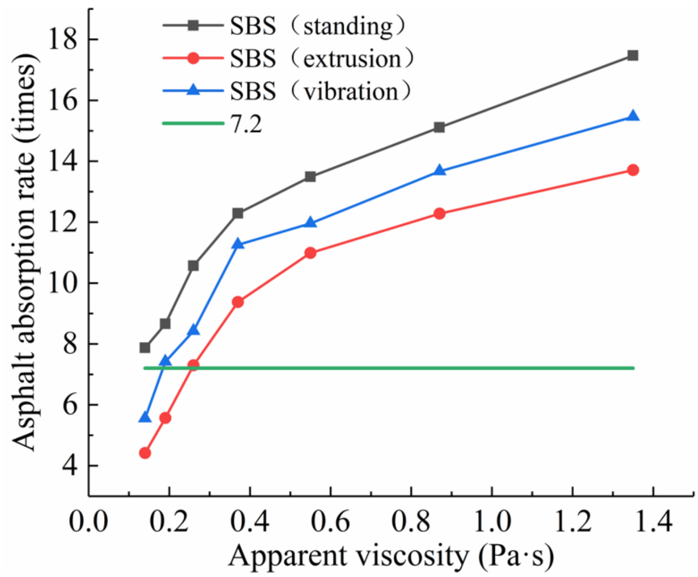

Figure 11. Relationship between asphalt absorption rate of LF and viscosity.

The ability of FBF to adsorb kerosene is about 4.3 times of its own mass, while the ability of FBF to adsorb asphalt is greater than 4.3 times, manifesting that kerosene cannot characterize the real asphalt absorption capacity of FBF in dense-graded and gap-graded asphalt mixtures. However, LF is often used in gap-graded asphalt mixtures, so it is necessary to compare the ability of LF to absorb kerosene with the ability to absorb asphalt under vibration. The test determined that the ability of LF to absorb kerosene is about 7.2 times at room temperature, which is roughly similar to that of LF to absorb asphalt at 180 °C. From this, it can be known that kerosene can indirectly evaluate the ability of fiber to absorb asphalt; however, the ability of kerosene to characterize the ability of fiber to adsorb asphalt is at higher temperatures, so kerosene cannot directly reflect the ability of fiber to adsorb asphalt.

4. Conclusions

1. The morphology of basalt fiber has a significant influence on the oil absorption rate. FBF could be uniformly dispersed in asphalt, which is consistent with the actual working state of fiber in asphalt mixtures.
2. For gap-graded asphalt mixtures, the fiber oil absorption rate is measured by the combination of vibration and centrifugation methods, and the fiber asphalt absorption rate is obtained by the vibration method.
3. For dense-graded asphalt mixtures, the combination of the extrusion and centrifugation methods is appropriate to determine the fiber oil absorption rate, and the extrusion method is suitable for determining the fiber asphalt absorption rate.
4. Kerosene could not directly reflect the ability of fiber to adsorb asphalt, it is more reasonable to select asphalt as the test medium. Kerosene can indirectly evaluate the difference in the fiber oil absorption performance.

Author Contributions: Conceptualization, C.S.; methodology, C.S.; formal analysis, J.W.; investigation, J.W.; data curation, C.G.; writing—original draft preparation, J.W.; writing—review and editing, S.S.; funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Jilin Province Transportation Technology Project (2019-2-1), Jilin Provincial Department of Education Scientific Research Project (JJKH20230348KJ).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors would like to thank the technicians from all the institutions involved in this work, who contributed to achieving this study's objectives. The authors would like to appreciate anonymous reviewers for their constructive suggestions and comments to improve the quality of the paper.

Conflicts of Interest: Author Jianan Wang was employed by the company CCCC Comprehensive Planning and Design Institute Co., Ltd. Author Cheng Guan was employed by the company, Jilin Provincial Highway Administration. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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