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Study on the Effect of Fibers on the Properties of Asphalt Mastics

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Abstract: To study the influence of fiber on the properties of asphalt mortar, the properties of lignin fiber, polyester fiber, and basalt fiber were summarized and analyzed respectively. The high- and low-temperature properties of fiber asphalt mortar were studied and analyzed by using three indexes, rutting factor and tensile fracture energy. The results showed that all three kinds of fibers could improve the performance of asphalt mortar to varying degrees, with lignin fiber demonstrating the best effect, followed by basalt fiber and polyester fiber. The type the fiber can be selected based on the required thermal stability and cost depending on the project type.

Keywords: Fiber; Asphalt mastics; High temperature; Low temperature; Rheological properties

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1. Introduction

With the rapid growth of the number of vehicles, to ensure the stability and durability of asphalt pavement, it is necessary to constantly improve the performance of asphalt mixtures. Fiber has been widely used as a stabilizing additive to improve the pavement performance of asphalt mixture. Therefore, it is of great significance to study the effect of fiber on asphalt and mixture. Xue *et al.*'s study showed that fiber enhances the performance of asphalt pavement in varying degrees [1]. Liu *et al.* believe that basalt fiber improves the mechanical properties of the pavement structure [2]. Wang *et al.* discovered that basalt fiber has a lesser impact on the phase angle, composite shear modulus, and viscosity of asphalt mortar compared to polyester fiber [3]. Liu *et al.* observed that the order of effectiveness in enhancing the low-temperature performance of asphalt and its mixtures was polyacrylonitrile fiber > lignin fiber > basalt fiber [4]. Zhou *et al.* found that a polyester fiber content of 0.2% enhanced the performance of concrete to the greatest extent [5]. Chen *et al.* advocate for expanding the range of environmentally friendly fibers that enhance concrete performance [6]. Liu *et al.* studied the impact of polypropylene fiber, polyester fiber, and polyacrylonitrile fiber at varying concentrations on the low-temperature performance of asphalt mixtures, noting that polypropylene fiber yielded the most significant improvement [7]. Pan *et al.* found that the addition of basalt fiber had little effect on the low-temperature rheological properties of asphalt mortar, but it significantly improved its high-temperature rheological properties [8].

The content of fiber also play a role in the enhancement of the concrete's performance aside from the type of fiber used. Tan et al. conducted a comparative test on the properties of carbon fiber, basalt fiber, polyester fiber asphalt mixture and non-fiber asphalt mixture and found that the mixture with 0.28% carbon fiber, 0.2% polyester fiber, and 0.33% basalt fiber had the best performance under high temperatures [9]. Lin found that polyester fiber significantly enhances the performance of asphalt pavement. Interestingly, the effectiveness of the fiber remains consistent whether the content is low with longer fibers or higher with shorter fibers [10]. Wu e*t al.*'s study found that optimal high-temperature performance was achieved when fly ash replaced 40% of the asphalt and the polyester fiber content was 0.4% [11]. Zhang Jun *et al.* investigated the effect of mineral fiber asphalt concrete on the strength of asphalt concrete under the conditions of freezing and thawing cycles by examining the effect of different types of fibers, and the effect of mineral fiber asphalt concrete on the strength of asphalt concrete. Zhang *et al.* determined that mineral fiber asphalt concrete exhibited the highest splitting strength. Specifically, at a 4% fiber content, all three types of fiber asphalt concrete demonstrated maximum splitting strength [12].

Many studies have been conducted on the properties and effects of various types of fibers in asphalt and asphalt mixtures, identifying their roles in reinforcement, crack resistance, adsorption, and bridging. Different fibers contribute uniquely to asphalt and its mixtures based on their distinct structures and properties, thereby influencing performance differently. Based on these considerations, comparisons and analyses were conducted on basalt fiber, lignin fiber, and polyester fiber in relation to their impact on the performance of asphalt mastics and the overall road performance of asphalt mixtures.

2. Materials and methods

2.1. Asphalt

The 90# matrix asphalt was selected and its performance was tested. The results are shown in **Table 1**. The results show that the asphalt meets the requirements and demonstrates good performance.

Table 1. Test results of 90# matrix asphalt

Item	Needle penetration	Softening point	Ductility	Apparent viscosity	Flash point	Asphalt density
Test result	90.6	45.7	109.5	0.30	292	1.023
Specification requirement	80–100	≥ 44	≥ 100	-	≥ 245	-

2.2. Fiber

In order to study the effect of different fiber types on the performance of asphalt mortar, lignin fiber (LF), polyester fiber (PF), and basalt fiber (BF) were selected and their basic physical properties were tested. The results are shown in **Table 2**.

Table 2. Fiber types and physical properties

Fiber type	Appearance	Diameter/ mm	Length/ mm	Density/ ($g \cdot cm^{-3}$)	Melting point/°C	Tensile strength /MPa
LF	Light gray, loosely flocculent	0.045	1.4	1.21	230	< 300
PF	Milky white, fascicular monofilament	0.020	6.0	1.39	220	980
BF	Golden brown, fasciculate	0.013	6.0	2.64	1500	3400

2.3. Mineral powder

To mitigate the negative effects of mineral powder dispersion on test results, mineral powders with particle sizes smaller than 0.075mm were selected. Their performance indicators were rigorously tested to ensure they met specification requirements.

2.4. Preparation of fiber asphalt mortar

The fiber dispersion degree significantly affects the performance of fiber asphalt mortar. To ensure the accuracy of asphalt mortar test results, fibers were dispersed before asphalt mortar preparation. The fixed powder-to-binder ratio was 1.0, with fiber content set at 3% of asphalt. The 90# matrix asphalt was heated to achieve dynamic flow. Mineral powder was added to the asphalt in batches multiple times, ensuring even dispersion. Subsequently, the dispersed fiber was added in batches multiple times under strict temperature control to maintain asphalt fluidity throughout the process.

3. Results

To ease differentiation, 90# matrix asphalt was abbreviated as 90#, basalt fiber asphalt mortar was abbreviated as 90#-BF, lignin fiber asphalt mortar was abbreviated as 90#-LF, and polyester fiber asphalt mortar was abbreviated as 90#-PF.

3.1. Three major indexes

The results of three indexes of each fiber asphalt mortar are shown in **Figures 1 & 2**.

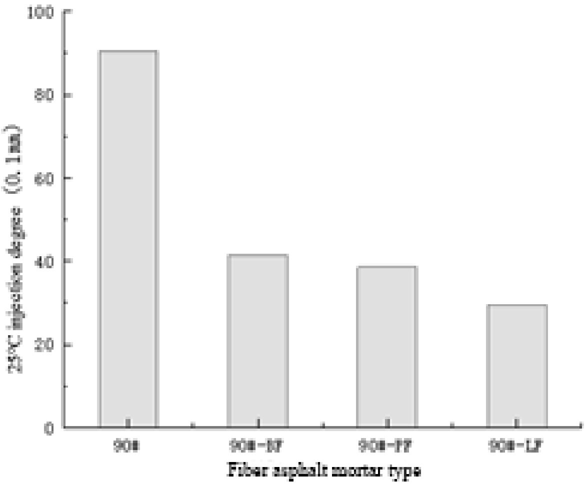

Figure 1. Results of needle penetration of asphalt mortar

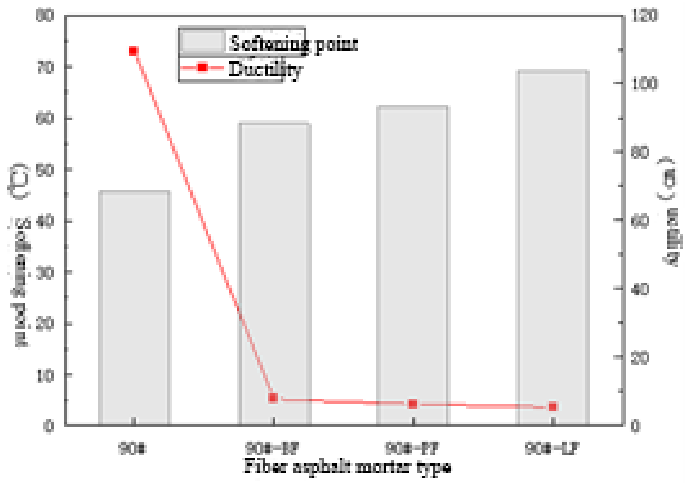

Figure 2. Results of asphalt mortar elongation and softening point

As shown in **Figure 1**, fibers had a significant effect on three major indicators of asphalt mastic. The addition of fibers led to a sharp decrease in the penetration of asphalt mastic, primarily due to uneven fiber dispersion within the mixture, which affected the accuracy of the data results. The penetration values of 90#-BF and 90#-PF were relatively similar, while 90#-LF had the smallest penetration value, attributed to LF's effective adsorption capabilities that caused asphalt to adhere to fiber surfaces, thereby increasing mastic hardness.

Furthermore, fibers reduced the ductility and increased the softening point of asphalt mastic, as illustrated in Figure 2. BF and PF exhibited similar effects on the softening point, whereas 90#-LF showed the highest softening point. This phenomenon resembled the impact on needle penetration; LF's adsorption increased asphalt viscosity, consequently raising the softening point. The increased viscosity due to fibers inevitably increased asphalt mastic brittleness, resulting in reduced ductility. Among LF, PF, and BF, BF demonstrated a more pronounced reinforcing effect on asphalt mastic. During stress, BF facilitated effective load transfer, mitigated stress concentration, and enhanced the mastic's ability to deform plastically.

3.2. High-temperature rheological properties

The rutting factor can better reflect the high temperature rheological property of asphalt mortar. **Figure 3** illustrates the curve showing how the rutting factor changes with temperature in fiber asphalt mortar.

Temperature significantly influenced the high-temperature rheology of fiber asphalt mastic, causing the rutting factors of the four types of asphalt mastic to decrease as temperature increases. The rutting factors of the four types of asphalt mortar followed this order: 90#-LF > 90#-PF > 90#-BF > 90#. The addition of fibers enhanced the rutting factor of asphalt mortar to varying degrees. This enhancement occurs because fibers reduce the amount of free asphalt in the mortar, promoting asphalt adhesion to fiber surfaces and thereby improving the viscosity of fiber asphalt mortar. Moreover, fibers can establish a stable three-dimensional network structure within the asphalt mortar, enhancing its resistance to high-temperature deformation. At 52°C, the fiber reinforcement effect was most pronounced. Compared to 90#, the rutting factors of 90#-LF, 90#-PF, and 90#-BF increased by 5.89 times, 4.13 times, and 2.97 times, respectively. Among the three fibers, LF demonstrated the most significant improvement in the high-temperature performance of asphalt mortar.

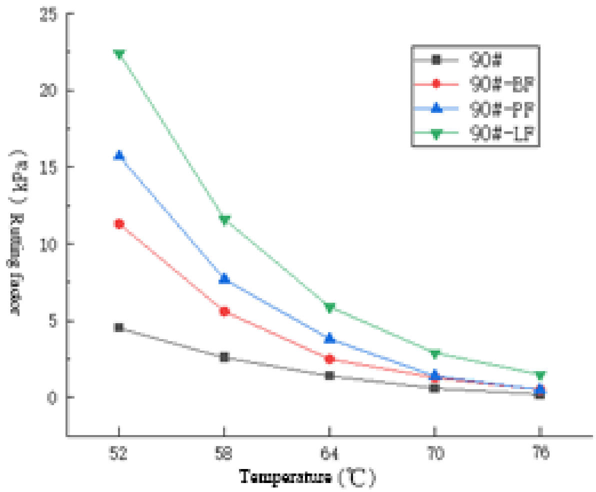

Figure 3. Rutting factor curves of fiber asphalt

3.3. Low-temperature tensile property

Tensile fracture energy serves as a critical indicator for evaluating the tensile resistance of asphalt mortar at low temperatures. **Figure 4** illustrates the curve depicting the change in tensile fracture energy of fiber asphalt mortar from -10°C to -30°C.

The tensile breaking energy of asphalt mastic is influenced by temperature and fiber type. Lower temperatures correspond to lower tensile breaking energies. Compared to 90#, the addition of fiber significantly enhanced the fracture energy of asphalt mastic. This improvement stems from the increased proportion of structural asphalt due to the addition of fiber and mineral powder, thereby increasing asphalt mastic viscosity and subsequently enhancing its low-temperature tensile properties. The tensile breaking energy of asphalt mastic is influenced by temperature and fiber type. Lower temperatures correspond to lower tensile breaking energies. Compared to 90#, the addition of fiber significantly enhances the fracture energy of asphalt mastic. This improvement stems from the increased proportion of structural asphalt due to the addition of fiber and mineral powder, thereby increasing asphalt mastic viscosity and subsequently enhancing its low-temperature tensile properties.

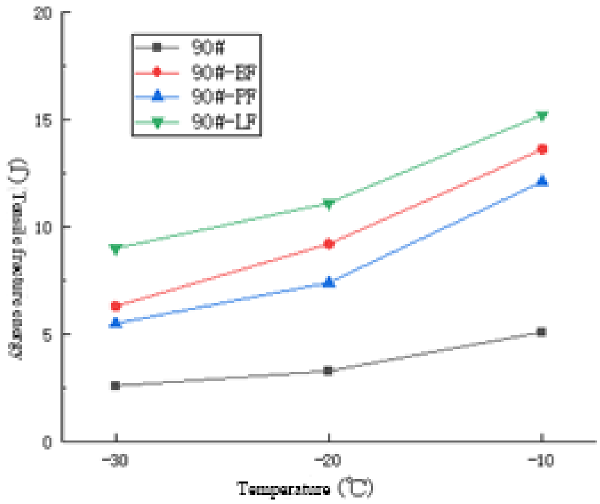

Figure 4. Changes in tensile fracture energy against increasing temperatures

4. Comparative analysis of fiber properties

The water absorption, thermal stability, oil absorption, and economic results of the three fibers are shown in **Table 3**.

Table 3. Water absorption and thermal stability of the fiber

Fiber type	Mean water absorption (%)	Quality loss (%)	Asphalt loss (%)	Price (Yuan·t^{-1})
LF	14.55	24.9	3.26	3500
PF	3.26	6.4	18.67	6000
BF	1.09	2.3	10.98	12000

Based on the data in **Table 3**, it is evident that among the three types of fibers, water absorption follows the order LF > PF > BF, thermal stability follows BF > PF > LF, oil absorption follows LF > BF > PF, and price follows BF > PF > LF.

When subjected to heating in an oven, the three fibers exhibited varying degrees of quality loss. From an appearance perspective, LF changed from its original light gray to brown, PF changed from white to light yellow, and BF showed minimal change in appearance. This difference is attributed to LF being composed of plant-based organic matter, which results in poorer thermal stability, whereas BF, being a mineral fiber, exhibits the best thermal stability.

Furthermore, it can be seen that LF has the lowest asphalt loss, indicating that LF has the best oil absorption. Scanning electron microscopy (SEM) analysis of the three fibers revealed that LF's surface was rougher, while BF and PF had smoother surfaces. The rougher the fiber surface, the better its asphalt adsorption capability. Additionally, LF's surface is irregular and features many intricate branches, whereas PF and BF are mostly factory-made with regular cylindrical shapes and smooth surfaces. Therefore, the surface texture and roughness of the fibers are crucial factors affecting asphalt bonding.

Economically, BF is the most expensive, costing twice as much as PF and 3.43 times more than LF. Consequently, it is essential to consider the performance requirements and preferences of asphalt mixtures when selecting fiber types in practical engineering applications to achieve high quality at a lower cost.

5. Conclusion

(1) Fibers can effectively enhance the softening point of asphalt mastic, with LF showing the best enhancement effect. At the same time, fibers increase the viscosity of asphalt mastic but inevitably sacrifice its ductility.

(2) Fibers can improve the rutting factor and low-temperature cracking resistance of asphalt mastic, indicating that fibers enhance asphalt mastic's high-temperature and low-temperature performance to a certain degree. Among the fibers, LF is the best for improving these two properties compared to BF and PF.

(3) Based on fiber performance analysis, LF is inexpensive with high oil absorption but poor thermal stability; PF is moderately priced with good thermal stability but poor oil absorption; BF has the best thermal stability and good oil absorption but is the most expensive.

Disclosure statement

The author declares no conflict of interest.

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