Properties of Basalt Fiber-Asphalt Mortars and Improved Mechanism

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ABSTRACT: This paper examines the physical and mechanical properties of asphalt mortar containing basalt fiber and other kinds of fibers as comparison by using different macroscopic and microscopic experimental methods. Experimental comparisons were made, in terms of adsorption performance, shear performance, crack resistance property and high temperature rheological property, between the innovative asphalt mortar made with basalt fiber and asphalt mortars made with two commonly used fibers. Then, the reinforcing mechanisms was explored by using SEM. Different types of samples with varying dosages and dimensions of the additives were studied, namely asphalt mortar with 3%, 5%, 7% and 10% of basalt fiber and that with 6mm and 9mm of basalt fiber. Laboratory test results indicate that basalt fiber have great effect on the ultimate tension and rheological properties of asphalt mortars, which derived from that basalt fibers make them forming a network structure to disperse stress and made a contribution to the stability of asphalt mixture.

KEYWORDS: Basalt fiber; Asphalt mortar; Rheological property; Ultimate tension; Reinforcing mechanism

1. INTRODUCTION

The reduction of asphalt pavement diseases is a crucial issue in highway engineering area all the time. One of the main factors of pavement diseases is related to construction materials. In recent years, fiber additives have been considered as reinforcement in pavement materials, which were used for preventing cracking, rutting and water damage. Among many types of fibers, organic fiber such as polypropylene fiber and lignin fiber cannot meet the design requirements of high grade pavement because of their shortcoming in elasticity modulus, anti-aging resistance, thermal stability and corrosion resistance. Basalt fiber is a kind of environment-friendly material to improve properties of asphalt mixtures, which could offset the weakness of organic fibers. Basalt fiber has gained increased interest in the area of road engineering.

Currently, many researches have been conducted many studies on asphalt materials reinforced by basalt fiber. Basalt fiber-polymer (BFRP) was early used to improve the performance of asphalt surface course on the concrete pavement, which could prevent or delay the development of reflective cracks[1]. As time went by, other effects of basalt fiber on asphalt mixtures were explored by researchers in China. Some researchers found that the high-temperature stability, low temperature crack resistance and the fatigue performance of specimens using basalt fiber were improved remarkably. Meanwhile, others analyzed the partial improving mechanism of basalt
fiber based on the composite material theory [2-5]. The asphalt mortars consist mainly of basalt fiber, asphalt and mineral powder, whose qualities are crucial for the intensity of asphalt mixture[6-7]. Zhang, et al [8-10] studied the three key indicators, apparent viscosity and rheological property of asphalt mortars containing basalt fiber, and drew out several meaningful conclusions about the fiber reinforcing mechanism. However, there is still lack of knowledge about the functional mechanism of basalt fiber on the performance of asphalt mortars. For instance, the studies concerning shear resistance, crack resistance and synthetic performance of basalt fiber-asphalt mortars are too rare for researcher to understand basalt fiber’s improving effect on asphalt mortars. At the same time, the issue that how to bring the superiority of basalt fiber into full play and how to solve the technical problems existing in its design are also still not known clearly in road engineering area.

On the basis of the above literature review, the aim of this research in this paper is to investigate the property and reinforcing mechanism of asphalt mortars modified with basalt fiber. Samples with varying dosages and dimensions of basalt fiber were studied in this paper. Web-leaking test, shear strength test, strip tensile test and DSR test were conducted on asphalt mortars with basalt fiber, lignin fiber and polypropylene fiber asphalt mortars. Finally, reinforcing mechanism of basalt fiber reinforced asphalt mortars was further studied based on SEM.

2. MATERIALS AND EXPERIMENTS

2.1. Materials

The asphalt used in this research is A-70 (Zhenghai Petrochemical industry, Zhejiang Province, P.R. China), whose needle penetration is between 60 and 80 (0.1 mm) applied in tropical areas. Basalt fiber (Haining Anjie Composites Co., China), lignin fiber and polypropylene fiber (Weibailai Trading Co., China) were used to reinforce the asphalt mortar and the technical indexes are shown in Table 1. Mineral filler is limestone with a density of 2.683 g/cm³, whose grain size is less than 0.6mm.

<table>
<thead>
<tr>
<th>Table 1. Technical indexes of fibers.</th>
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<tbody>
<tr>
<td>Fiber type</td>
</tr>
<tr>
<td>----------------------------</td>
</tr>
<tr>
<td>Basalt fiber</td>
</tr>
<tr>
<td>Lignin fiber</td>
</tr>
<tr>
<td>Polypropylene fiber</td>
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</tbody>
</table>

2.2. Experimental methods

2.2.1. Preparation of asphalt mortar

The basalt fiber and mineral filler were dried through using a stove with a temperature of 60℃, then the mixture were added into contact with the asphalt at 160±5℃ and evenly mixed for 3min to get the fiber-asphalt mortars. A mineral filler to asphalt ratio of 1:50 was used and different fibers were chosen.
2.2.2. Web-leaking test

Web-leaking test was designed to evaluate the adsorption and stability performances of different fiber-asphalt mortars. Dosage of fiber by weight per mass unit of asphalt is 10% and the mass of asphalt mortar was 50g. The samples were molded naturally and placed into a metal basket (sieve size: 0.25 mm) while it cooled down and took shape, and continuously maintained its temperature at 130°C for 1h[3]. Afterwards, the precipitation rate of asphalt mortar was measured every 30min, which was the mass ratio between precipitated asphalt and asphalt mortar.

2.2.3. Cone penetration test

The cone penetration test was carried out to evaluate the shear resistance of fiber-asphalt mortars, which was shown in FIG.1. The vicat apparatus was converted into the test apparatus by putting a 500g weight on the cone. The mix proportion of fiber-asphalt mortars in this test was the same as that in the web-leaking test. Firstly, the hot fiber-asphalt mortar (500g) was poured into conical vessel for the apparatus and stood for 30 min at normal temperature until it cooling down. Then the sample was immersed in water bath at 25°C for 1h. Afterwards, the cone was put down and pierced into the fiber-asphalt mortar. The penetration depth was reading from the measurer and the shear strength $\tau_f$ was calculated by formula (1), while the cone angle $\alpha=30^\circ$, $k=0.85$.

$$\tau_f = k \frac{G}{h^2}$$ (1)

2.2.4. Strip tensile test

Strip tensile test was conducted by MTS system to measure the ultimate tension and evaluate the crack resistance of asphalt mortars with fibers for different species and dosages, as illustrated in FIG.2. The Specimens (12.0cm×8.0cm×0.5cm) were tensioned at the normal temperature (25°C) with a tensile speed of 10mm/min. Meanwhile, the loading process was recorded by data acquisition system throughout the whole experimental process. When the tension decreased to 80% of the limit value, the strip tensile test was terminated.

![Figure 1. Cone penetration test.](image1)

![Figure 2. Strip tensile test.](image2)

2.2.5. DSR test

The high temperature rheological property (HTRP) of fiber-asphalt mortars
were tested by DSR C-VOR120 (produced by Bohlin Co.US), which could evaluate the rutting resistance of road materials. In this study, rutting factor were measured with a sinusoidal oscillation loading frequency of \( \omega = 10 \text{rad/s} \) and at the temperature range of 60\(^\circ\)C-90\(^\circ\)C (64\(^\circ\)C, 70\(^\circ\)C, 76\(^\circ\)C, 82\(^\circ\)C), whose heating rate is 2\(^\circ\)C/min.

3. RESULTS AND DISCUSSIONS

3.1. Properties of basalt fiber-asphalt mortar

3.1.1. Asphalt adsorption

Two dimensions of basalt fibers for 6mm and 9mm were chosen in this paper to compare with other two commonly used fibers. The results of web-leaking precipitation rates of different fiber-asphalt mortars were shown in Table 2.

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>Precipitation rate (%)</th>
<th>30min</th>
<th>60min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-fiber</td>
<td>64.32</td>
<td>84.75</td>
<td></td>
</tr>
<tr>
<td>6mm Basalt fiber</td>
<td>7.39</td>
<td>10.39</td>
<td></td>
</tr>
<tr>
<td>9mm Basalt fiber</td>
<td>8.21</td>
<td>13.05</td>
<td></td>
</tr>
<tr>
<td>Lignin fiber</td>
<td>3.60</td>
<td>5.04</td>
<td></td>
</tr>
<tr>
<td>Polypropylene fiber</td>
<td>9.07</td>
<td>16.00</td>
<td></td>
</tr>
</tbody>
</table>

The instrumental error of metal basket could be ignored due to the dramatic value differences between non-fiber and fiber asphalt mortars. The precipitation rate of 6mm basalt fiber is steadily lower than that of 9mm separately at 30min and 60min, which means that the asphalt adsorption performance of former is better than the latter. Asphalt adsorption performances of different dimensions of basalts fibers are higher than polypropylene fibers and simultaneously far lower than lignin fibers. In this experiment, it is also found that the viscosity of asphalt mortar was increased dramatically with the use of basalt fiber, which could be explained that the asphalt turned the isotropic body into non-isotropic body to strengthen the internal friction of basalt fiber-asphalt mortar based on the principle of material science. Furthermore, the moderate asphalt adsorption performance of basalt fiber could save the asphalt content of asphalt mixture to ensuring the stability of asphalt mixture.

3.1.2. Shear resistance

The same material scheme with web-leaking test was chosen to conduct this cone penetration test. The shear resistance of asphalt mortars containing 6mm and 9mm basalt fiber, lignin fiber and polypropylene fiber were measured compared to that of original asphalt mortar with non-fiber. The experimental results were shown in FIG.3.
According to the FIG.3, the shear resistance of 6mm basalt fiber asphalt mortar is superior to that of 9mm, which is probably 16.3 times higher than that of the original asphalt mortar. Among the three kinds of fiber-asphalt mortar, polypropylene fiber gets the highest shear resistance with 34.6% higher than that of basalt fiber, and highest shear resistance of lignin fiber is about only 50% of that of basalt fiber.

At the condition of same total mass, the quantity of 6mm basalt fiber is more than that of 9mm, which shown that the contacting area with matrix of former is larger than latter. Generally, the larger contacting area with matrix of fiber was, the higher cohesiveness and shear resistance of the fiber-asphalt mortar would be. For the different kinds of fibers, lignin fiber with low elasticity modulus has little contribution to the shear resistance of asphalt mortar. Conversely, both basalt fiber and polypropylene fiber have high elasticity modulus so that they could resist the vertical shear force caused by the cone by a large extent.

3.1.3. Effect of basalt-fiber dosage on cracking resistance

The 6mm basalt fiber was selected in the strip tensile test, which has better asphalt adsorption and shear resistance properties than those of 9mm. There are 4 kinds of basalt fiber dosages of asphalt mortar, specifically 3%, 5%, 7% and 10%. Lignin fiber and polypropylene fiber were mixed into asphalt through experience dosages, 3% and 5% respectively. Ultimate tension results are presented in FIG.9.

Ultimate tension results are presented in FIG.4, which shows that the ultimate tension is analyzed from FIG.9 that the ultimate tension of basalt fiber firstly increases and then decreases, when the dosage increases from 3% to 10%. The maximal value of basalt fiber asphalt mortar reaches 4.5 times as that of original asphalt mortar. However, the enhancing effect of basalt fiber sharply decreases once the fiber dosage larger than 7%. The reason caused this phenomenon is that the excessive amount of fiber into the asphalt mortar would result in their joining together and damage the homogeneity of fiber-asphalt mortar.
Otherwise, polypropylene fiber-asphalt mortar gets the largest ultimate tension among three kinds of asphalt mortars, which is 43% larger than that of basalt fiber. Meanwhile, the ultimate tension of lignin fiber-asphalt mortar is only 51% of basalt fiber-asphalt mortar. It could be analyzed from the perspective of physical mechanic that the polypropylene fibers would still stay in a tension state while the specimen occur tensile failure, which derive from the high fracture strain and enhance the cracking resistance of asphalt mortar. Basalt fiber has high tension strength of 4000-4850 Mpa so that the asphalt mortar with basalt fiber gets an excellent cracking resistance performance. However, due to the low-intensity, lignin fiber could make little contributions to the strength of asphalt mortar only though its good asphalt adsorption property.

### 3.1.4. Effect of basalt-fiber dosage on HTRP

Table 3 illustrates the comparison of rutting factor and performance grade (PG) for asphalt mortar with different dosages and types of fibers.

<table>
<thead>
<tr>
<th>Asphalt mortar type</th>
<th>Dosage(%)</th>
<th>temperature (℃)</th>
<th>Rutting factor(kPa)</th>
<th>PG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>—</td>
<td>76</td>
<td>0.6594</td>
<td>70</td>
</tr>
<tr>
<td>Basalt fiber</td>
<td>3</td>
<td>76</td>
<td>0.6234</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>82</td>
<td>0.6801</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>82</td>
<td>0.7121</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>—</td>
<td>0.6350</td>
<td>76</td>
</tr>
<tr>
<td>Lignin fiber</td>
<td>3</td>
<td>82</td>
<td>0.9878</td>
<td>76</td>
</tr>
<tr>
<td>Polypropylene fiber</td>
<td>5</td>
<td>82</td>
<td>0.4981</td>
<td>76</td>
</tr>
</tbody>
</table>

The data in Table 3 exhibits that the performance grade of asphalt mortar is upgraded by basalt fiber from PG70 to PG76, which achieves a prominent improvement on its HTRP. The rutting factor of asphalt mortar with basalt fiber firstly increases and then decreases when the dosage varies from 3% to 10%. The maximal value of asphalt mortar with basalt fiber reaches 1.08 times as original asphalt mortar, when the dosage is about 7%. In addition, the rutting factor of fiber-asphalt mortars ranked in a decreased order as follows: lignin fiber (0.9878), basalt fiber (0.7121), polypropylene fiber (0.4981).

In conclusion, polypropylene fiber gets the best shear resistance performance and cracking resistance performance, but the worst HTRP. Lignin fiber has the strongest asphalt adsorption capability, but the worst shear resistance and cracking resistance performances. Thus, it could be concluded that basalt fiber-asphalt mortar has the best comprehensive properties compared to the other two kinds of fibers.

### 3.2. Improved mechanism of basalt fiber-asphalt mortar

The SEM images of interface and damaged facet for 7% basalt fiber-asphalt mortar are shown in FIG.4 and FIG.5 respectively.
3.2.1. Viscidity and stability function

It is clearly observed from FIG.4 that the basalt fiber disperses well in the asphalt matrix, which has large area of asphalt saturated surface. That is the main reason why basalt fiber gets well asphalt adsorption. It could be explained from chemical analysis that all the asphalt molecules uniformly line up on the surface of basalt fibers of the saturated surface, meanwhile partially immerses inside the fibers that forms a steady asphalt- fiber interface. The cohesive force of asphalt inside this steady interface is much higher than that of unfettered asphalt outside the interface. Thus basalt fiber could improve the high temperature stability of asphalt mortars and mixtures.

3.2.2. Bridging and crack resistance function

FIG.5 shows that basalt fibers are composed of a plurality of filaments, whose ends are filled with asphalt so that it can build a "bridge" to connect the asphalts together. Moreover, with the increasing dosage of basalt fibers, a 3d-network structure is formed by fibers in the asphalt mortar, which can optimize the force state and inhibit the micro-crack extension for asphalt mortar under the MTS operating conditions. The functional mechanism could be the same to that inside asphalt mixture.

4. CONCLUSIONS

(a) Cracking resistance performance and HTRP of asphalt mortar substantially are improved significantly after basalt fiber modification. However, excess fibers will causes their joining together and damage the homogeneity and force state of asphalt mortar.

(b) Basalt fiber-asphalt mortar, having the optimum comprehensive properties, combines the advantages of both the lignin fiber and polypropylene fiber on asphalt absorption and crack resistance respectively, meanwhile offsets the disadvantages of them.

(c) The results of mechanical testing and SEM analysis indicates that basalt fiber provides better bridging mechanism and improve cohesiveness, which suppresses localization of micro-cracks and hinder micro-crack propagation due to tensile loadings.

REFERENCES


