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# The Performance of Basalt Fiber Modified Asphalt Mixtures: A Review

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## Abstract

**This paper reviews the role of basalt fibers as modifiers in asphalt mixtures. At present, the road performance testing of asphalt mixture mainly adopts rutting test, low temperature bending test, immersion Marshall test, freeze-thaw split test, etc. Through these tests, the high temperature stability and low temperature crack resistance of basalt fiber to asphalt mixture are analyzed. and water stability and other road performance. The results show that the road performance of the asphalt mixture with basalt fiber is significantly improved, especially the high temperature performance. Previous studies have shown that the optimum amount of basalt fiber added to the asphalt mixture is 0.3-0.5%.**

## Keywords

**Basalt Fiber; Road Performance; Asphalt Mixture.**

## 1. Introduction

Asphalt pavement is considered as the best way to pave highway because of its good driving performance, high comfort, low noise, convenient construction and maintenance [1-3]. In addition, bitumen is susceptible to temperature, being soft in hot climates and brittle and hard in cold climates [4]. Asphalt mixture is a composite material composed of asphalt, aggregate and other modifiers, which has been widely used in the construction of high-grade highways at home and abroad.

With the rapid increase of road traffic volume, people flow and logistics, as well as the increasing difficulty of overload control of heavy vehicles, ineffective overload control, untimely maintenance and other factors, a large number of pavement damage has been caused [5]. In order to improve the service life of the road and reduce the maintenance cost, in addition to optimizing the pavement design and strictly controlling the construction quality, it is often achieved by improving the performance of the pavement material. As the adhesive material in the asphalt mixture, asphalt is used for the asphalt mixture. The mechanical properties play a decisive role. However, it is more and more difficult for base asphalt to meet the requirements of pavement performance, so it is necessary to modify all aspects of its performance to improve the mechanical properties of the mixture.

How the addition of fiber affects the performance of asphalt mixture is one of the hot fields for road researchers all over the world [6]. The research on the performance of fiber-reinforced asphalt mixture can be traced back to 1950 [7]. The dispersion of fiber in the mixture improves the stiffness and strength of the composite, so as to improve the high-temperature stability [8], low-temperature performance [9], water stability energy [10] and fatigue performance [11] of asphalt mixture, The service life of asphalt concrete pavement is prolonged and the pavement maintenance cost is reduced.

At present, the fibers used in asphalt pavement mainly include basalt fiber, lignin fiber, polyester fiber and so on. Basalt fiber has high mechanical strength, durability, high temperature resistance and chemical stability [12], which are second only to carbon fiber and silicon carbide fiber, and basalt materials are widely distributed and cheap [13, 14]. Therefore, the application of basalt fiber in asphalt

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pavement is also a major focus of current research. Based on the relevant literature of fiber modified asphalt mixture, this paper will focus on the application of basalt fiber in mineral fiber in asphalt mixture, analyze the problems existing in the current research, and put forward the research and development direction of basalt fiber asphalt mixture in the future.

## 2. Preparation of Fiber-Modified Asphalt Mixtures

Methods of adding fibers to asphalt mixtures include dry mix, wet mix and post mix [15-18]. Fig.1, Fig.2, Fig.3 are the process flow diagrams corresponding to the dry mixing method, the wet mixing method and the post mixing method. Preparation process of dry mixing method: firstly, before adding fiber, put the aggregate into the oven for heating, add fiber and mix after heating for a period of time, and then add preheated asphalt binder to the fiber aggregate mixture for mixing [19]. Preparation process of wet mixing method: first, add the fiber into the asphalt for full mixing to disperse and evenly form fiber asphalt slurry, then add the fiber asphalt slurry and aggregate into the mixing pot for full mixing, and then add mineral powder into the mixing pot for full mixing [20]. The post mixing method is based on the conventional asphalt mixture mixing process. After mixing evenly, the fiber is added for mixing evenly, that is, the asphalt is mixed with the aggregate first, then the mineral powder is added for mixing evenly, and finally the fiber is added for mixing evenly [21].

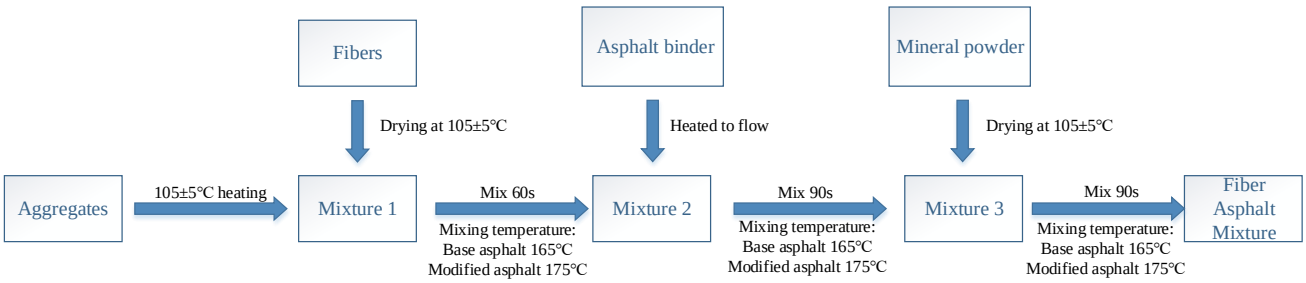


**Figure 1.** Dry mixing process

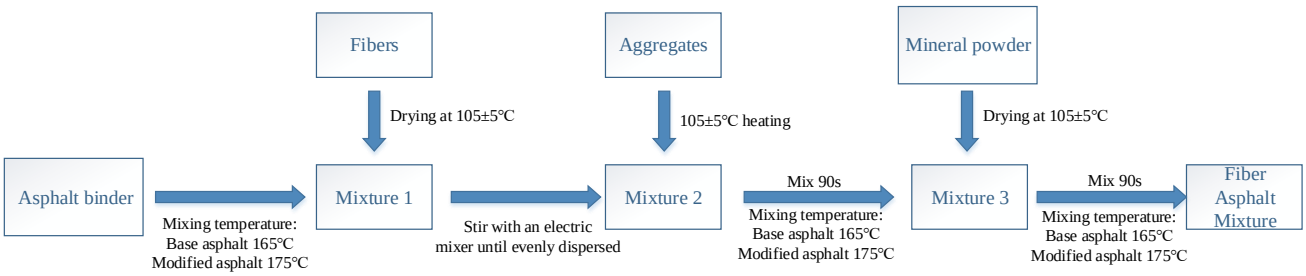


**Figure 2.** Wet mixing process

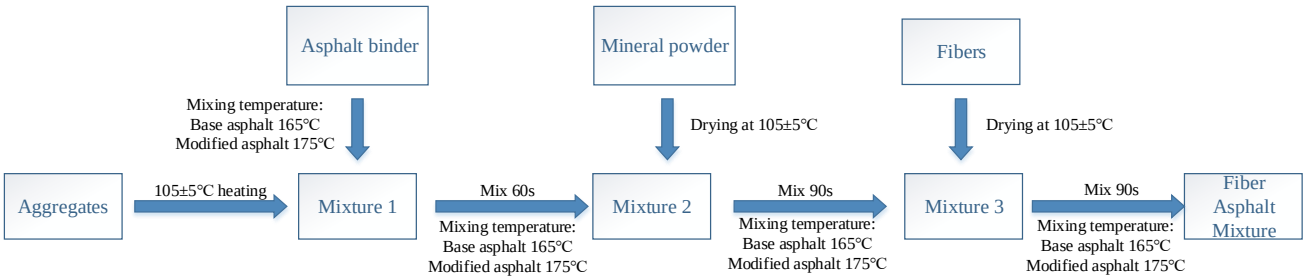


**Figure 3.** Post-mixing process

The fiber distribution in these three mixing processes is three-phase distribution, but there are slight differences in the uniformity and adsorption of asphalt, which have a significant impact on the performance of asphalt mixture [15]. The process of wet mixing method is more complicated, which

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will increase the construction cost [22]. At the same time, the mixing time of fiber and asphalt will also affect the uniformity of fiber dispersion, but the wet mixing method also gives full play to the fiber absorption of asphalt to form a structure The effect of asphalt increases the proportion of structural asphalt and improves its Marshall stability. In the post-mixing method, the mixing time of fibers and asphalt is the shortest. If the mixing time is too short, the dispersion effect of the fibers will be seriously affected, so that the mixing time needs to be prolonged, which will affect the production efficiency of the actual production site. After the mineral powder is fully mixed, the fibers added later can absorb and absorb the excess free asphalt, which can also increase the proportion of structural asphalt. Compared with the wet mixing method and the post-mixing method, the dry mixing method has a simple process, energy saving and environmental protection, and does not require other special equipment. At the same time, the fibers and aggregates are mixed first to ensure the dispersion effect of the fibers and the mixing time does not need to be prolonged. Therefore, at present, the dry mix method is often used in the preparation of fiber-asphalt mixture [23, 24].

# 3. Road Performance of Asphalt Mixture

## 3.1 High Temperature Performance of Asphalt Mixtures

Asphalt mixture is a kind of viscoelastic plastic material, which is greatly affected by temperature, especially in hot climate. The higher its temperature is, the worse the ability of asphalt mixture to resist deformation is, resulting in a series of diseases such as high-temperature deformation, rutting and displacement of asphalt pavement [25]. With the increase of load action time, rutting repeated tire stress accumulates and viscous flow deformation occurs. When the load disappears, this viscous flow deformation is permanent and unrecoverable, which forms rutting on the road [26, 27]. There are many reasons affecting the formation of rutting, which can be summarized as internal factors and external factors. Internal factors are mainly reflected in the quality of the material itself, while external factors are mainly reflected in climatic conditions and traffic conditions [28]. There are many test methods used to evaluate the high temperature stability of asphalt mixture, such as triaxial test, creep test, rutting test and so on. At present, rutting test is the most widely used test method to detect the high temperature stability of asphalt mixture all over the world.

### 3.1.1 Rut Test

Rutting test is a laboratory test technology used to evaluate the high-temperature rutting resistance of asphalt mixture. Its advantage is that the test process of rutting test is similar to the rolling process of vehicles on asphalt pavement. Therefore, the measurement results are consistent with the damage form of actual pavement and the actual situation. Therefore, it is widely used in high-temperature stability test.

Firstly, three square plate specimens with length of 300 mm, width of 300 mm and thickness of 50 mm were made with the best asphalt aggregate mix ratio, and compacted 24 times with impact hammer after Marshall test. Before the test, place the rutting test piece together with the test mold on the test bench of the rutting tester and preheat it at 60 ± 1 ℃ for 4-5h to ensure that the temperature of the test piece is 60 ℃. According to the standard specification [29], carry out the round-trip movement with the grounding pressure of 0.7 ± 0.05MPa. The round-trip speed of the rubber wheel is 21 times / min for about 1H, or stop when the maximum deformation reaches 25mm.

After the test, the dynamic stability of rutting specimen is calculated according to the specification requirements, and the dynamic stability DS is used as the evaluation index of high temperature performance of asphalt mixture. Dynamic stability is defined as follows:

$$DS = \frac{(t_2 - t_1) \times N}{d_2 - d_1} \times C_1 \times C_2 \tag{1}$$

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Where, DS is the dynamic stability of asphalt mixture (times / mm); N s the round trip speed of rubber wheel; C1is the test instrument type factor; C2 is the coefficient of test piece is 1.0 when the prepared test piece is 300mm wide; d1 is the deformation at time t1 (mm); d2 is the deformation at time t2 (mm).

## 3.2 Low Temperature Properties of Asphalt Mixtures

Low temperature stability is generally used to characterize the resistance of asphalt mixture to low temperature cracking. Low temperature cracking of asphalt pavement is a common form of pavement failure. After the cracking of asphalt pavement, under the joint action of vehicle and water, the cracks will develop rapidly, forming large-area network cracks, cracks and large pits, which will reduce the road service quality and even seriously shorten the service life of the road. Therefore, if the asphalt mixture has high ultimate strain, fracture resistance and tensile strength at low temperature, it can improve its ability to withstand the appearance and propagation of cracking before material deterioration, and reduce the number of transverse cracks [30]. Low temperature cracking is the basic hazard of asphalt mixture. At present, many test methods have been applied to evaluate the cracking resistance of asphalt mixture. In this paper, there are two test methods to evaluate the low-temperature crack resistance of asphalt mixture, namely low-temperature bending test and splitting test.

### 3.2.1 Low Temperature Bending Test

Low temperature bending test is used to evaluate the crack resistance of asphalt mixture at low temperature. Before the bending test, place the beam specimen with length of 250mm, width of 30mm and height of 35mm in the constant temperature water tank at the specified temperature for insulation for no less than 45min, keep the trabecular temperature at 15 ℃± 0.5 ℃, and the distance between the specimens shall not be less than 10mm. At the same time, the temperature of the environmental incubator of the testing machine shall reach 15 ℃± 0.5 ℃, and the position of the specimen support shall be fixed. Until the internal temperature of the test piece reaches the experimental temperature ± 0.5 ℃. Four identical specimens with the same mixture design were used for each test [29]. The beam specimen adopts the three-point bending method, the loading rate is 50 mm / min and the span is 200 mm. After the test, the point load is applied to the midspan of the sample until the beam sample is damaged. The system records the values of intermediate displacement and maximum load through automatic process, and the results are drawn into X-Y recorder.

Bending tensile strength RB, maximum bending tensile strain εB and bending stiffness modulus SB are calculated as follows:

$$R_B = \frac{3 \times L \times P_B}{2 \times b \times h^2} \tag{2}$$

$$\varepsilon_B = \frac{6 \times h \times d}{L^2} \tag{3}$$

$$S_B = \frac{R_B}{\varepsilon_B} \tag{4}$$

Where: RB is the flexural tensile strength of specimen in failure (MPa); εB is the maximum bending tensile strain of specimen at failure (με); SB is the flexural tensile progress modulus of specimen at failure (MPa); b is the specimen width of midspan section (mm); h is the specimen height of mid span section (mm); L is the span of test piece (mm); PB is the maximum load at failure of test piece (N); d is the mid span deflection when the specimen is damaged (mm).

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### 3.2.2 Split Test

Compared with the widely used bending test to evaluate the low-temperature crack resistance of asphalt mixture, the indirect tensile test is the splitting test. The test method is easy, the specimen preparation is simple, and its test parameters have a good correlation with the performance of asphalt mixture, which can qualitatively evaluate the low-temperature crack resistance of asphalt mixture. According to the standard specification [29], the test temperature is - 10 ± 0.5 ℃, and the loading rate is 1mm / min. The size of the test piece is 101.6mm in diameter and 63.5mm in height. Each side shall be compacted 75 times, and then the test piece shall be placed in the test chamber for 6 hours before the test. Once the test is started, take the test out of the test chamber at - 10 ℃. The test shall be completed in a short time to ensure that there is no change in the temperature of the test piece. During the whole test, record the vertical deformation and load on the upper surface of the test piece. The tensile strength and tensile failure strain are calculated according to the standard, and the formula is as follows:

$$R_T = \frac{0.006287P_T}{h} \tag{5}$$

$$\varepsilon_T = \frac{X_T \times (0.0307 + 0.0936\mu)}{1.35 + 5\mu} \tag{6}$$

$$X_T = \frac{Y_T \times (1.35 + 0.5\mu)}{1.794 - 0.0314\mu} \tag{7}$$

Where: RT is the indirect tensile strength (MPa); PT is the indirect tensile failure load (N); h is the height of test piece (mm); εT is the Tensile failure strain (με); μ is the poisson's ratio; YT is the vertical deformation (mm); XT is the horizontal deformation, calculated in YT (mm).

## 3.3 Water Stability of Asphalt Mixtures

Water damage of asphalt pavement is one of the main damage forms of asphalt pavement. The main reason is the insufficient water stability of asphalt mixture, which is mainly reflected in: asphalt is separated from the surface of aggregate particles, and loose aggregate particles appear on the pavement. Under the joint action of water and vehicles, it is easy to reduce the adhesion between asphalt and stone, and lead to peeling, particle falling, looseness, potholes and other damage. The properties of asphalt mixture, aggregate type, environmental conditions, construction conditions, traffic environment and pavement structure design can affect the water stability of asphalt mixture. At present, many test methods can be used to evaluate the water stability of asphalt mixture. This paper studies and discusses the most commonly used immersion Marshall test and freeze-thaw splitting test in the laboratory.

### 3.3.1 Immersion Marshall Test

Immersion Marshall test is to calculate the water stability of asphalt mixture by calculating the immersion residual stability, which is defined as the ratio of Marshall stability of wet sample and dry sample. According to the standard specification [29], first prepare the standard Marshall test piece, which is 101.6mm straight and 63.5 ± 1.3mm high. Then, the test pieces are divided into two groups. One group is kept in a constant temperature water tank at 60 ± 1 ℃ for 30 ~ 40min, then take out the test pieces, start the loading equipment at a loading speed of 50mm / min, and record the stability of the sample. The other group is kept in a constant temperature water tank at 60 ± 1 ℃ for 48h, and then conduct the same test. On this basis, the residual stability of asphalt mixture is calculated. The formula is as follows:

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$$MS_0 = \frac{MS_1}{MS} \times 100 \tag{8}$$

Where: MS0 is the residual stability (%); MS1 is the stability after immersion for 48h (kN); MS is the Stability (kN).

### 3.3.2 Freeze-thaw Split Test

The freeze-thaw splitting test of asphalt mixture is mainly used to test the alternating action of continuous freezing and thawing of pavement in winter in northern China, which is mainly used to determine the water stability index. However, due to the freezing and thawing process of asphalt mixture, the test is also used to indirectly evaluate the low-temperature performance of asphalt mixture. According to the standard specification [29], eight cylindrical specimens with a diameter of 101.6 mm and a height of 63.5 mm are made, and the Marshall specimens are made by double-sided compaction for 50 times. Then they are randomly divided into two groups with four test pieces in each group. The first group is placed on the room temperature platform for standby. The second group of test pieces are saturated according to the vacuum water saturation method of vacuum water saturated Marshall test pieces. After being saturated, the test pieces are placed in the vacuum drying oven for 0.5h, and then the saturated test pieces are quickly put into the plastic bag, add 10ml of water, tie the bag mouth tightly, and put them into the refrigerator at - 18 ± 2 ℃ for 16 ± 1H. After freezing, Take it out immediately and put it into the water tank at 60 ± 0.5 ℃ for 24h. Then put the first group of spare test pieces and the second group of test pieces into a constant temperature water tank at 25 ℃± 0.5 ℃ for insulation for no less than 2h, and the distance between test pieces shall not be less than 1cm. Finally, the specimen is taken out for splitting test, and the maximum load of the test is obtained.

The tensile strength ratio and freeze-thaw splitting strength ratio of asphalt mixture are calculated through the freeze-thaw splitting strength, and the formula is as follows:

$$R_{T1} = 0.006287 P_{T1}/h_1 \tag{9}$$

$$R_{T2} = 0.006287 P_{T2}/h_2 \tag{10}$$

$$TSR = \frac{R_{T2}}{R_{T1}} \times 100 \tag{11}$$

Where: RT1 is the splitting tensile strength of the first group of specimens without freeze-thaw cycle (MPa); RT2 is the splitting strength of the second group of specimens after freeze-thaw cycle (MPa); P T1 is the maximum test load of the first group of specimens (N); P T2 is the maximum test load of the second group of specimens (N); h1 is the test piece height of the first group of test pieces (mm); h2 is the test piece height of the second group of test pieces (mm); TSR is the strength ratio of freeze-thaw splitting test (%).

## 4. Application of Basalt Fiber in Asphalt Mixture

Tables 1 and 2 refer to the effects of basalt fibers on asphalt mixtures in relevant literature studies. Table 1 shows the influencing factors of basalt fiber-modified asphalt mixture, including asphalt type, aggregate type, gradation type, filler type, fiber content, optimum oil-stone ratio and fiber length. Table 2 lists the modification properties of basalt fiber to asphalt mixture corresponding to Table 1, including high temperature stability, low temperature crack resistance and water stability.

Liu [31] comprehensively studied the modification effect of basalt fiber asphalt mixture from five aspects: the reinforcement mechanism of fiber, the rheological properties of fiber asphalt, the optimal

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content of fiber, the road performance of fiber asphalt mixture and the paving of solid engineering. It is found that basalt fiber can improve the viscosity, consistency, hardness and rheological properties of asphalt. At the same time, the road performance of basalt fiber, lignin fiber and polyester fiber asphalt mixture is compared. It is found that in AC-16C and SMA-13 structures, basalt fiber asphalt mixture is stronger than polyester fiber and lignin fiber in terms of high-temperature rutting resistance, low-temperature cracking resistance and water damage resistance.

Ren [32] mixed basalt fiber into the asphalt mixture of AC-13C, SMA-13 and OGFC-13. It was found that the addition of fiber improved the road performance of the asphalt mixture of these three grades. Through comparison, it was found that the improvement advantage of basalt fiber in dense mixture was more obvious.

The research of Li and Wen [33, 34] shows that basalt fiber has a significant modification effect on the mixture, and the high-temperature stability, low-temperature crack resistance and water stability of basalt fiber asphalt mixture have been significantly improved compared with matrix asphalt mixture and SBS asphalt mixture, which proves that basalt fiber can comprehensively improve the road performance of asphalt mixture, It shows that basalt fiber asphalt mixture has good application effect and popularization and application value.

Qin et al. [35] compared the modification effects of 6mm and 9mm basalt fiber and found that the performance of 6mm basalt fiber asphalt mortar is better than 9mm. At the micro level, they also observed that a three-dimensional network structure was formed between basalt fiber and asphalt binder and aggregate, which was conducive to inhibiting crack propagation.

Celauro et al. [41] studied the feasibility of basalt fiber asphalt concrete for the application in bus lanes in urban areas, so they mainly focused on its wear resistance and rutting performance. It is found that compared with the traditional mixture, basalt fiber asphalt mixture shows better effect in permanent deformation resistance.

**Table 1.** Design composition of basalt fiber modified asphalt mixture

| Additive Type | Asphalt type | Aggregate Type | Filler Type | Optimum fiber content % | Optimum bitumen content % | Fiber length (mm) | Ref. |
|---|---|---|---|---|---|---|---|
| Basalt fiber | AH-90<br>SBS | Dadingzishan stone | Limestone | 0.3 | 5.0<br>5.6 | 6 | [31] |
| | SBS | Basalt | - | 0.3<br>0.4<br>0.3 | 5.48<br>6.28<br>4.85 | 3-6 | [32] |
| | SBS | Basalt | Limestone | 0.5 | 6.0 | ≤6 | [33] |
| | AH-70 | Basalt, Limestone | - | - | 4.6-4.75 | 6 | [34] |
| | AH-90 | Andesite | Limestone | 0.4 | 5.41 | 6 | [35] |
| | AH-90 | Basalt | Limestone | 0.25 | 5.09 | 6 | [9] |
| | AH-90 | Basalt | Limestone | 0.3 | 4.8 | 6 | [36] |
| | AH-90 | - | - | 0.4 | 4.6 | - | [37] |
| | SBS | Basalt | Limestone | 0.35 | 5.38 | 3.7 | [38] |
| | SBS | Basalt, Limestone | Limestone | 0.3 | 5.0 | 1.5 | [39] |

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**Table 2.** Results of adding basalt fiber to asphalt mixture to improve its high temperature performance, low temperature performance and water stability

| Additive Type | Gradation type | Dynamic stability(times/mm) | Flexural strength (MPa) | maximum bending strain(με) | Residual stability(%) | TSR(%) | Ref. |
|---|---|---|---|---|---|---|---|
| Basalt fiber | AC-16C<br>SMA-13 | 1557<br>4176 | 12.7<br>15.7 | 2919<br>3374 | - | 98.2<br>96.7 | [31] |
| | AC-13C<br>SMA-13<br>OGFC-13 | 5206<br>8873<br>4452 | 44.34<br>38.07<br>26.11 | - | +8.2%<br>+8.6%<br>+4.3% | 91.2<br>94.4<br>84.9 | [32] |
| | SMA-13 | 6218 | 21.8 | 3203 | 92.3 | 97.7 | [33] |
| | AC-16C | - | - | 2823 | 86.99 | 87.63 | [34] |
| | AC-13 | 2198 | 14.23 | 5225 | 91.9 | 93.3 | [35] |
| | - | +30.3% | - | - | - | 76.2 | [9] |
| | AC-16 | +17.3% | +27.9% | +17.8% | +18.1% | | [36] |
| | AC-16 | +46.9% | +30.2% | +27.1% | +10.9% | +17.3% | [37] |
| | AC-13C | 4037 | 12.07 | 4878 | 88.4 | 90.6 | [38] |
| | AC-13 | 5568 | - | +22.2% | - | +6% | [39] |

Yang [36] verified the road performance of basalt modified asphalt mixture by paving the test road, and found that the pavement flatness is good within four years of opening to traffic. The test road is consistent with the laboratory research results for the improvement of high-temperature stability, low-temperature crack resistance and water stability of basalt modified asphalt mixture, and the practical application effect is remarkable.

Lu [37] paved the basalt fiber modified asphalt pavement relying on the project. Through the test of the basic road performance of high and low temperature performance and water stability of basalt fiber modified asphalt mixture in the laboratory, it is found that the addition of basalt fiber can effectively improve the road performance of asphalt mixture. The project cost can also be reduced by adding basalt fiber.

Chen [38] studied the role of basalt fiber in asphalt mortar from the micro perspective and found the distribution state and interface range of basalt fiber in asphalt mortar. Basalt fiber and mineral powder have adverse effects on the low-temperature performance and fatigue performance of asphalt mortar. With the increase of fiber content, these two properties of asphalt mortar decrease in varying degrees.

Zhao [39, 9] et al. Studied the modification effect of asphalt mixture mixed with lignin fiber, polyester fiber and basalt fiber, and compared their road performance. The results show that basalt fiber can significantly improve the mechanical properties, low temperature, high temperature and water stability of asphalt mixture. At the same time, compared with the test results of lignin fiber and polyester fiber, basalt fiber has significant advantages in improving the low temperature crack resistance of asphalt mixture.

Wu et al. [40] studied the modification effect of basalt fiber on asphalt from asphalt binder, evaluated the rheological properties of basalt fiber asphalt and lignin fiber asphalt through viscosity test, DSR and BBR test, and found that both basalt fiber and lignin fiber have significantly improved the high-temperature and low-temperature properties of asphalt.

Adding basalt fiber can comprehensively improve the performance of asphalt mixture, so it is also one of the most applied fibers. From the microscopic point of view, the addition of basalt fiber

improves the viscosity and consistency of asphalt, improves the rheological properties of asphalt, and forms a three-dimensional network structure between asphalt, aggregate and fiber, which is conducive to inhibiting the diffusion of cracks; From a macro point of view, the addition of basalt fiber increases the strength of asphalt mixture and improves the road performance of asphalt mixture.

## 5. Conclusions and Recommendations

The purpose of this paper is to summarize the application research of basalt fiber in asphalt pavement and analyze the influence of the incorporation of basalt fiber on the high temperature stability, low temperature crack resistance, water stability and other road properties of asphalt mixture, so as to make decision-making. The user can apply basalt fiber in a targeted manner to prolong the service life of asphalt pavement. According to the high temperature performance, low temperature performance and water stability tests mentioned in this paper, the following conclusions and suggestions are obtained:

(1) The basalt fiber obviously improves the high temperature stability of the asphalt mixture, and also greatly promotes the low temperature crack resistance and water stability of the asphalt mixture.

(2) The research found that the optimum dosage of basalt fiber in the asphalt mixture is 0.3-0.5%, and the optimum length is 6 mm.

(3) It is recommended that future research be carried out by composite modification, and composite modification with nanomaterials and resin materials is added for different application scenarios to comprehensively improve the road performance of asphalt mixtures.

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