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Research Article

Effect of Polyester Fiber on Air Voids and Low-Temperature Crack Resistance of Permeable Asphalt Mixture

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With the rapid development of asphalt pavement, the drainage capacity of asphalt pavement is becoming more and more demanding. Therefore, it is imperative to study the permeable asphalt mixture. The air voids and the connected air voids are the main factors affecting the drainage function and low-temperature performance of asphalt pavement. In order to solve the drainage and low-temperature cracking problem, it is proposed to incorporate a certain amount of polyester fiber into the permeable asphalt mixture. This paper studies the air voids and low-temperature performance of asphalt mixture with different polyester fiber contents. It is concluded that with the increase of polyester fiber content, both the air voids and the connected air voids decrease first and then increase and reach the minimum value when the polyester fiber content is 0.4%. At this time, the low-temperature crack resistance of the permeable polyester fiber asphalt mixture is also the best.

1. Introduction

Asphalt pavement has the advantages of smooth surface, comfortable driving, low noise, and no dust. It has become the main form of high-grade road pavement. However, the ordinary asphalt pavement has poor water permeability and the road surface-gathered water cannot be eliminated in time, which leads to a decline of road surface antisliding performance and affects driving safety [1, 2]. The permeable asphalt mixture has a large void ratio which can remove the surface water quickly and protect the pavement structure layer from water erosion. The permeable asphalt mixture requires high performance of asphalt; therefore, the high viscosity-modified asphalt is usually used for the asphalt mixture instead of ordinary asphalt. But the expensive modified asphalt with high viscosity limits the popularization and application of permeable asphalt pavement.

In permeable asphalt mixture, it is difficult to satisfy the high viscosity requirement by using ordinary modified asphalt alone, but the viscosity can be increased by incorporating with polyester fiber [3, 4], and its viscosity also increases with the increase of the polyester content [5]. Polyester fiber has a large specific surface area and can absorb some asphalt to reduce leakage loss. In addition, polyester fiber can also absorb saturated hydrocarbon and aromatic hydrocarbon in the asphalt mixture and increase the adhesion force between the asphalt and aggregate surface [6]. In recent years, it has been observed that polyester fibers can increase the compressive strength, water stability, and temperature sensitivity of SMA mixtures [7–10]. There is a large number of fiber-modified asphalt binders and fiber-modified asphalt mixtures that can be used to deal with major flexible pavement problems such as rutting, fatigue cracking, thermal cracking, and loosening [11]. Furthermore, some drainage problems are investigated in porous mixture and the results show that polyester fiber incorporation reduces drainage problems [12, 13].

The permeable asphalt mixture is a kind of special hot asphalt mixture, which has the characteristics of high voids, high content coarse aggregate, and good aggregate contact performance. Compared with densely packed asphalt mixtures, permeable asphalt mixtures have a higher proportion of voids, which is obtained by reducing sand and mineral fillers [14]. Due to the presence of more voids, the pavement will be damaged to some extent. Therefore, the compaction process must be strictly controlled in the preparation process to give full play to the contact state between aggregates so as to ensure sufficient resistance to decomposition and permanent deformation of the mixture [15–18]. Some studies have shown that the content of coarse aggregate in the permeable asphalt mixture is as high as 80%, and the nesting and extrusion between mineral particles and the binder with high adhesion force make it have higher high-temperature resistance performance than the dense-graded asphalt mixture [19–21], but its low-temperature performance is worse.

The permeable asphalt mixture can quickly remove the road surface water due to the existence of more connected voids, but the semiclosed voids will leave some water in the voids, which will cause frost heaving damage of asphalt pavement at low temperature. Low-temperature cracking is one of the main diseases of asphalt pavement, which greatly affects the function of pavement. Some studies have shown that polyester fiber has a certain effect on the low-temperature crack resistance of the asphalt mixture [22, 23]. The incorporation of polyester fiber can increase the toughness of the asphalt mixture, reduce the sensitivity of the mixture to water, improve the crack resistance of the mixture, and prolong the service life of the mixture at low temperature [5, 24, 25].

In summary, the research on permeable asphalt mixture mostly focuses on the analysis of the aggregate contact surface of the mixture and some literatures have studied the high-temperature performance and water stability of permeable asphalt mixture. However, little research has reported the effect of polyester fiber on the porosity and low-temperature properties of permeable asphalt mixtures. Therefore, this paper gives reasonable polyester fiber content and void content by analyzing the influence of polyester fiber content on air voids and low-temperature performance and provides guidance for paving permeable asphalt mixture pavement.

2. Materials, Grading, and Methods

2.1. Materials

2.1.1. Aggregates. The coarse and fine aggregates are, respectively, rolled limestone gravel and mechanical limestone sand produced by Huainan, which are clean, dry, non-weathered, and free of impurities. They have enough strength and wear resistance, the needle-like content is small, and the particles are angular. Filler refers to mineral powder with a particle size of less than 0.075 mm. The mineral powder must be grounded from the hydrophobic stone, such as strong-basic rock in limestone or magmatic rock, and can flow freely from the silo. The physical properties and chemical composition of the mineral powder are shown in Tables 1 and 2.

Table 1: Physical properties of mineral powder.

Project	Measured value
Apparent density ($g{\cdot}cm^{-3}$)	2.15
Water content (%)	0.92
Hydrophilic coefficient	0.90
Plasticity index	3.60

2.1.2. Asphalt. In the design of permeable asphalt pavement materials, the requirements for asphalt are high and high viscosity-modified asphalt should be selected. At present, there are two types of high viscosity-modified asphalts used in China: one is finished high viscosity-modified asphalt and the other is directly adding modifier into the asphalt mixture. However, due to the relatively high cost of the two types of asphalt, the promotion and application of permeable asphalt pavement is greatly limited. Therefore, the test uses the SBS-modified asphalt [26, 27], and the high viscosity-modified asphalt is achieved by adding polyester fiber to reduce the cost of permeable asphalt pavement. The technical indicators of SBS-modified asphalt are shown in Table 3.

2.1.3. Polyester Fiber. In asphalt mixture, the polyester fiber forms a three-dimensional network structure which mainly plays a reinforcing role in increasing the asphalt film thickness of the aggregate surface and enhances the adhesion between the aggregate and the asphalt [4, 28]. The interlocking effect between the polyester fiber and the encapsulated particle improves the strength and stability of the asphalt mixture and reduces the leakage and scattering loss of drainage mixture [29]. The polyester fiber used in the test is shown in Figure 1, and the technical indexes are shown in Table 4.

2.2. Air Voids and Grading

2.2.1. Target Air Void Determination. Air void is an important indicator that affects the structural function of the permeable asphalt mixture. However, the air voids of the permeable asphalt mixture are closely related to the rainfall intensity. Table 5 gives the requirements for rainfall intensity and air voids in East China [30–32]. According to the statistical investigation of traffic accidents, it is found that when the rainfall intensity is moderate and light, the incidence of traffic accidents is higher than that in heavy rain. Therefore, the design of air void ratio mainly considers the drainage requirements of light rain and moderate rain [33].

It can be seen from Table 5 that when the rainfall intensity is moderate, the air voids are 14.1%~18.6%. In the process of using permeable asphalt pavement, dust and debris will block the void. In addition, after repeated rolling of the vehicle load, the void ratio will decrease year by year. Therefore, the upper limit is generally taken when designing the void ratio. But the functional and structural requirement of the permeable asphalt mixture should be comprehensively considered when determining the target air voids. The target air voids of the permeable polyester fiber asphalt mixture are determined to be 20%. [34–36].

2.2.2. Determination of Grading. The air voids of the permeable asphalt mixture directly affect the drainage function, but the choice of mineral aggregate gradation determines the

Table 2: Chemical composition of mineral powder.

Chemical constituents	Si_2O	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	Other
Content (%)	4.38	1.56	0.76	0.49	48	0.14	0.03	44.64

Table 3: Technical indexes of SBS-modified asphalt.

Technical index	Measured values
Penetration (25°C, 100 g, 5 s)/0.1 mm	48.1
Ductility (25°C, 5 cm/min)/cm	>100
Softening point (°C)	81.5
Relative density	1.043

Figure 1: Polyester fiber.

Table 4: Technical indexes of polyester fiber.

Project	Performance	Pavement requirements
Length (mm)	12 ± 2	≥3
Diameter (μm)	20 ± 2.5	20 ± 5
Strength (MPa)	500~680	≥500
Elongation at break (%)	15~35	≥15
Young's modulus (GPa)	>13.5	—
Proportion	1.36	1.36 ± 0.05
Melting point (°C)	259	≥258

Table 5: Air void requirement in different rainfall intensities.

Rainfall intensity	Rainfall ($mm \cdot h^{-1}$)	Air voids (%)
Rainstorm	≥16.0	≥22.0
Heavy	8.1~15.9	18.7~21.6
Moderate	2.6~8.0	14.1~18.6
Light	≤2.6	—

air voids [37], and the mass percentage of 2.36 mm and 4.75 mm mesh have an important influence on the air voids [38, 39]. When the optimum mass percentage of the 4.75 mm mesh is 15%, the connected air voids are 15.4% and the air voids are 19.7%, which is close to the target air voids of 20% [39]. The mass percentage of mineral with 2.36 mm and 4.75 mm is finally determined to be 12% and 15%. According to the traffic characteristics and climatic conditions in China, the fine-grained PAC-13 type permeable asphalt mixture is used and the gradation composition is shown in Figure 2.

2.3. Polyester Fiber Content and Optimum Asphalt Content. The fiber can improve the water immersion stability of the asphalt mixture, and the enhancement effect is related to the fiber type. In the experiment of the influence of salt on water stability of the fiber asphalt mixture, Ji [40] studied and analyzed the same fiber content (0.3%, mass percentage of asphalt mixture) of lignin fiber, polyester fiber, and basalt fiber and found that the asphalt mixture with polyester fiber (0.3%) had the best water stability. Based on the Schellenberg binder drainage test, Marshall test, and freeze-thaw splitting test, Zhang [41] studied the variation rules of leakage loss, Marshall performance index, splitting tensile strength, and water stability of the permeable asphalt mixture with polyester fiber content of 0.3%~0.5%. When the amount of polyester fiber is 0.4%, the draindown of binder is the least, the Marshall stability and flow value are the maximum, the splitting tensile strength is the largest, and the water stability is the best. Considering, the polyester fiber content in the asphalt mixture is generally from 0.3% to 0.5% [23, 24], the polyester fiber content in this paper is 0.3%, 0.35%, 0.4%, 0.45%, and 0.5%. Meanwhile, those without polyester fibers are taken as the control group.

Although the Marshall test is commonly used to determine the mix proportion of the asphalt mixture [42], the permeable asphalt mixture is a multivoid-embedded structure, and the optimum asphalt content cannot be obtained according to the Marshall test method. The optimum amount of asphalt used in the permeable asphalt mixture can be obtained on the basis of the Schellenberg binder drainage test [43]. According to the different instruments used in the test [44], it can be divided into the beaker method [43], enamel disc method [45], and basket method [46]. In this paper, the asphalt film thickness is set to 14 μm [47]. According to the calculation method of asphalt film thickness [48, 49], the optimum asphalt content of the permeable asphalt mixture with the polyester fiber content of 0% is determined to be 4.95%. The optimum asphalt content of the permeable asphalt mixture under different polyester fiber contents is determined by the beaker method. The comparison chart before and after the Schellenberg binder drainage test is shown in Figure 3. The test results are shown in Table 6. The draindown of binder is calculated by the following equation:

$$\Delta m = \frac{m_2 - m_1}{m_1 - m_0} \times 100, \tag{1}$$

where m_0 is the mass of beaker, g; m_1 is the total mass of the beaker and asphalt mixture, g; m_2 is the mass of beaker and asphalt mortar adhered to the beaker, g; and Δm is draindown of binder, %.

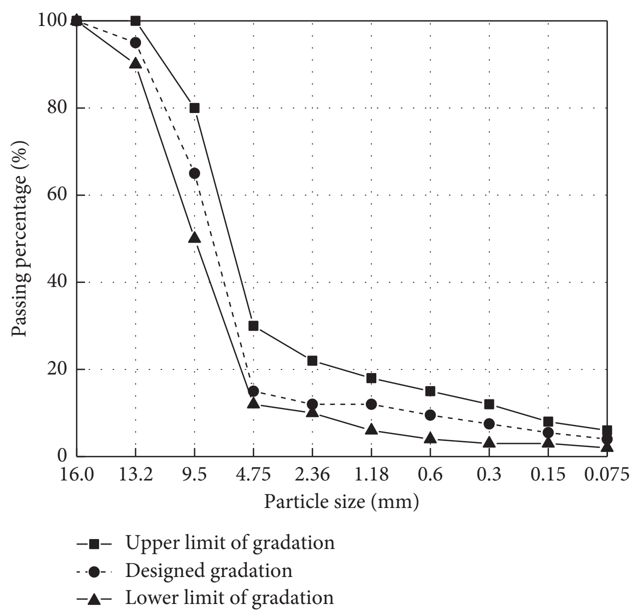
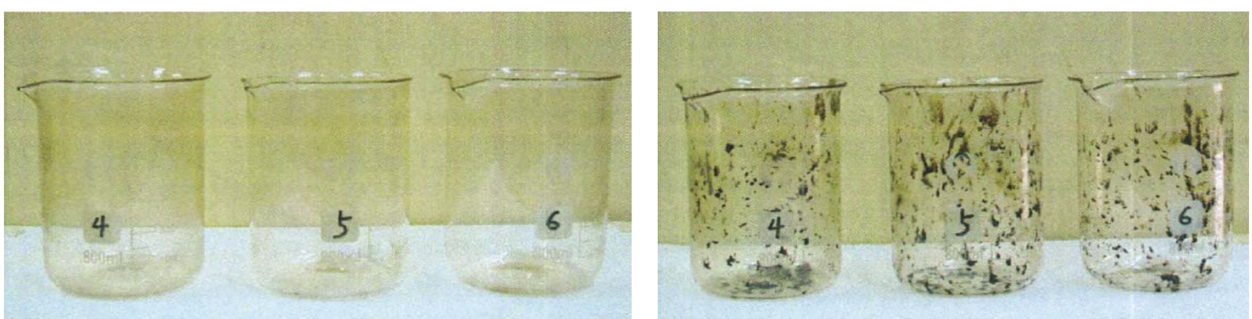


FIGURE 2: Aggregate gradation.



(a) (b)

FIGURE 3: Comparing (a) before and (b) after the beaker test.

TABLE 6: Schellenberg binder drainage test results.

Polyester fiber content (%)	Run-off loss at different asphalt content (%)				
	3.9	4.4	4.9	5.4	5.9
0	0.037	0.040	0.043	0.057	0.063
0.3	0.023	0.027	0.033	0.033	0.060
0.35	0.020	0.027	0.037	0.040	0.043
0.4	0.020	0.027	0.033	0.040	0.053
0.45	0.020	0.023	0.027	0.033	0.043
0.5	0.043	0.047	0.053	0.057	0.060

According to the results of the Schellenberg binder drainage test, the smaller the draindown of binder, the larger the film thickness of the asphalt on the aggregate surface and the better the bond performance between the aggregates. The incorporation of polyester fiber can reduce the draindown of binder of asphalt and enhance the adhesion between aggregate and asphalt. The main reason for this phenomenon is that the polyester fiber has the characteristics of lipophilicity and large specific surface area and can adsorb the free asphalt to form the asphalt film and reduce the loss of binder drainage. However, in the case of a certain amount of fiber, the adsorption of the fiber on the asphalt is basically the same as the effect of obstructing the flow. As the amount of the asphalt increases, the leakage loss increases. Therefore, there is a certain relationship between the amount of polyester fiber and the amount of asphalt. Combined with the test results of Zhang and Wu [50], it is found that the optimum amount of asphalt used in the permeable asphalt mixture is proportional to the fiber content, which can be seen from Figure 4.

2.4. Methods

2.4.1. Calculation of Air Voids and Connected Air Voids. There are three types of air voids, connected air voids, semiconnected air voids, and closed air voids. As shown in Figure 5, the connected air voids refer to the gap inside the mixture that can communicate with the outside and have the functions of drainage and absorption of noise. The air voids of the permeable polyester fiber asphalt mixture are measured by a volumetric method. The air void ratio and the

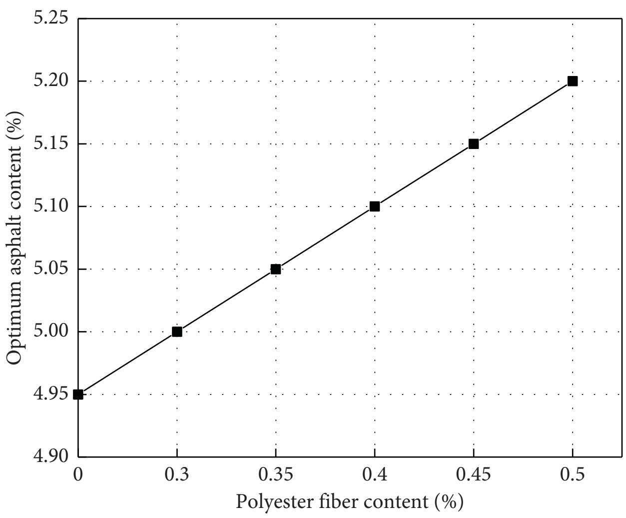


FIGURE 4: The relation between the fiber content and optimum asphalt content.

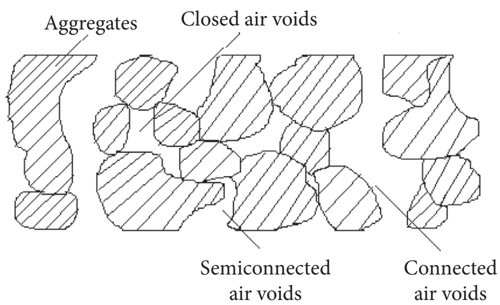


FIGURE 5: Air void types in the permeable polyester fiber asphalt mixture.

connected air void ratio can be calculated by the following equations [51]:

$$VV = \left(1 - \frac{\gamma_f}{\gamma_t}\right) \times 100\%,$$
$$VV' = \left(\frac{V - V'}{V}\right) \times 100\%,$$
$$V = \frac{\pi d^2 h}{4}, \tag{2}$$
$$V' = \frac{(A - C)}{\rho_W},$$

where VV is percent air voids in bituminous mixture, %; γ_f is bulk density of bituminous mixture; γ_t is theoretical maximum specific gravity of bituminous mixture; VV' is connected air voids of the specimen, %; V is volume of the specimen, cm^3; V' is aggregate and closed void volume, cm^3; d and h are diameter and height of the specimen, cm; A is mass of dried specimen in the air, g; C is mass of the specimen in water, g; and ρ_w is density of water, 1.0 g/cm^3.

The size of connected air voids directly determines the strength and the drainage capacity of the permeable polyester fiber asphalt mixture [52]. Therefore, obtaining an accurate connected air void ratio is important for the drainage capacity of the pavement.

2.4.2. Three-point Bending Test. Bending test is one of the main methods for evaluating the low-temperature performance of the asphalt mixture. The size of the beam specimen is 250 mm × 30 mm × 50 mm, which is cut from a 300 mm × 300 mm × 50 mm plate specimen formed by a wheel rolling method, as shown in Figure 6. The test conditions are −10°C and 50 mm/min loading rate. When the specimen is a failure, record the maximum load and midspan deflection. At the time of failure, the flexural tensile strength, the maximum flexural tensile strain, and the flexural stiffness modulus can be calculated by the following equations:

$$R_B = \frac{3 \times L \times P_B}{2 \times b \times h^2},$$
$$\varepsilon_B = \frac{6 \times h \times d}{L^2}, \tag{3}$$
$$S_B = \frac{R_B}{\varepsilon_B},$$

where R_B is flexural tensile strength when the specimen is a failure, MPa; ε_B is maximum flexure tensile strain when the specimen is a failure, $\mu\varepsilon$; S_B is bending stiffness modulus when the specimen is a failure, MPa; b is width of the specimen, mm; h is height of specimen, mm; L is span of the specimen, mm; P_B is maximum load when the specimen is a failure, N; and d is midspan deflection when the specimen is a failure, mm.

3. Results and Discussion

3.1. Effect of Polyester Fiber Content on Air Voids and Connected Air Voids. The test results of air voids and connected air voids of the permeable asphalt mixture with different polyester fiber contents are shown in Table 7.

It can be seen from Table 7, when the content of polyester fiber increases from 0.3% to 0.5%, the air voids of the permeable asphalt mixture are 19.4%, 19.3%, 19.1%, 19.6%, and 19.7%, respectively, while the connected air voids are 15.1%, 15.0%, 14.9%, 15.2%, and 15.3%. Compared with those without polyester fiber, the air voids of the permeable asphalt mixture decrease by 1.5%, 2.0%, 3.0%, 0.5%, and 0%, respectively, while the connected air voids decrease by 1.9%, 2.6%, 3.2%, 1.3%, and 0.6%. It can be seen that polyester fiber has little influence on the air voids and the connected air voids. In addition, the minimum air void is 19.1% and the minimum connected air void is 14.9% of the permeable asphalt mixture when the polyester fiber content is 0.4%, which meets the requirements of the specification (18%~25%, >14%) [51]. It is indicated that the addition of polyester fiber to the modified asphalt can replace the high viscosity-modified asphalt for the permeable asphalt mixture.

According to Table 7, the relationship between the air voids and the amount of the polyester fiber is shown in Figure 7. The relationship between the connected air voids and the amount of polyester fiber is shown in Figure 8.

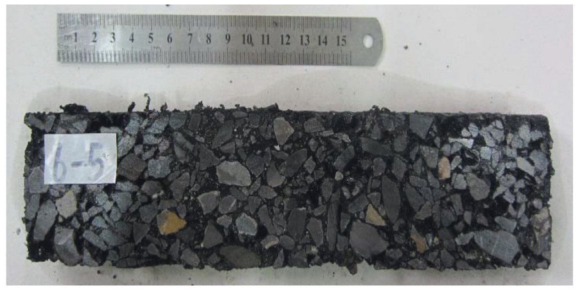


Figure 6: Specimen.

Table 7: Connected air voids and air voids relationship under different polyester fiber dosage.

Fiber content (%)	Asphalt content (%)	Test piece height (%)	Air voids (%)		Connected air voids (%)	
			Single value	Average value	Single value	Average value
0	4.95	64.8	19.8	19.7	15.1	15.4
		64.6	20.3		14.8	
		64.3	19.2		14.6	
		63.7	19.6		17.1	
0.3	5.0	64.8	19.5	19.4	15.2	15.1
		64.8	19.2		15.0	
		64.6	19.5		14.8	
		64.7	19.5		15.3	
0.35	5.05	64.5	19.2	19.3	14.6	15.0
		64.9	19.6		15.4	
		64.6	19.3		14.8	
		64.3	19.1		15.0	
0.4	5.1	64.2	18.4	19.1	14.0	14.9
		63.7	19.5		15.4	
		63.5	19.6		15.1	
		63.4	19.0		15.2	
0.45	5.15	64.6	19.3	19.6	14.5	15.2
		63.6	19.9		15.5	
		63.6	20.0		16.3	
		64.2	19.1		14.3	
0.5	5.2	63.7	18.3	19.7	14.0	15.3
		64.2	21.1		17.1	
		64.7	19.6		15.0	
		64.8	19.8		15.0	

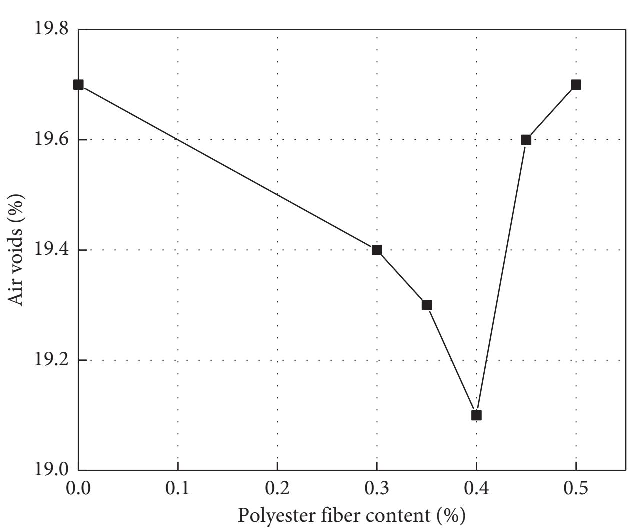


Figure 7: Relation between total air voids and polyester fiber content.

It can be seen from Figures 7 and 8 that the air voids and the connected air voids of the permeable polyester fiber asphalt mixture exhibit similar trends. When the polyester fiber increases from 0.3% to 0.5%, the change in the air voids and the connected air voids of the permeable asphalt mixture decreases first and then increase. As the polyester fiber content increases from 0.3% to 0.4%, the air voids and the connected air voids gradually reduce from 19.4% and 15.1% to 19.1% and 14.9%, respectively. While with the increase of the polyester fiber content from 0.4% to 0.5%, the air voids and the connected air voids gradually increase from 19.1% and 14.9% to 19.7% and 15.3%, respectively.

The major reason for this phenomenon is that, in the case where the content of the polyester fiber is little, it can be uniformly distributed in the mixture to fill the internal void of the mixture. When the polyester fiber content increases to 0.4%, the uniform distribution of the polyester fiber in the asphalt mixture reaches a maximum, and the number of

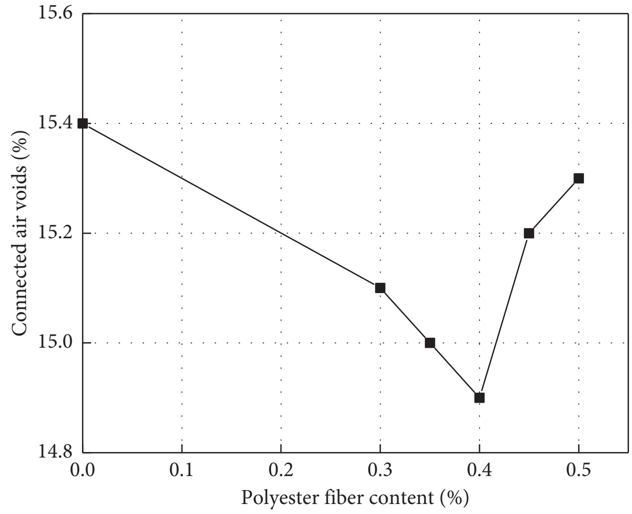


Figure 8: Relation between connected air voids and polyester fiber content.

filled voids also reaches a maximum, and the corresponding air voids and connected air voids reach a minimum. However, with the polyester fiber content exceeding 0.4%, the air voids of the asphalt mixture gradually increase [53]. Because the polyester fibers are unevenly distributed in the asphalt mixture, agglomerates and entanglements occur between the fibers, and the agglomerated fibers separate the aggregates and increase the internal voids of the asphalt mixture.

3.2. Effect of Polyester Fiber Content on Low-Temperature Crack Resistance. Bending test is used to analyze the effect of polyester fiber on the low-temperature crack resistance of the permeable asphalt mixture. The test results are shown in Table 8.

It can be seen from Table 8 that the flexural tensile strength of the permeable asphalt mixture is 3.57 MPa, 5.02 MPa, 5.87 MPa, 6.66 MPa, 4.48 MPa, and 4.24 MPa as the amount of the polyester fiber content from 0% to 0.5%. Compared with the flexural tensile strength without polyester fiber, the flexural tensile strength of the polyester fiber asphalt mixture increases by 40.6%, 64.4%, 86.6%, 25.5%, and 18.8%, respectively. Therefore, the polyester fiber can significantly improve the bending strength of the mixture and improve the resistance to low-temperature shrinkage stress.

The maximum flexure tensile strain is an index to measure the low-temperature deformation ability of the asphalt mixture. The larger the maximum flexure tensile strain, the larger the deformation range of the asphalt mixture and the better the low-temperature crack resistance. It can be seen from Table 8 that the maximum flexure tensile strain of the permeable asphalt mixture is 1575 $\mu\varepsilon$, 2538 $\mu\varepsilon$, 3308 $\mu\varepsilon$, 4174 $\mu\varepsilon$, 2014 $\mu\varepsilon$, and 2266 $\mu\varepsilon$, respectively. When the polyester fiber content is 0.4%, the maximum flexure tensile strain reaches the maximum, 4174 $\mu\varepsilon$. At this time, the low-temperature crack resistance of the permeable polyester fiber asphalt mixture is the optimal. This is because the polyester fiber exerts the reinforcing action and bridging effect in the mixture, which enhances the adhesion between the aggregate and the asphalt and increases the crack resistance of the mixture [54].

The drainage effect of permeable asphalt pavement depends on the content of air voids. The higher the air void content, the better the drainage effect and the poorer low-temperature crack resistance. As can be seen from Table 8, when the polyester fiber content is 0%, the air voids of the permeable asphalt mixture is 19.7%, which is close to the target air voids. However, both the flexural tensile strength and the maximum flexure tensile strain of the permeable asphalt mixture are the minimum. When the content of polyester fiber is 0.4%, the air void of the permeable asphalt mixture is 19.1%. Compared with the polyester fiber content 0%, the air voids decrease by 3.0% and drainage effect slightly decreases. But the flexural tensile strength increases by 86.6%, and the maximum flexure tensile strain increases by 165.0%. Therefore, polyester fiber can improve the low-temperature crack resistance of the permeable asphalt mixture and reduce its drainage capacity slightly. But it still meets the specification requirements [51].

According to the low-temperature bending test results, the relationship among the flexural tensile strength, the flexural stiffness modulus, and the polyester fiber content of the permeable asphalt mixture are shown in Figures 9 and 10.

The bending failure of asphalt mixture girders is mainly caused by cracking along the interface of aggregate. The encountered large particles during cracking produce extrusion and shear and cause damage to the SBS-modified asphalt mixture under low-temperature conditions. It can be seen that good interface strength is an important guarantee to prevent cracking of the mixture [53]. In addition, the agglomeration of polyester fiber in asphalt leads to uneven distribution of asphalt film and uneven distribution of polyester fiber network structure in asphalt [55]. This leads to the discontinuous phase of SBS-modified asphalt, which greatly reduces the interface strength of SBS-modified

Table 8: Bending testing results at low temperature.

Fiber content (%)	Asphalt content (%)	Air voids (%)	Flexural tensile strength (MPa)		Maximum flexure tensile strain ($\mu\varepsilon$)		Flexural stiffness modulus (MPa)	
			Single value	Average value	Single value	Average value	Single value	Average value
0	4.95	19.7	2.34 (−) 3.60 3.87 3.24	3.57	1785 (−) 1575 1523 1682	1575	1311 (−) 2286 2542 1991	2273
0.3	5.0	19.4	5.19 4.93 5.06 4.91	5.02	3045 (−) 2573 2415 2625	2538	1704 1916 2095 1870	1896
0.35	5.05	19.3	6.02 5.84 5.70 5.90	5.87	3203 3518 3098 3413	3308	1880 1660 1840 1729	1777
0.4	5.1	19.1	6.82 8.19 (−) 6.84 6.32	6.66	4043 4148 4305 4200	4174	1687 1975 (−) 1589 1505	1594
0.45	5.15	19.6	4.60 4.61 4.33 4.38	4.48	2258 1756 1890 2153	2014	2038 2625 2291 2035	2121
0.5	5.2	19.7	4.26 4.37 3.95 4.36	4.24	2100 2553 2363 2048	2266	2029 1712 1672 2129	1886

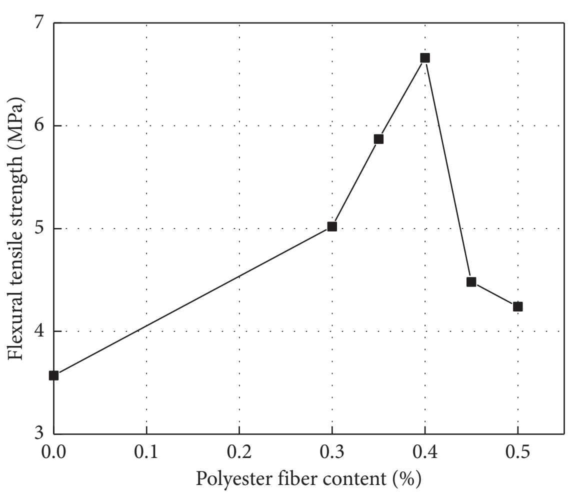


Figure 9: Relation between flexural tensile strength and polyester fiber content.

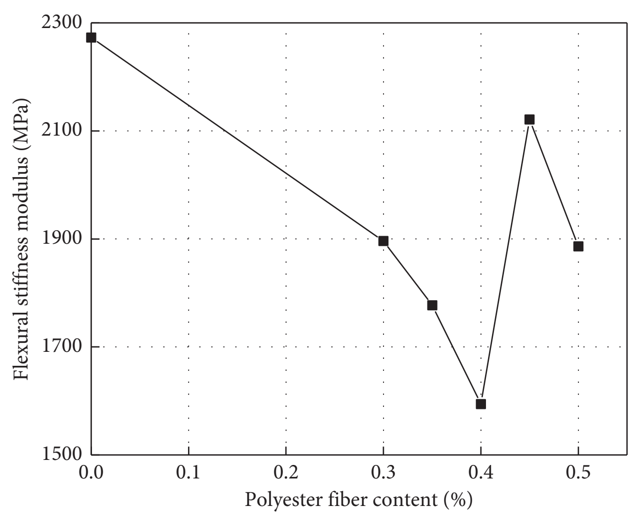


Figure 10: Relation between flexural stiffness modulus and polyester fiber content.

asphalt mixture. Therefore, under the action of load, the stress concentration of SBS-modified asphalt mixture appears and causes cracking in low temperature.

It can be seen from Figure 9 that with the increase of the amount of polyester fiber, the flexural tensile strength of permeable polyester fiber asphalt mixture increases first and then decreases and reaches a peak when the polyester fiber content is 0.4%. The flexural tensile strength is an indicator to measure the effect of low-temperature shrinkage stress on the asphalt mixture. The higher the flexural tensile strength, the stronger the ability of the mixture to resist low-temperature damage and the better the low-temperature crack resistance. The flexural stiffness modulus can reflect the difficulty of low-temperature cracking of the asphalt mixture to a certain extent. The smaller the bending stiffness modulus, the greater the energy required for the mixture to crack and the better the crack resistance. It can be seen from Figure 10 that the flexural stiffness modulus has a minimum value of 1594 MPa when the polyester fiber content is 0.4%, and the permeable polyester fiber asphalt mixture has the best low-temperature crack resistance.

Through the comprehensive analysis of Figures 9 and 10, it is shown that the addition of polyester fiber improves the viscosity and stiffness of SBS-modified asphalt and delays the low-temperature cracking of the permeable asphalt mixture. When polyester fiber content is lower than 0.4%, the low-temperature performance of the permeable asphalt mixture gradually increases, the polyester fiber is dispersed inside the structure to form an interface layer, and the structural asphalt on the interface layer has a larger viscosity than the free asphalt outside. The close combination of the aggregate and the polyester fiber gives play to the reinforcing action effect and bridging effect and improves the low-temperature performance of the asphalt mixture. However, when the content of polyester fiber is more than 0.4%, the low-temperature performance of the permeable asphalt mixture begins to decrease and the low-temperature performance of the asphalt mixture is reduced, which is mainly due to the obvious agglomeration effect and the decrease of the adhesion between the asphalt and the aggregated with continuous increase of polyester fiber.

It can also be seen from Table 8 that when only the maximum flexural tensile strain or flexural stiffness modulus is used to evaluate the low-temperature performance of the asphalt mixture, the conclusion differs to flexural tensile strength. Therefore, the flexural tensile strength, the maximum flexure tensile strain, and flexural stiffness modulus index should be adopted in the evaluation of the low-temperature crack resistance. Considering the three indexes comprehensively, when the polyester fiber content is 0.4%, the permeable asphalt mixture has the best low-temperature crack resistance.

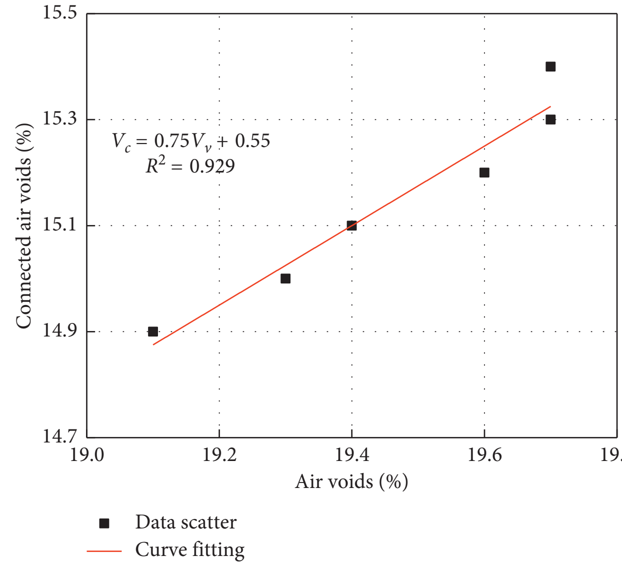


Figure 11: Relation between connected air voids and air voids.

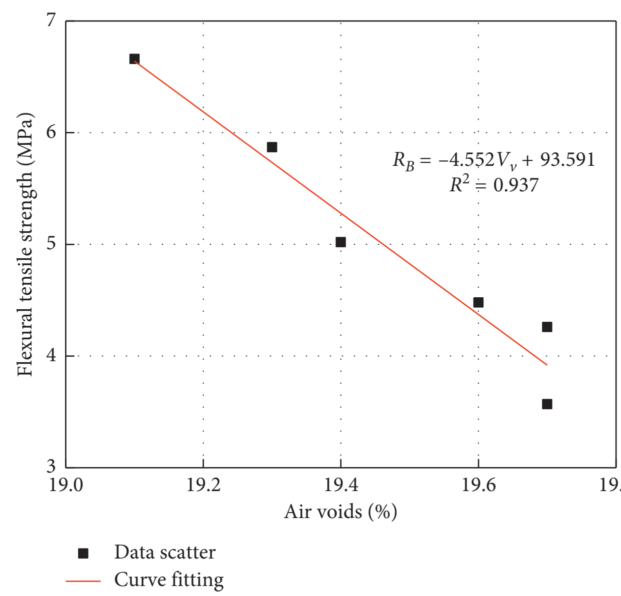


Figure 12: Relation between flexural tensile strength and air voids.

3.3. Effect of Air Voids on Low-Temperature Crack Resistance. The relationship between the connected air voids and air voids of the permeable polyester fiber asphalt mixture and the relationship between the air voids and the flexural tensile strength are shown in Figures 11 and 12.

It can be seen from Figure 11 that the connected air voids and the air voids of the permeable polyester fiber asphalt mixture are linearly related, and the correlation coefficient is 0.929. It is shown that the connected air voids also increase continuously with the increase of air voids. This conclusion is similar to the conclusion of the study of Pattanaik et al. [56]. The air voids and the connected air voids determine the drainage performance of the mixture. Therefore, under the premise of satisfying the function of the permeable polyester fiber asphalt mixture, a large air void should be adopted as much as possible to ensure the drainage function.

It can be seen from Figure 12 that the flexural tensile strength of the permeable polyester fiber asphalt mixture has a good linear correlation with the air voids. As the air voids increase, the flexural strength of the mixture decreases continuously. It shows that the larger the air voids, the worse the ability of the mixture to resist low-temperature damage and the worse the low-temperature crack resistance. The relationship between air voids and connected air voids is linearly increasing, and the connected air voids is the key factor in controlling the drainage of the mixture [57]. Therefore, it is very important to choose a suitable air void on the premise of ensuring the low-temperature performance and drainage performance of the asphalt mixture. According to the analysis of Figures 11 and 12, it can be concluded that when the air void is 19.1%, it not only meets the requirements of drainage function but also ensures the low-temperature crack resistance of the mixture.

4. Conclusion

This paper mainly analyzes the influence of the polyester fiber content on the low-temperature crack resistance and air voids of the permeable asphalt mixture and obtains the following main conclusions.

(1) The air voids and connected air voids of the permeable polyester fiber asphalt mixture decrease first and then increase with the increase of the polyester fiber content; the air voids and connected air voids reach the minimum values of 19.1% and 14.9% when the polyester fiber content is 0.4%.

(2) The flexural tensile strength of the permeable polyester fiber asphalt mixture reaches the maximum value when the content of polyester fiber is 0.4%, indicating that the mixture has the strongest resistance to low-temperature damage and the best crack resistance at low temperature.

(3) Air void is an important factor affecting the flexural tensile strength of the permeable polyester fiber asphalt mixture. The flexural tensile strength decreases with the increase of air voids. At the air void of 19.1%, the flexural tensile strength reaches the maximum value.

(4) Adding proper amount of polyester fiber and choosing reasonable air voids can improve the low-temperature crack resistance of the permeable polyester fiber asphalt mixture.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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