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Study on the effect of compounded fibers on the performance of modified asphalt mixtures in the framework of multidimensional data computational analysis

Mingjing Li[1], Xiaoli Zhuo[2,✉]

[1] *Guangxi Pinglu Canal Construction Co., Ltd., Nanning, Guangxi, 530029, China*
[2] *Kunming University of Science and Technology, Kunming, Yunnan, 650093, China*

ABSTRACT
Asphalt as a common material for urban road construction, asphalt pavement has been favored by the municipal industry because of its good wear resistance and stability. This paper identifies the raw materials for this study, and obtains the samples for this study under the technical guidance of the preparation process. In order to more intuitively observe the role of the two, the construction of two-dimensional numerical model, and with the help of water-immersion Marshall test, freeze-thaw splitting test, rutting test, trabecular bending test, together to explore the effect of compounded fibers on the performance of modified asphalt mixtures. When 6% SBR was added on 2% ZnO+4% DTDM, the flexural strength modulus increased from the initial 5482.76 to 6217.54 MPa, and its increase was 18.53%, which indicates that the addition of fiber has a promoting effect on the flexural properties of modified asphalt mixtures.

Keywords: two-dimensional numerical model, fiber, modified asphalt mixture, immersion Marshall test

1. Introduction

At the beginning of this century, China gradually began to implement the construction of sponge city, and the town road project also changed from functionalization to diversification [1]. Town roads should not only have the basic transportation function, but also have the nature characteristics of sponge city. In order to meet the specific requirements of sponge city, the corresponding design, construction and acceptance of town roads are constantly updated and changed, as a common material for urban road construction, asphalt pavement has been favored by the municipal industry due to its good wear resistance and stability [2-4]. At present, asphalt pavement surface materials are usually made of densely graded asphalt mixtures, such as traditional continuous densely graded asphalt

✉ Corresponding author.
E-mail address: 13878473333@163.com (X. Zhuo).
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mixtures and asphalt tellurite crushed stone mixtures graded. Asphalt mixtures have smaller voids, superior stability properties, and fatigue resistance. However, in the context of urban resistance, this type of pavement is unable to drain water and runoff caused by heavy rainfall, which not only leads to an increase in the heat island effect, but also creates instability in terms of driving safety during the rainy season [5-8]. Therefore, many experts and scholars in the field use this as a starting point to study the asphalt surface structure that meets the requirements of road permeability. Permeable asphalt pavement can not be selected dense structure, in order to hydrophobicity, its pore space needs to be larger, generally by the coarser aggregate and asphalt mixed compaction, this type of asphalt mixture pavement porosity is generally controlled in about 20% [9-10]. However, due to less fine aggregate, this type of asphalt mixture is not dense enough, and in actual operation, there will be pavement cracking, poor stability of the situation, and China's early asphalt pavement design does not take into account the differences in geographic and climatic differences, the asphalt pavement in some areas of the water damage, cracks, and other diseases, resulting in a substantial reduction in road service life [11-14].

In order to solve such problems, some scholars try to add different types of fibers in modified asphalt to further improve its performance. Wu et al [15] used basalt fibers, polyester fibers and polyacrylonitrile fibers to produce modified asphalt mixtures, and after indirect stretching asphalt cracking test, semicircular bending test, evaluation of cracking resistance performance indexes, and quantitative characterization of digital images and other testing sessions, they obtained the basalt fiber asphalt mixtures have better cracking resistance. Lou et al [16] also added basalt fibers to asphalt and found that the addition of basalt fibers not only increased the fatigue resistance of the modified asphalt mixtures, but also increased the cumulative dissipation energy of the mix and its rate of change, and this dissipation energy was linearly correlated with the fatigue resistance. Abd and Latief [17] compared the rutting resistance of asphalt mixtures with the incorporation of basalt fibers, glass fibers, and steel fibers; all three had a modifying effect, but basalt fibers were the best reinforcement. Liu et al [18] used ceramic fibers to improve the properties of asphalt mixtures and the results presented good wettability and dispersion. Xia et al [19] evaluated three durability properties of bamboo fibers on asphalt mixtures through seven tests such as Marshall test, indoor aging test, and uniaxial compression test, and the addition of bamboo fibers to asphalt can effectively enhance the durability of asphalt mixtures. Wu et al [20] reported that the water stability and low-temperature crack resistance of polyester fiber asphalt mixtures decreased with increasing degree of aging for asphalt mortar aging, asphalt mixture short-term aging, and long-term aging conditions over the same period of time, with short-term aging having the greatest effect. Chen et al [21] mentioned that there may be some compatibility between fibers and asphalt, which makes the asphalt mixture enhanced, and the effect of polyester fibers on asphalt mixture modification is more significant at high temperatures, while the opposite is true for straw fibers. Xiao et al [22] analyzed the water stability of asphalt mixes with lignin fibers, polyester fibers and polypropylene fibers from static and dynamic point of view and the asphalt mixes with polyester fibers were extremely water stable both statically and dynamically. Zhang et al [23] added a high dose of cured carbon fiber composite to a porous asphalt mixture, the ductility, crack resistance, and water penetration of this composite fiber asphalt mixture was improved, but the high dose addition leads to a reduction in the indirect tensile strength of the material. Yue et al [24] concluded that a single material addition does not have the effect of improving the overall performance of asphalt mixtures. Zhao et al [25] compounded high styrene-butadiene-styrene copolymers or high styrene-butadiene rubber + microfine carbon fibers, which can improve the dynamic and low temperature stability and fatigue resistance of modified asphalt mixtures. Abdelsalam et al [26] utilized a composite addition of diatomaceous earth and lignin fibers and the composite asphalt mixture performed better than the single asphalt mixture and showed the best performance in terms of water stability and flow properties. Khater et al [27] demonstrated that the addition of single lignin fibers significantly enhanced the thermal cracking resistance of asphalt mixtures, whereas the composite of lignin fibers and glass fibers modified asphalt mixtures showed enhanced performance in terms of both low temperature and water stability and material quality. In general, fibers can form a good interfacial bond with asphalt, increase the viscosity and consistency of asphalt, and improve the cohesion and internal friction of asphalt mixtures, and the appropriate ratio is an effective way to achieve the material's resistance to cracking, durability, weathering, high-temperature stability, water stability, fatigue resistance, and reduced maintenance costs. However, at present, permeable asphalt mixtures either use high viscosity modifiers or add a single fiber as an improved material, but the effect of adding more than two kinds of fibers has been studied quite little. As suggested by previous studies, single material addition has a small effect on the comprehensive modification performance of asphalt, therefore, it is necessary to study the mechanism of multi-fiber synergistic modification on the performance of asphalt mixtures.

In this paper, matrix asphalt, nano ZnO, SBR, and vulcanizing agent DTDM are used as the raw materials for the study, and the preparation work of sulfurized SBR modified asphalt and nano ZnO-SBR sulfur composite modified asphalt is completed under the theoretical requirements of the preparation process. With the help of digital image processing and discrete element simulation technology, the design work of two-dimensional numerical model of asphalt mixtures is completed together, so as to determine the optimal mixing length of fibers. In the framework of multi-dimensional data calculation and analysis, from the water stability, water resistance, high temperature characteristics, bending characteristics of modified asphalt mixtures, the targeted development of water-immersed Marshall test, freezing and thawing splitting test, rutting test, and beam bending test, aiming to reveal the impact of compounded fibers on the performance of modified asphalt mixtures.

2. Preparation of raw materials and composite modified bitumen

2.1. Raw materials

2.1.1. Matrix asphalt. Matrix asphalt for Panjin 90 # A asphalt, the relevant parameters such as Table 1 matrix asphalt technical indicators.

Table 1. Matrix asphalt technical index

Test index	Test result	Specification requirements
Penetration (25℃, 5s, 100g) /0.1mm	76	83~91
Softening point /℃	52	⩾51
Dynamic viscosity (60℃) /Pa-s	385.1	⩾153
Ductility (10℃) /cm	37.3	⩾31
Flash point / °C	307.2	⩾257
Solubility /%	94.35	⩾91.8
Density (15°C)/(g/cm^3)	0.987	--
After aging		
Mass change /%	-0.263	±0.72
Residual penetration ratio /%	61.5	⩾58

2.1.2. Nano-ZnO. Nano ZnO was selected from a new material limited company in Nanjing, the appearance of white powder, see Table 2 nano ZnO technical indicators.

Table 2. Technical indicators of nano-ZnO

Technical index	Test result	Technical requirements
Zinc oxide content (mass fraction) 1%	98.9	⩾90
105℃ volatile matter /%	0.4	⩽0.9

Specific surface area/(cm2/g)	105	⩾42
Electron microscope average particle size /nm	21	⩽72

2.1.3. SBR. Currently modifiers are broadly divided into fibers such as graphene fiber, basalt fiber, glass fiber, synthetic fiber and wood fiber, etc. SBR (Styrene-Butadiene Rubber) is selected from a chemical material limited company, the appearance of a yellowish powder, SBR technical specifications are shown in Table 3.

Table 3. Technical indicators of SBR

Indicator type	Unit	Numerical value	Indicator type	Unit	Numerical value
Particle size	Class	⩽36	Tensile strength	Mpa	43
Water mass fraction	%	⩽5	Styrene mass fraction	%	15%~35%
Molecular weight	Ten thousand	35~42	Dry glue content	%	⩾76

2.1.4. Thiolating agent DTDM. The vulcanizing agent DTDM was selected from Kasei a (A city) Co. Ltd Appearance is slightly yellow powder, the basic indicators are shown in Table 4.

Table 4. Technical index of curing agent DTDM

Indicator type	Unit	Numerical value
Particle size	Class	⩽23
Water mass fraction	%	⩽5
Molecular weight	Ten thousand	30~50

2.2. Modified asphalt preparation

To achieve the purpose of uniform dispersion of the modifier in the asphalt mastic, it is necessary to use an appropriate preparation method to avoid agglomeration and segregation during the preparation process. In this paper, a high-speed shear method was used to prepare modified asphalt [28]. The preparation principle is that the aggregated modifier is dispersed by extremely high shear speed, so that the modifier achieves a well-dispersed state in the asphalt mortar.

2.2.1. Preparation process. Firstly, the oven temperature was raised to 141°C, and after the temperature was stabilized, the matrix asphalt was put into the oven for 1.5 hours, and after the heating was completed, the softened matrix asphalt was poured into a beaker to be weighed and the weight of asphalt was recorded, and after the recording was completed, the beaker with asphalt was put into an oil bath at 182°C and waited for the addition of the modifier. Afterwards, the SBR was weighed at 1% of the recorded asphalt mass, and the DTDM at 1% of the SBR mass was weighed, and the weighed SBR was added to the waiting matrix asphalt in batches, small amounts, and several times. In the process of adding constantly stirred with a glass rod, when stirring to the SBR in the asphalt completely invisible to the naked eye and stop stirring with a glass rod, replaced by a high-speed shearer at a rate of 4800 r/min shear for 50 min. to stop stirring, add the weighed DTDM and continue to stir for 50 min. in accordance with the same steps, the preparation of 4%, 6%, 8%, 10% a total of 5 sets of SBR Modified asphalt. Subsequently, according to the same steps and methods of adding SBR, nano-ZnO of 4%, 6%, 8%, 10% and 12% of the mass of the matrix asphalt was added, and finally the sulfurized nano-ZnO-SBR sulfurized modified asphalt was produced.

2.2.2. Preparation of vulcanized SBR-modified bitumen. SBR-modified asphalt with SBR doping of 2%, 4%, 6%, 8%, and 10% were prepared respectively, and the SBR-modified asphalt was comprehensively evaluated using the data of needle penetration, softening point, and ductility. The comprehensive evaluation results are shown in Table 5. Modified asphalt softening point with the increase in SBR dosage was a continuous upward trend, on the contrary, the needle penetration was a continuous downward trend, and in addition to the first addition of modifiers when the SBR dosage of 4%, the asphalt softening point increment is the most obvious, compared with the last dosage rose 1.79%, compared with the matrix asphalt increased by 12%. Ductility showed a gradual increase trend, it is worth noting that after 4% dosage, the increase in ductility began to accelerate. The higher softening point and ductility, lower needle penetration, means that the asphalt has better high and low temperature performance and more convenient mechanical construction conditions. Therefore, in order to further study the comprehensive performance of composite modified asphalt, 4% dosage of sulfurized SBR modified asphalt and ZnO were selected for the reference blend.

Table 5. Comprehensive evaluation result

Asphalt type	Softening point /℃	Penetration /0.1mm	Penetration /0.1mm
Matrix	44.94	81.72	37.67
2%SBR + 1%DTDM	49.24	79.37	41.96
4%SBR + 1%DTDM	49.82	75.67	45.53
6%SBR + 1%DTDM	50.51	63.71	56.94
8%SBR + 1%DTDM	50.19	59.66	59.46

2.2.3. Preparation of nano Zn O-SBR vulcanized composite modified bitumen. In order to discuss the effect of nano ZnO on modified asphalt, choose to 4% SBR + 2% DTDM modified asphalt for the secondary modification, the preparation of nano ZnO doping of 4%, 6%, 8%, 10%, 12% nano ZnO-SBR sulfide composite modified asphalt, and through the degree of penetration, softening point, the ductility indicators of the composite modified asphalt for a comprehensive evaluation. The basic performance indexes of composite modified asphalt are shown in Table 6. Among the compound fiber 1 to 6 were 2% ZnO + 4% DTDM, 2% SBR + 2% ZnO + 2% DTDM, 4% SBR + 2% ZnO + 2% DTDM, 6% SBR + 2% ZnO + 2% DTDM, 8% SBR + 2% ZnO + 2% DTDM, 10% SBR + 2% ZnO + 2% DTDM, respectively, the needle penetration of the composite modified asphalt decreased with the increase of fiber SBR doping, and the softening point showed an increasing trend with SBR doping, but the increasing trend of softening point began to slow down after 4% SBR doping. Ductility with the increase of SBR doping showed a gradual decline, it is worth noting that the 4% SBR doping after the ductility decline accelerated, taking into account the high and low temperature performance of modified asphalt, 4% doping of SBR doping modification effect is better. The reason for this phenomenon is that the SBR fiber material is much smaller than ZnO material, and secondly, due to the SBR fiber material and asphalt has a certain chemical reaction, so the compatibility is more advantageous than ZnO. When the SBR fiber material surrounds the nano ZnO, on the one hand, it avoids the agglomeration between the nano ZnO materials, and on the other hand, it is equivalent to the SBR particles having a chemical reaction with the asphalt with the help of the nano materials. In order to further discuss the comprehensive performance of the composite modified asphalt, the following section will design the immersion Marshall test, freeze-thaw splitting test, rutting test, and beam bending test for the matrix asphalt and the modified asphalt with five different SBR fiber materials.

Table 6. Basic performance indexes of composite modified asphalt

Asphalt type	Softening point /℃	Penetration /0.1mm	Ductility (5°C) /cm
Blending 1	50.6	63.5	56.2
Blending 2	52.6	62.7	53.4
Blending 3	54.4	60.8	51.8
Blending 4	56.4	57.9	47.3

Blending 5	56.9	57.9	39.3
Blending 6	57.7	55.6	36.4

3. Modeling and experimental design

3.1. *Two-dimensional numerical modeling*

On the basis of the above raw materials and composite modified asphalt preparation, in order to study the impact of compounded fibers on the performance of modified asphalt mixtures, two-dimensional numerical models of asphalt mixtures are constructed through digital image processing and discrete element simulation technology, and the characteristic parameters of the skeleton of the discrete element model are extracted in order to determine the optimal length of the fiber blending.

3.1.1. Digital Aggregate Generation. A high-speed camera was used to obtain the shape and contour of each grade of coarse aggregate in modified asphalt, and a number of typical particles were selected from the three grades of aggregates of 9.42-13.13mm, 4.68-9.23mm, and 2.28-4.48mm, and then placed on the bench to obtain high-definition pictures after they were washed and dried. The specific steps are as follows:

1) Input the pictures of modified asphalt coarse aggregates into MATLAB software, and perform image processing on the pictures to obtain their binarized images.

2) Filter out the aggregate contour pixels from the binarized image of the aggregate, and obtain the 2D coordinate point set of all the contour pixels of the aggregate.

3) Derive the 2D coordinates of the contour pixel points from MATLAB, and establish the surface contour model of modified asphalt mixture coarse aggregate in STL format.

4) Import the STL format model of modified asphalt mixture coarse aggregate surface contour into PFC2D software, fill the model with Clump Template command and Pebble particles through the built-in algorithm of PFC2D software to form Clump particles in order to generate the corresponding coarse aggregate particles model, and establish the coarse aggregate template library.

3.1.2. Mathematical modeling:

1) Calculation of coarse and fine aggregate volume of each grade. According to the results of the design ratio, calculate the volume of coarse and fine aggregates in each grade and the gap rate of mineral material, and adopt the average density of coarse and fine aggregates. The particle size of coarse aggregate particles is 2.28~13.15mm, the particle size of fine aggregate particles is 0.069~2.28mm, the density of asphalt is $\rho_a = 1.029 g/cm^3$, the density of both coarse and fine aggregates is $\rho_b = 2.66 g/cm^3$, the total volume of asphalt mixture specimen is V=120×130=15600 (mm^3), the design void ratio is VV=3.47%, the volume of coarse and fine aggregates is v, and the ratio of oil to stone is $a = 6.42\%$. The mineral gap ratio (VMA) is the volume fraction of the specimen accounted for by the fraction other than coarse and fine aggregates:

$$VMA = 1 - \frac{v}{V} = 1 - \frac{1 - VV}{1 + \dfrac{\alpha\rho_b}{\rho_a}} \tag{1}$$

The particle size of each grade of coarse and fine aggregate is $D_1, D_2 \cdots, D_n$, and the passing rate of each grade of aggregate is 80% in turn, and the volume of each grade of coarse and fine aggregate can be calculated according to the parameters.

2) Modeling. According to the modified asphalt mixture of each grade of aggregate particle volume, generate asphalt mixture mineral distribution model, model generation steps include: defining the calculation area, generating walls, generating coarse and fine aggregate particles and loading coarse

aggregate template library. The final generation of modified asphalt mixture two-dimensional numerical model.

3) Fiber length determination. Extract the two-dimensional discrete element model of modified asphalt mixture skeleton gap characteristic parameters, including the shortest axis of the skeleton gap, the longest axis of the skeleton gap and the average axis of the skeleton gap. Statistics in the length interval (0, 1), (1, 2), (2, 3), ..., (n-1, n), where n is an integer greater than 1, according to the distribution of the skeleton void parameters, due to the distribution of the three kinds of parameters in the 9 mm or more is less, so the value of n is taken to be 9. Comprehensively considering the results of the characteristic parameters, it is found that the length of 8 mm is more closely matched to the distribution of the skeleton void frequency, so 6 mm was chosen as the fiber in the modified asphalt mixture. Therefore, 6 mm is chosen as the blending length of fiber in modified asphalt mixture.

3.2. Experimental design

In order to further improve the performance of modified asphalt mixture, the use of different types of fibers to improve the performance of modified asphalt mixture, in order to verify the role of fibers to improve the performance of modified asphalt mixtures, were designed to design the water-immersed Marshall test, freezing and thawing splitting test, rutting test, trabecular bending test, to test the role of different content of fibers on the modified asphalt mixture of water stability, water resistance, high temperature, bending properties. The detailed experimental design is as follows:

3.2.1. Submerged Marshall Tests. The test method of immersion Marshall test is evaluated according to the test method in T0709-2011 in the test protocol.

In accordance with the method of testing the molding strength to produce specimens, the specimens are divided into two groups: one group put into the 60 ℃ water bath for 30min, test the Marshall strength MS_1. the other group is placed in the 60 ℃ water bath for 48h, test the value of the Marshall strength MS_2. According to the formula (2) to calculate the residual stability MS_0. ie:

$$MS_0 = \frac{MS_2}{MS_1} \times 100 \tag{2}$$

3.2.2. Freeze-thaw splitting test. Freeze-thaw splitting test test method is evaluated according to the test method in T0729-2000 in the test protocol.

1) The molding Marshall specimen is divided into two groups, the first group is kept at room temperature for spare parts, and the second group of specimens is vacuum saturated with water for 15min, and after the air pressure is restored to normal, the specimens are placed in the water and kept for 30min.

2) Put the water-saturated specimens into a plastic bag, inject about 10mL of pure water into the bag, and put the specimens into the -18℃ low temperature environment and freeze for 16h. After the specimens are taken out, they are put into the 60℃ constant temperature water bath for 24h.

3) All the two groups of specimens were put into the constant temperature water tank at 25°C for 2 h. Then the specimens were subjected to splitting test to obtain the maximum load of the test [29]. The data were processed according to Equation (3), Equation (4), and Equation (5). Namely:

$$R_{T1} = \frac{0.006287 \times P_{T1}}{h_1} \tag{3}$$

$$R_{T2} = \frac{0.006287 \times P_{T2}}{h_2} \tag{4}$$

$$TSR = \frac{R_{\pi 1}}{R_{\pi 2}} \times 100 \tag{5}$$

In Eq:

R_{Π} - Splitting tensile strength of the specimen without freeze-thaw cycle, MPa.

R_{r2} - Split tensile strength of specimen after freeze-thaw cycle, MPa.

P_{η} - Load at destruction of the specimen without freeze-thaw cycle, N.

P_{n} - Load at destruction of the specimen after freeze-thaw cycle, N.

h - Height of the specimen, mm.

TSR - Freeze-thaw splitting ratio, %.

3.2.3. High temperature rutting test

High temperature rutting test test method is evaluated according to the test method in the test protocol, T0719-2011:

1) The composite modified asphalt mixture is molded into rutting test specimens by wheel milling method according to the method of T0703-2011 in the test protocol.

2) Place the molded specimens without demolding at room temperature for 48 h. Then place the specimens together with the molds at a constant temperature of 60°C for not less than 5 h, and then run the rutting instrument for 1 h of round-trip rolling.

3) Read the rutting deformations d_1 and d_2 at 45 $\min(t_1)$ and 60 $\min(t_2)$, and calculate the dynamic stability DS according to Equation (6) [30]. That is:

$$DS = \frac{(t_2 - t_1) \times N}{(d_2 - d_1)} \times C_1 \times C_2 \tag{6}$$

The formula:

C_1 - crank linkage drive loading wheel round trip mode of operation, take 1.0.

C_2 - Test piece coefficient, take 1.0.

N - Test wheel round trip crushing speed, take 42 times min.

3.2.4. Trabecular bending tests. The test method of trabecular bending test of modified asphalt mixture is evaluated according to the test method in T0715-2011 in the test protocol.

1) In accordance with the rut test molding specimen method to produce rutting plate, and cut the specimen with a cutting machine to cut the specimen into prismatic cylinders, the specimen size should be consistent with the length of 250mm, width of 30mm, height of 35mm, the error does not exceed the requirements of 2mm.

2) Place the specimen in a constant temperature sink at the test temperature for sustenance for a period of not less than 45min.

3) Start the press and apply load to the specimen span at the specified rate until the specimen is destroyed. Calculate the maximum bending and tensile strains at the time of specimen destruction in accordance with equation (7) ε. i.e:

$$\varepsilon = \frac{6hd}{L^2} \tag{7}$$

Tensile and bending strength of the trabecular specimen at fracture R_B. i.e.:

$$R_B = \frac{3 \times L \times P_B}{2 \times b \times h^2} \tag{8}$$

Flexural modulus of strength at failure of a trabecular specimen S_B. i.e.:

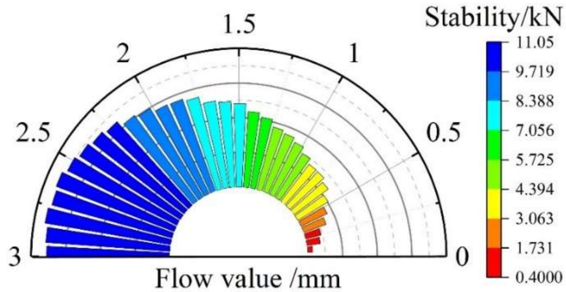
$$S_B = \frac{R_B}{\varepsilon_B} \tag{9}$$

4. Analysis of the results of the experiment

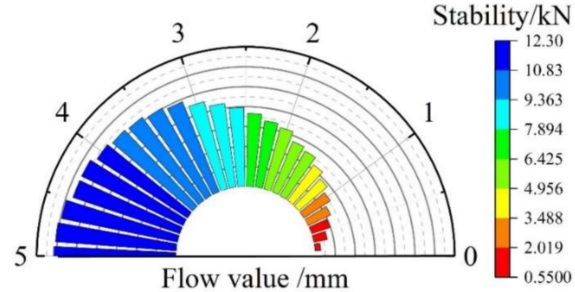
In order to study the performance of permeable asphalt pavement, the asphalt mixture of 2% ZnO+2% DTDM was used as the base material, and the effects of compounding different contents of SBR fibers on the performance of modified asphalt mixtures were investigated by means of the water-soaked Marshall test, freeze-thaw splitting test, rutting test, and beam bending test under the framework of two-dimensional numerical modeling and multidimensional data analysis. The specific descriptions are as follows:

4.1. Analysis of Submerged Marshall Tests

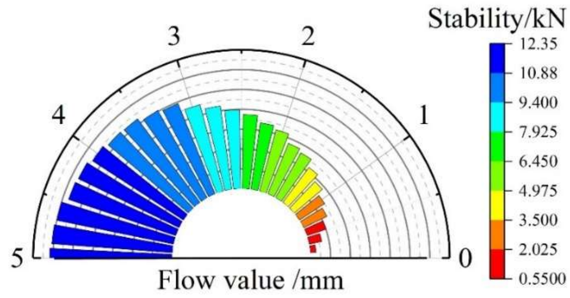
When the automatic Marshall tester is used, the data collected by the computer is plotted as the pressure-deformation curve, or the load-deformation curve is recorded automatically by the X-Y recorder, the curve is prolonged in the tangent direction and the horizontal coordinate intersects at O1, which is the corrected origin, and the deformation corresponding to the maximum value of load is taken as the flow value from O1, and the maximum load is the stability (MS), and the maximum load is the stability (KN), which is measured by kN, and the accuracy is 0.01KN. The maximum load is the stability (MS), which is measured in kN and accurate to 0.01 KN. Fig. 1 shows the pressure-deformation curves plotted with the data collected by the computer, in which (a)~(f) are the six kinds of modified asphalt compounded with fibers, the radian is the streaming value in mm, and the pole diameter is the maximum load in KN, and the results of the stability and streaming test results are shown in Table 7, which were collected for six kinds of modified asphalt compounded with fibers, and the maximum load in mm. pressure data for each of the six types of fiber-mixed modified asphalt (mentioned in subsection 2.2.3 above). The specification stipulates that the stability of asphalt crushed stone mixtures in the range of AC-13, 16 and 20 grades for general (except for highways and primary roads) graded highways is generally not less than 5KN, and the flow value is generally in the range of 2-5mm. it can be clearly seen that the stability and the flow value satisfy the specification, and in addition, it is also found that the stability and the flow value change with the change of compounded fibers (SBR), and the stability and the flow value gradually increase. The stability and flow values gradually increase, which can be interpreted in another way that as the doped fiber becomes larger (SBR concentration increases from 2% to 12%), the corresponding stability and flow values will also become larger. In summary, although after 48 hours of soaking, modified asphalt mixtures with the increase in the concentration of blended fibers, stability and flow values show a monotonically increasing trend, indicating that the blended fibers have a promotional effect on the water stability of modified asphalt mixtures.



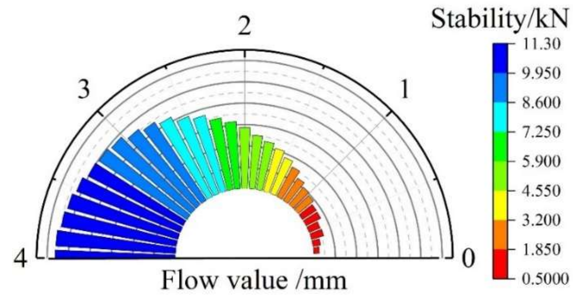
(a)2%ZnO+4%DTDM



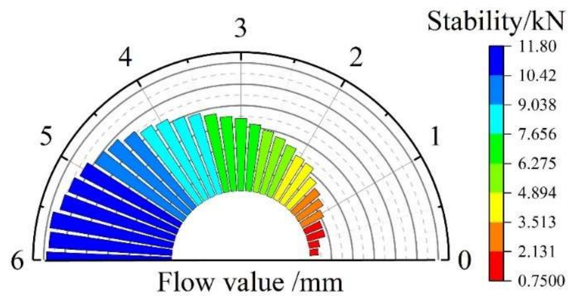
(b)2%SBR+2%ZnO+2%DTDM



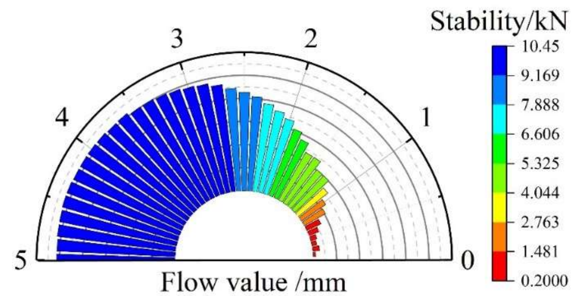
(c)4%SBR+2%ZnO+2%DTDM



(d)6%SBR+2%ZnO+2%DTDM



(e)8%SBR+2%ZnO+2%DTDM



(f)10%SBR+2%ZnO+2%DTDM

Fig. 1. Pressure deformation curve

Table 7. Stability and flow value test results

Name	Stability (MS)	Unit	Flow value (FL)	Unit
2%ZnO+4%DTDM	10.72	KN	2.56	mm
2%SBR+2%ZnO+2%DTDM	10.86	KN	3.88	mm
4%SBR+2%ZnO+2%DTDM	11.54	KN	4.55	mm
6%SBR+2%ZnO+2%DTDM	11.67	KN	4.68	mm
8%SBR+2%ZnO+2%DTDM	12.71	KN	4.86	mm
10%SBR+2%ZnO+2%DTDM	12.76	KN	4.98	mm

4.2. Analysis of freeze-thaw splitting test

Combined with the content of the above subsection 3.2.2, six kinds of modified asphalt mixtures compounded with fibers were subjected to freeze-thaw cycles to determine the strength ratio of the mixture specimens before and after being subjected to water damage, in order to evaluate the water stability of asphalt mixtures, and the results of the analysis of freeze-thaw splitting test are shown in Table 8. Non-specified, the test temperature of 25 ℃, loading rate of 50mm/min, remove the above six kinds of compound fiber modified asphalt mixture, immediately according to this specification T0716 with a loading rate of 50mm/min splitting test, to get the maximum value of the test. On the basis of the use of formula (5) to calculate the six kinds of modified asphalt mixtures mixed with fiber freeze-thaw splitting ratio. It can be clearly seen that the value of freeze-thaw splitting test strength to meet the specification requirements (freeze-thaw splitting test strength greater than 70.00%), in addition, when gradually adding compound doped fibers, freeze-thaw cycle after the splitting strength of the first increase and then decrease, when the fiber doping is too much, the splitting strength of the post-freeze-thaw drop significantly, a very good reveal compound doped fibers on the water-resistant properties of modified asphalt mixtures, which is the true purpose of this test. This is the real purpose of this test. The water stability performance of asphalt mixture is related to many factors, depending on the adhesion of asphalt and aggregate, the thickness of asphalt film and the void ratio of the mixture, etc. The water resistance of modified asphalt mixtures with six kinds of compounded fibers can also consider the above three factors. The effective service time of the existing highway generally failed to reach the design service life, often due to the lack of water resistance of the asphalt concrete surface layer caused early water damage to the pavement, so that the highway in the opening of 2-3 years there will be obvious potholes, loose and other phenomena, which has become one of the main forms of highway damage to the asphalt concrete pavement, which puts forward the requirements of water stability of the asphalt pavement. Asphalt pavement water resistance, that is, the ability to resist damage by water erosion. For asphalt pavement, in addition to load and moisture and other external conditions, water resistance is mainly determined by the asphalt mixture resistance to water damage, water immersion Marshall test, freeze-thaw split test can be used to evaluate the asphalt mixture resistance to water damage.

Table 8. Results of Dongrong splitting test

Name	Freeze-thaw cycle	No freeze-thaw cycle	Strength of freeze-thaw splitting test
2%ZnO+4%DTDM	1.11MPa	1.25MPa	88.80%
2%SBR+2%ZnO+2%DTDM	1.18MPa	1.48MPa	79.73%
4%SBR+2%ZnO+2%DTDM	1.05MPa	1.15MPa	91.30%
6%SBR+2%ZnO+2%DTDM	0.76MPa	1.08MPa	70.29%
8%SBR+2%ZnO+2%DTDM	0.74MPa	0.97MPa	75.24%
10%SBR+2%ZnO+2%DTDM	0.79MPa	0.94MPa	83.52%

4.3. Rutting test analysis

JTG F40-2004 “highway asphalt pavement construction specifications” provides: heavy traffic sections of the large pore open-graded drainage asphalt wearing course mixture and modified asphalt mixture rutting test stability requirements for the 3000 times / mm, this test also requires the same compound fiber high-viscosity permeable modified asphalt mixture rutting test stability for the 3000 times / mm, the test results are shown in Table 9. /mm, the rutting test results are shown in Table 9. The dynamic stability of each group of specimens is greater than 3000 times/mm, all in line with the specification. In the group doped with fiber, the high-temperature rutting stability is greatly improved compared with the data of group 1. Especially in group 2, the value of the dynamic stability is 6004 times/mm when doped with SBR compound fiber with a mass fraction of 4%, and with the increasing mass fraction of SBR compound fiber, the dynamic stability shows a monotonically increasing tendency. It was concluded that when the SBR doped fibers were uniformly dispersed in the permeable asphalt mixture, the SBR doped fibers had good chemical properties, which could improve the structural stability of the fiber spatial network, effectively preventing the slippage of the mixture particles, and the stabilization of this internal structure maintained the stability of the physical properties of the modified asphalt mixture on the whole.

Table 9. Rutting test results

Asphalt type	Name	Dynamic stability/(time·mm^{-1})
Blending 1	2%ZnO+4%DTDM	5218
Blending 2	2%SBR+2%ZnO+2%DTDM	6004
Blending 3	4%SBR+2%ZnO+2%DTDM	6546
Blending 4	6%SBR+2%ZnO+2%DTDM	6724
Blending 5	8%SBR+2%ZnO+2%DTDM	6943
Blending 6	10%SBR+2%ZnO+2%DTDM	6967

4.4. Analysis of trabecular bending tests

The low-temperature crack resistance of asphalt concrete in cold climates refers to its ability to resist cracking and crack extension at low temperatures. In cold regions, especially in winter, pavements may face challenges such as cold temperature-induced shrinkage, freeze-thaw cycles, etc., so low-temperature crack resistance is one of the key properties to safeguard the durability and performance of asphalt concrete pavements. Low-temperature performance tests are an important means of evaluating the performance of asphalt concrete in cold climates. These tests are designed to examine the modulus of elasticity, cracking resistance, fracture toughness, and other metrics of asphalt concrete under low-temperature conditions to ensure that pavements will maintain their durability and minimize cracking and damage during the cold season.

The trabecular flexural test is a test method used to determine the flexural properties of materials, and this test is commonly used to study and evaluate the flexural properties of thin, weak or coated materials. The trabecular bending test provides an effective means of evaluating the bending properties of asphalt concrete, which helps to determine the deformation and cracking behavior of asphalt concrete under bending loading under actual conditions of use, provides a means of simulating bending loading under actual conditions of application, and contributes to a better design and optimization of pavement structures, as well as ensuring that the asphalt concrete produced meets the requirements of the design and specifications by monitoring the bending properties of the material. In accordance with the Test Procedure for Asphalt and Asphalt Mixture in Highway Engineering (JTG E20-2011), the molded rutted plate specimen is used as a small beam-shaped specimen, and the rutted plate mold with the size of 300mm×300mm×35mm is cut by the cutter to cut the specimen into a small beam specimen with the size of 250mm×30mm×35mm. The trabecular specimen is put into the freezer at -10℃ for a period of not less than 45min, and then put on the adjusted testing machine for testing after the temperature of the trabecular specimen reaches the requirement, record the load value when the trabecular specimen is pressed off, and note down the displacement of the trabecular specimen across the span shown by the strain gauge at this time, and calculate the bending modulus by using the formulae (7), (8), and (9), and the trabecular bending test The analyzed results are shown in Table 10. For example, the bending strength modulus of 2%ZnO+4%DTDM=10^6×14.31/2610=5482.76, and the same for the remaining ones. On the basis of 2% ZnO+4% DTDM, doped with 6% SBR, the flexural strength modulus increases from 5482.76 MPa to 6498.69 MPa, which is more prominent compared to other concentrations of SBR, indicating that the addition of suitable SBR fibers on the basis of modified asphalt mix has an enhancement effect on the flexural properties of asphalt mixes.

Table 10. Trabecular bending test analysis

Name	Flexural tensile strength(Mpa)	Ultimate flexural strain($\mu\varepsilon$)	Bending stiffness modulus(MPa)
2%ZnO+4%DTDM	14.31	2610	5482.76
2%SBR+2%ZnO+2%DTDM	15.67	2626	5967.25
4%SBR+2%ZnO+2%DTDM	16.83	2634	6389.52
6%SBR+2%ZnO+2%DTDM	17.41	2679	6498.69
8%SBR+2%ZnO+2%DTDM	17.53	2787	6289.92
10%SBR+2%ZnO+2%DTDM	17.72	2850	6217.54

5. Conclusion

In this paper, raw materials are selected, and on the basis of the preparation process, the modified asphalt blends are prepared with the corresponding equipment, and a two-dimensional numerical model is constructed. Through the water immersion Marshall test, freeze-thaw splitting test, rutting test, beam bending test, respectively, to test the different content of fiber on the modified asphalt mix water stability, water resistance, high temperature, bending effect. When the compound fiber concentration increased to 10%, the corresponding stability and flow value also showed a monotonically increasing trend, with the values of 12.76 KN and 4.98 mm, respectively.In addition, in the freeze-thaw splitting test, rutting test, and beam bending test, it also showed that the compounded fibers improved the performance of modified asphalt mixes.

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