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Properties of Nano-montmorillonite Modified Asphalt Mixture Isolation Layer

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Abstract: With the large-scale construction of advanced roads, the requirements for the performance and durability of asphalt pavements are getting higher and higher, and improving the performance of existing asphalt materials is an important basis to meet this requirement. Factors that affect the performance and service life of asphalt pavements include the aging resistance of the asphalt and the compositional design of the mix. Montmorillonite has a very wide range of applications, especially inorganic and organic modifications, which make it rich in many unique properties, further expanding the application field, especially in polymer layer nanocomposites. In view of this, this paper proposes the modification of asphalt mixtures with nano-montmorillonite and further explores the performance of MMT-modified asphalt through practical experiments on high-temperature rutting, low-temperature cracking, water resistance and fatigue resistance. The experimental results in this paper show that the addition of organic montmorillonite can significantly improve the water stability of asphalt mixtures and the improvement effect is most obvious when the addition amount is 6%.

1. Introduction

With the gradual deterioration of the natural environment around the world, rutting, spalling, cracking and other diseases have occurred, causing their service life to be far from the design life. For this reason, many experts and scholars at home and abroad have devoted themselves to the research and exploration of long-life asphalt pavement for many years to improve the performance of asphalt pavement and achieve the goal of long-life. Asphalt material plays an important role in asphalt pavement, and its performance has always been the focus of attention. If the performance of asphalt as a binder is not good, it is easy for the asphalt pavement to fail to achieve a breakthrough in road construction planning in the long run, and it is necessary to continuously renovate and maintain the road surface. Therefore, how to make the service life of asphalt pavement longer, reduce the occurrence of pavement diseases, and improve the economic benefits of road construction is a major challenge that needs to be solved at present.

The development of modified asphalt technology has driven the development of asphalt concrete pavement technology, enabling asphalt concrete to be used on roads in extreme climates, which was previously considered impossible. It is foreseeable that the application scale of modified asphalt will continue to increase, and research will also flourish. Due to its unique microscopic size effect, nanotechnology enables the nano-asphalt modification mechanism to improve the performance of asphalt at the microscopic scale, which is unmatched by other asphalt modification methods. Nano-modified asphalt is becoming a new economic growth point for the research and application of transportation materials, so it is very necessary to use nano-monomers to modify asphalt.

As traffic loads increase and the road service environment complicates, asphalt pavements are prone to rutting and cracking. However, conventional asphalt pavements do not adequately meet the needs of traffic development. There is an urgent need to develop high performance asphalt materials. Therefore, this paper proposes to study the modification of asphalt by nano-montmorillonite, and provides some theoretical support for asphalt modification technology by analyzing the performance of asphalt mixture.

2. Related Work

Since the publication of the patent in the UK in 2007, the research and practical application of modified asphalt pavements has attracted a lot of attention from researchers. Among them, Vivek A K compared the properties of bitumen mixes with the use of Montelite (MMT) clay nanoclay with sulfur as a modifier. Vivek A K's study focused on describing the physics as well as the strength properties of MMT clay nanoclay and sulfur modification of bitumen adhesives [1]. Shah P M aimed to assess effectiveness application of organic modifier Montelukast clay (OMMT) to plain bitumen binder as well as to styrene butadiene rubber (SBS) modified bitumen binder. Therefore, it can be concluded that OMMT addition to polymer modified binders (SBS) contributes to physical and rheological properties under conditions where the clay is dispersed in the binder at the nanoscale [2]. Vargas M A conducted rheological comparative trials of bituminous mixes with unmodified Montelite (Mt) and two organic modified Montelite. Softening point, permeability and rheology tests were used to characterize the binder properties of the mixes and to compare them with unmodified asphalt. The results showed TMOA amended bitumen exhibited better viscoelastic response and resistance to the rutting excavation [3]. The scholars have further proposed the application of nanomaterials for the modification of asphalt matrix, but most of them are mainly based on evaluation, and there is no specific application implementation process.

The theme of this paper is the performance research of nano-montmorillonite modified asphalt. And the related research was collected accordingly. In order to study the effect and mechanism of nano-montmorillonite (MMT) on the aging resistance of modified asphalt, Cui Y used SK90# base asphalt and 1%, 3% and 5% (mass ratio) nano-montmorillonite modified asphalt as samples to measure the aging resistance of nano-MMT modified asphalt by bitumen index and bent beam rheometer (BBR) test using three conventional methods. The results showed that nano-MMT significantly improved the changes of penetration, ductility and softening point, and the optimal dosage in the short-term aging stage was 0%-3%. Through AFM root-mean-square (RMS) roughness Sq and 3D images, it was found that the formed nano-MMT flakes and nanocomposite structures are the main reasons for the delayed aging effect [4]. Tan Z H added an organic muntjac (OMMT) into colloid modified asphalt (CRMA) for improving its high temp properties. aging resistance and storage stability. The results showed that the high temp property as well as the aging resistance improved with the increase of O content[5]. Lee E J investigated the silylation performance and optimal conditions of 3-aminopropyltriethoxysilane (APS) on cation exchange K-10 (NA-MMT-K). The results showed that the optimal conditions included the APS-MMT reaction time, and the APS stirring time before the APS-MMT reaction[6]. Feng Z prepared a storage stabilized styrene-ethylene/butylene-styrene (SEBS) modified (SM) bitumen by adding 4 mass/% of SEBS and 3 mass/% of organic muntjac (OMMT). The tests showed that the SOSM bitumen aged more easily and had higher elasticity after aging [7]. The above-mentioned related studies all require a complex research process, and there are certain influencing factors in the process. These influencing factors will cause differences in research results and affect the performance of materials.

3. Method of Montmorillonite Modified Asphalt

3.1. Modified Asphalt

The preparation of modified asphalt refers to adding one or more modified materials with special effects to the base asphalt. According to the special properties of raw materials, appropriate processing technology is adopted. Among many organic asphalt modifiers, polymer modifiers endow asphalt with good high and low temperature properties, fatigue resistance, adhesion, etc. [8-9]. It has become the most common of road asphalt modifiers, because it can be used to modify various polymers of asphalt according to different modifiers, which can generally be divided into three categories: rubber, thermoplastic rubber and plastic. The high temperature and low temperature properties of matrix asphalt modified with polymer materials are significantly improved, and the physical and rheological properties are also greatly improved [10-11]. However, polymer-modified asphalt has some disadvantages. In the preparation of polymer modified asphalt, the material being altered and the asphalt do not form a homogeneous system. Polymer modified asphalt is prepared in a very simple process and is therefore relatively susceptible to segregation. Polymer modified materials are more expensive. The modifiers themselves tend to deteriorate when exposed to the external environment for long periods of time and suffer from long-term performance degradation, which greatly reduces the service life of asphalt pavements [12-13].

3.2. Montmorillonite Structure

(1) Montmorillonite structure

Montmorillonite is the most widely studied type of layered silicate material, known as MMT. As shown in Figure 1, it has a 2:1 LS molecular structure, that is, each cell is sandwiched by a silicon-oxygen tetrahedral layer between aluminum (or magnesium) and oxygen (or hydroxy) octahedral layers. It consists of two layers with high rigidity between layers to prevent sliding [14-15].

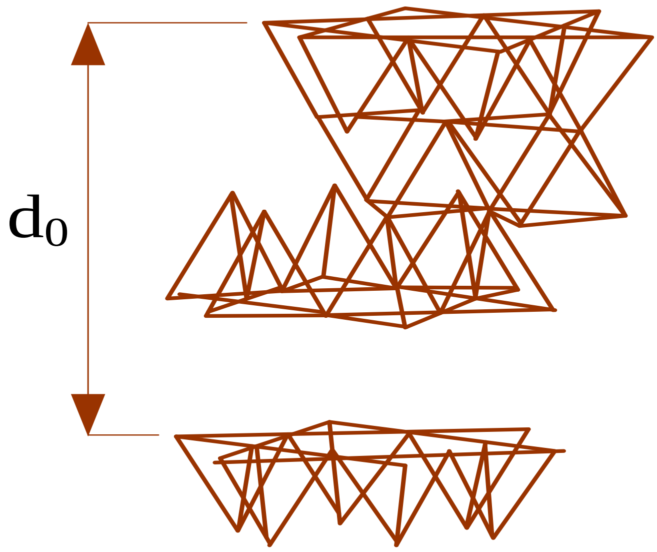


Figure 1. Schematic diagram of the molecular structure of montmorillonite

(2) Structure of montmorillonite polymer nanocomposites

As shown in Figure 2, montmorillonite polymer nanocomposites are generally classified into three categories according to the microstructure of the composites and the dispersion of montmorillonite flakes in the polymer matrix.

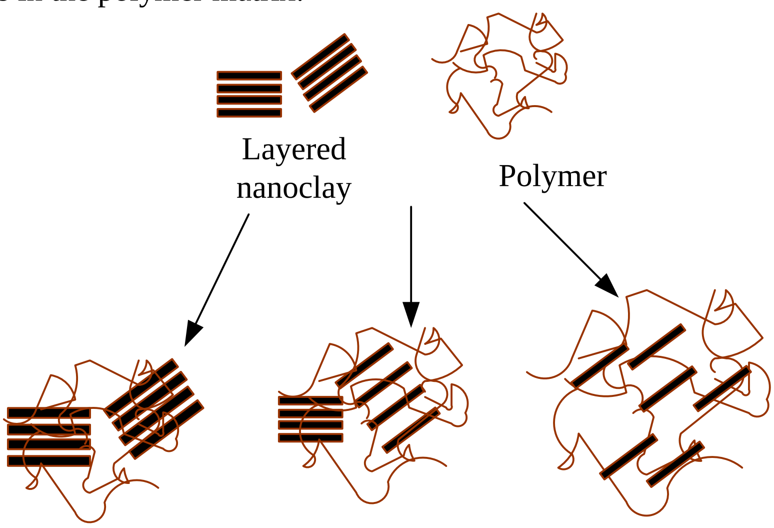


Figure 2. Schematic diagram of different types of montmorillonite polymers

3.3. Preparation Method of Montmorillonite Polymer Nanocomposites

Interlayers based on sheet-like structures of sheet silicates have emerged as an effective method for the preparation of montmorillonite polymer nanocomposites. Polymers and polymer monomers are intercalated in the sheet-like structure of sheet silicates [16-17]. This intercalation method generally has two methods.

(1) Intercalation polymerization: The polymer monomer is intercalated into the sheet silicate layer, and then in-situ polymerization is carried out using the heat of polymerization to overcome the Coulomb force between the sheet silicate layers, and the sheet silicate layer is exfoliated into nano-scale, thereby forming a chemically capable sheet silicate layer. A polymer matrix is obtained

using this method. It has been realized as a bonded composite [18-19].

(2) Polymer intercalation refers to the mixing of sheet silicates with polymer melts or solutions. Sheet silicates are exfoliated into nanoscale sheet-like structures by thermodynamics or mechanochemistry, which are uniformly distributed in the polymer matrix [20-21].

4. Nano-montmorillonite Modified Asphalt Experiment

4.1. Raw Materials

The asphalt raw material adopted for the present study is No. 90 Road petroleum bitumen, whose specific performance indexes are shown in Table 1.

Table 1. Properties of Asphalt

Pilot projects		result	skills requirement
Penetration		93	80-100
Softening Point		46	≥45
ductility		167	≥100
Flash point		330	≥245
density		1	Measured record
Solubility		99.7	≥99.5
Aging test	quality change	0.05	≥±0.8
	Penetration	77	≥57
	Residual ductility	22	≥20

The test results in Table 1 show that the technical performance of the asphalt raw material meets the performance requirements of the national road asphalt specification.

The specific technical properties of the smectite clays used in this study are shown in Table 2. Montmorillonite, as an additive of nanopolymer polymers, has good dispersibility and is widely used in the polymer material industry to improve the impact resistance, fatigue resistance and gas barrier properties of materials to improve the physical properties of polymers [22].

Table 2. Properties of nano-montmorillonite powder

project	Technical indicators
composition	Montmorillonite Organic Derivatives
Exterior	Off-white powder
Montmorillonite content	96%-98%
Apparent density	0.45g/cm3
Dry powder thickness	99.9%pass 200 mesh
Diameter/Thickness Ratio	200
Lamination thickness	⩽25
moisture content	⩽3

4.2. Organic Treatment of Montmorillonite

Asphalt is modified with montmorillonite, usually by organically treating the montmorillonite. Although the inorganic montmorillonite formed a structure separated from the asphalt after modification, many experiments showed that the organically treated montmorillonite formed a sandwich or exfoliated structure with the asphalt. This is because the organic amine salt has a good adsorption effect on the negative charge on the surface of the montmorillonite lattice layer, which makes the organic amine ion almost replace the inorganic cation between the montmorillonite layers, and the charge amount is equal. Organic montmorillonite has high lipophilicity and low surface free energy, which greatly improves its compatibility with bitumen.

The organic structure process is shown in Figure 3:

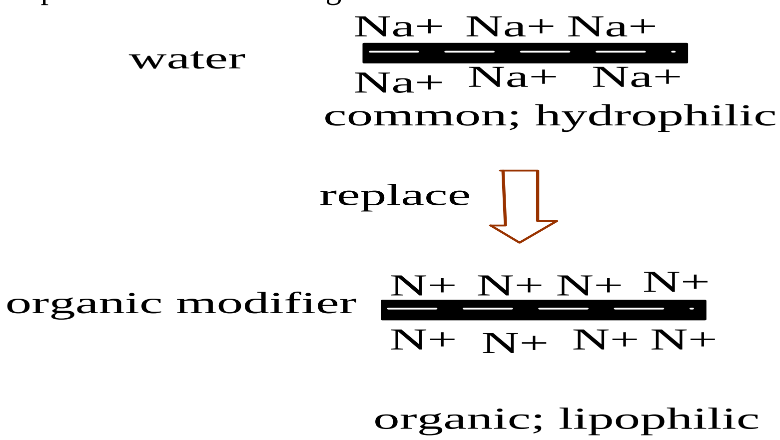


Figure 3. Schematic diagram of organic treatment

4.3. Preparation Technology of Nano-montmorillonite Modified Asphalt

The preparation of nano-montmorillonite-modified asphalt was mainly done by indoor high-shear method, and the equipment used was mainly high-shear emulsifier. In the process of preparing nano-montmorillonite modified asphalt, the most important factors are shearing time and shearing temperature. In the process of mixing montmorillonite and base asphalt, too high processing temperature or too long processing time will lead to thermal aging and oxidative aging of asphalt, reducing its performance. The performance of asphalt is unstable and it is difficult to form nanocomposites. Therefore, the appropriate stirring temperature and stirring time must be determined.

(1) Processing time: Under the fixed amount of modifier (4%) and processing temperature (160 ℃), the effect of processing temperature on the basic properties of organic montmorillonite nano-modified asphalt is shown in Table 3.

Table 3. Effect of processing time on physical properties of asphalt

physical index	blank group	1h	2h	3h	4h
Penetration	56.6	55.1	54.5	52	48.4
Softening Point	47.9	49	51.3	51.8	52.2
ductility	103	79	66	58	44
Viscosity	491	502	515	523	537

(2) Processing temperature

With the condition of fixed modifier dosage (4%) and processing time (2h), Table 4 shows the effect of processing temperature on the basic physical properties of organic montmorillonite nanomodified asphalt.

Table 4. Physical effects of processing temperature on modified asphalt

physical index	blank group	140℃	150℃	160℃	170℃
Penetration	56.6	55.2	54.1	52	42
Softening Point	47.9	49	50.4	51.2	54.2
ductility	103	94	90	82	77
Viscosity	492	499	514	531	556

It can be seen from the experimental results that in the process of preparing layered silicate nano-modified asphalt, one of the indexes of processing temperature and processing time is constant, and the other is gradually increasing, which has a great influence on the basic physical properties of asphalt. Therefore, it is very important to choose the appropriate processing temperature and processing time. The test results show that the correct processing conditions should be as follows: the test temperature is 160℃ and the stirring time is 2h. Under these conditions, the nanoclay modified asphalt with the best performance can be prepared.

In this study, 2%, 4%, 6% and 8% nano-montmorillonite modified asphalts were prepared in the laboratory in order to determine the optimal amount of montmorillonite.

(1) According to the test specification, calculate the mass of base asphalt m1 and montmorillonite m2 required for the test.

(2) Weigh the base asphalt and montmorillonite according to the test conditions and place them in a water basin.

(3) Put a clean metal basin on the electronic scale, set the data of the electronic scale to zero, pour in the heated asphalt with a mass of m1, continue stirring, use a thermometer to detect the temperature of the asphalt, and heat the asphalt to 160 ℃. Add nano-montmorillonite with a mass of m2 to the asphalt. Slowly add the asphalt, and control the speed of the high-shear emulsifier at about 3000 rpm. Keep the temperature of the asphalt at 160 ℃, and the adding time should not exceed 30 minutes.

(4) When no white powder can be seen, that is, most of the montmorillonite and asphalt have been fused. Adjust the speed of the shearing emulsifier to about 5000 rpm, and continue to shear for 90 minutes. The temperature during the stirring process should be strictly controlled at around 160 ℃. The temperature cannot be too high or too low. At high temperature, montmorillonite will cause asphalt aging, and at low temperature, the dispersion degree of matrix asphalt will be affected. After a period of time, the shearing machine is turned off, and the nanoclay-modified asphalt in the metal container is poured into the relevant test molds to determine the microstructure and properties of the modified asphalt for physical testing.

(5) After the modification is completed, before the temperature of the shearing machine drops too low, the shearing machine needs to be quickly wiped with paper for the next use. The same procedure is used for the base bitumen as a blank comparison sample in order to compare tests to determine the optimum montmorillonite blend. This will help in comparisons for future tests.

5. Application of Modified Asphalt

The pavement properties of asphalt mixtures mainly include resistance to hot rutting excavation, cold cracking, water resistance and fatigue resistance. In this chapter, the performance of modified asphalt mixtures is studied and analyzed.

5.1. Determination of Asphalt Application Ratio

(1) Determination of asphalt mixture ratio

The asphalt mixture ratio used is Superpave 12.5, based on the American SHRP high-performance asphalt concrete design method. The synthetic particle size of the asphalt aggregate in this study is shown in Table 5 through the test and particle size design, and this synthetic particle size is used in the performance test and analysis of the asphalt mixture in this paper. This composite particle size is used for performance testing and analysis of asphalt mixtures.

Table 5. Mixture ratio design table

Aperture	19	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	percentage
19-9.5	100	91.2	32.5	0.4	0.3	0.3	0	0	0	0	28%
9.5-4.75	100	100	99	24.1	1.1	0.9	0.8	0	0	0	42%
4.75-2.36	100	100	100	100	98	51.9	33	21.9	13.9	8.6	8%
<2.36	100	100	100	100	99.6	88	63	41	25	16.2	18%
Mineral powder	100	100	100	100	100	100	99.5	99	97	83.5	4%

(2) Determination of the optimal amount of asphalt

The amount of bitumen is determined by varying the content of asphalt binder under the design aggregate structure, while comparing the mix standards to obtain acceptable volume and compaction characteristics.

The specific representation of the calculation process is as follows:

M_g represents the gross volume relative density of asphalt mixture aggregate, and its calculation formula is:

$$M_g = \frac{\sum D_n}{\sum D_n / M_n} \tag{1}$$

D_n represents the proportion of a single aggregate in the total aggregate, and the relative density of the gross volume of a single aggregate is represented by M_g.

The calculation formula of the effective relative density M_{xe} is:

$$M_{xe} = \frac{100 - D_i}{[\frac{100}{M_{cc}} - \frac{D_i}{M_i}]} \tag{2}$$

In the formula, D_i is the amount of asphalt raw material. The relative density of the bituminous material is denoted by M_i, and the maximum theoretical relative density of the bituminous mixture sample is denoted as M_{cc}.

$$M_{cc} = \frac{100}{\frac{D_e}{M_g} - \frac{D_i}{M_i}} \tag{3}$$

D_e represents the amount of aggregate used.

The percentage absorption of bitumen D_{ir} is:

$$D_{ir} = \frac{100M_i(M_k - M_{ir})}{M_k M_{ir}} \tag{4}$$

The relatively effective bitumen content D_{in} is:

$$D_{in} = D_i - [\frac{P_{ir}D_e}{100}] \tag{5}$$

Mineral material gap KMA is:

$$KMA = 100 - [\frac{D_{Mi}D_e}{D_{ir}}] \tag{6}$$

In the formula, D_{Mi} is the gross volume relative density of the asphalt mixture.
The interstitial ratio 1 is:

$$T_u = 100[\frac{M_{cc} - D_{Mi}}{M_{cc}}] \tag{7}$$

At this time, the porosity of asphalt is expressed as:

$$LT_u = 100[\frac{KMA - T_u}{KMA}] \tag{8}$$

The formula for calculating the volume fraction of asphalt is:

$$T_f = \frac{D_{mi}G_i}{M_i}] \tag{9}$$

The gap ratio of the mineral material is expressed as:

$$KMA = T_u + T_f \tag{10}$$

At least two specimens received the estimated binder content, binder content, four different binder content ±5%, and 1% compression. Two parallel tests were also performed to determine the maximum theoretical density for the estimated number of binders. The optimum amount of bitumen is determined. The technical requirements for the design of the asphalt mixture used in the test are listed in Table 6.

Table 6. Design requirements for asphalt mixtures

project		Design requirements
compactness	N9	<89
	N125	96
	N205	<98
H125	Tf	4
	KMA	>14
	LTu	65-75
Powder to glue ratio		0.8-1.6

5.2. Data of Rutting Test

Dynamic stability is the most important index for evaluating high temperature rutting resistance performance, and it is an auxiliary test index for asphalt mixture mix ratio test, which reflects the ability of pavement to resist deformation under dynamic load.

Its meaning is to generate 1mm of deformation wheel repeated loading times. The formula for calculating dynamic stability is:

$$F_d = \frac{(s_1 - s_2) \cdot I}{c_2 - c_1} \times Y_1 \times Y_2 \tag{11}$$

The deformation corresponding to time S1 is C1, and C2 is the deformation corresponding to S2. Y_1 is the type coefficient of the testing machine, Y_2 is the test coefficient, and I is the rolling speed of the test reciprocating wheel, generally 42 times/min.

The test temperature was 60 ℃. Figure 4 records the corresponding dynamic stability and cumulative deformation of the asphalt mixture under different addition amounts of montmorillonite.

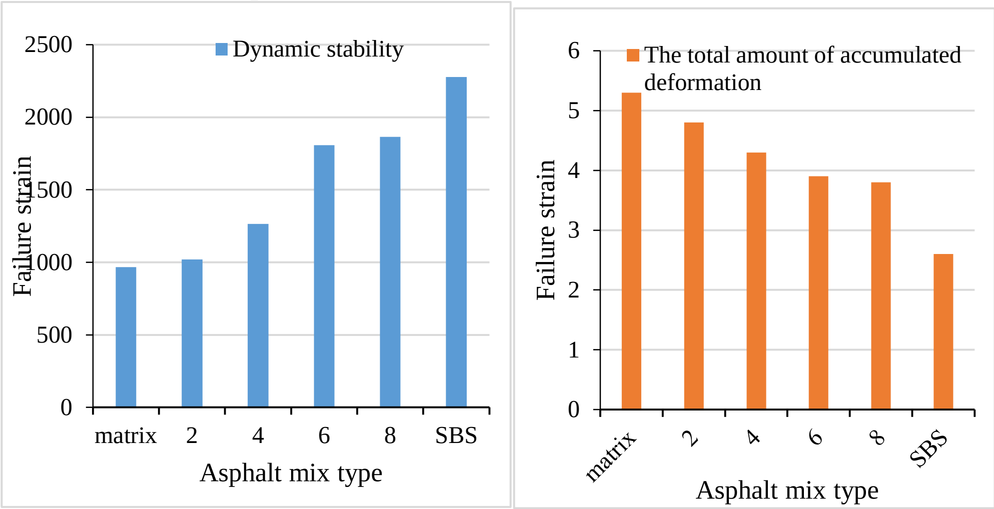


Figure 4. Data graph of rutting test

Figure 4(1) shows the dynamic stability changes of different types of asphalt mixes in the rutting excavation test. The dynamic stability of the asphalt mixes gradually increased when the organic montmorillonite content changed to 0.6% and the increasing trend became gradually larger, indicating that OMMT can improve the high-temperature stability of the matrix asphalt mix. The difference between its dynamic stability and that of the matrix asphalt mixture was found to be very small. The dynamic stability of the asphalt mix was essentially the same, showing a slight increase during the variation of the OMMT content from 6% to 8%. It can be seen that the dynamic stability of the asphalt mixes does not necessarily increase with the increase of the organic montmorillonite content. The dynamic stability of the asphalt mixes containing OMMT was better than that of the base asphalt. Figure 4(2) represents the variation of cumulative deformation with asphalt mixture type in the rutting excavation test. The higher the stability, the smaller the cumulative deformation and the higher the resistance of the asphalt mixture to rutting excavation. In the asphalt mixture containing OMMT, the cumulative deformation at 6% addition was the smallest and significantly smaller than that of the base asphalt. Therefore, the nano-montmorillonite asphalt mixture can improve the rutting excavation resistance of asphalt pavement. When the addition amount of montmorillonite was lower than 6%, the cumulative deformation showed a large change. When the addition amount is higher than 6%, the cumulative change is relatively flat and basically unchanged, however, for base asphalt, OMMT can still effectively reduce the rutting deformation.

5.3. Freeze-thaw Split Test Results

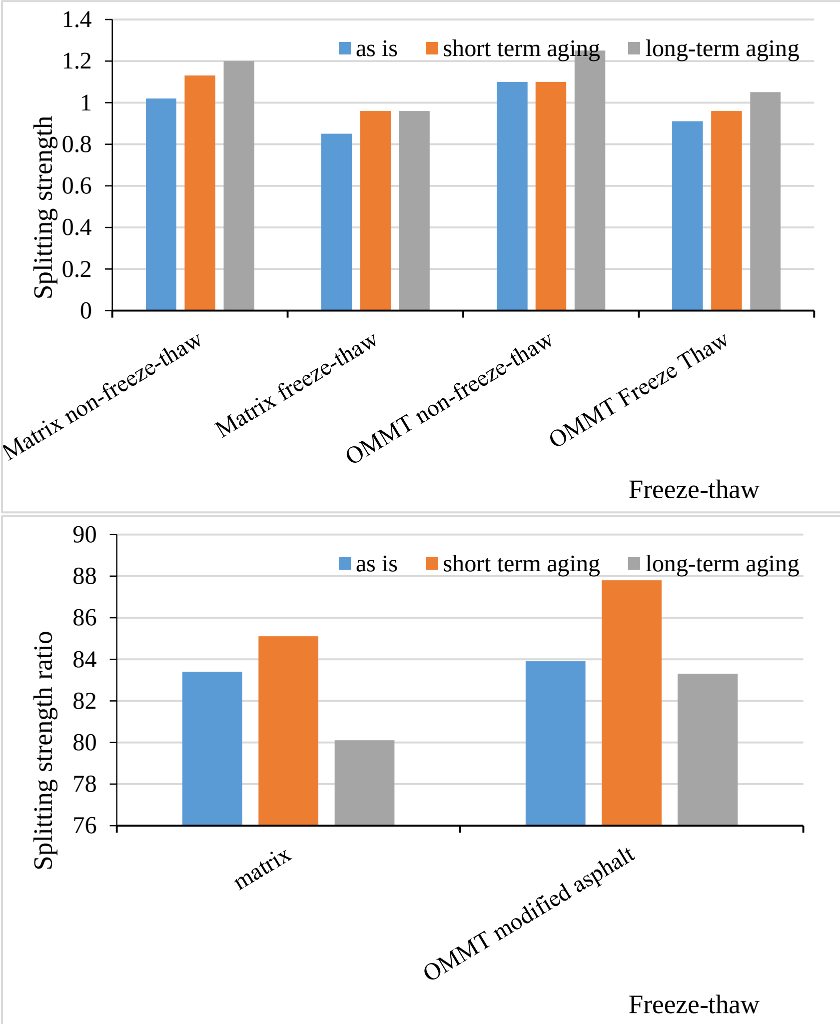


Figure 5. Freeze-thaw splitting test results of base asphalt and montmorillonite modified asphalt mixture

The cracking strength of various asphalt mixes decreased significantly after freeze-thaw. The comparative graph of freeze-thaw strength ratio is shown in Figure 5. It can be seen from the graph that the freeze-thaw strength ratio of pre-aged asphalt mixes increased slightly from 83.4% to 83.9% after the addition of nano-montmorillonite powder, but the change was not significant. The freeze-thaw strength ratio of the aged modified asphalt mixture increased significantly from 85.1% to 87.8% in the short-term aging and from 80.1% to 83.3% in the long-term aging. The results indicated that the OMMT content of nano-montmorillonite powder could significantly improve the water stability of the aged asphalt mixture.

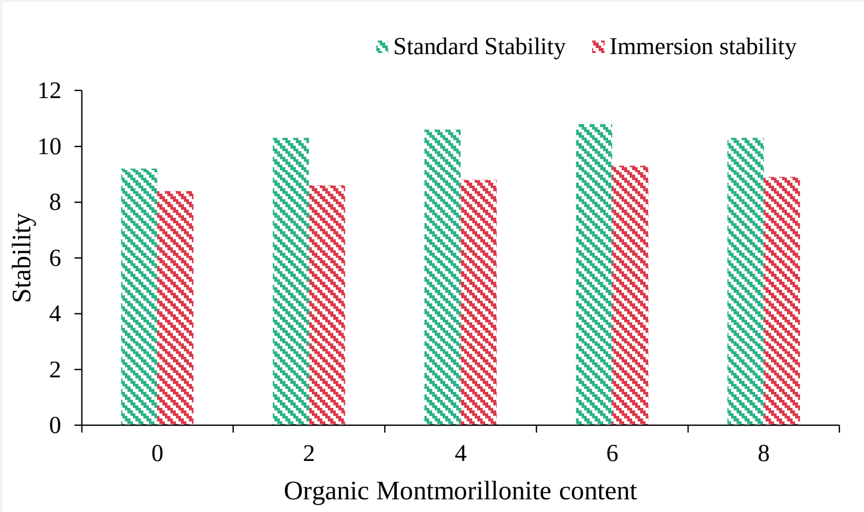
5.4. Water Immersion Marshall Test

The test method of the immersion Marshall test differs from the standard Marshall method in that the specimen must be placed in a constant temperature water bath at 60 ℃ for 48 hours. The residual stability of the specimen is calculated using this formula

$$CL_0 = \frac{CL_1}{CL} \cdot 100 \qquad (12)$$

Among them, CL_0 is the residual stability of the submerged specimen, and CL_1 is the stability of the submerged specimen after 48 hours.

Marshall immersion tests were performed on two graded mixes with different doses of high modulus agents added. The final data of the test are shown in Figure 6.



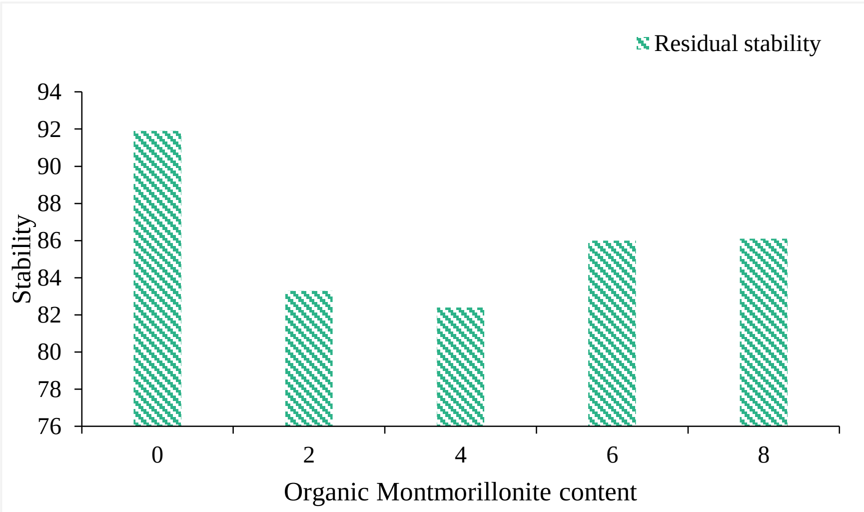


Figure 6. Data plot of immersion Marshall test

It can be seen from the bar graph 6(1) that the standard stability and the water immersion stability tend to increase during the addition of organic montmorillonite from 0% to 6%. When only 6% was added to the maximum, the rate of increase was slower, thereby increasing the strength of the mix. The amount of addition has a clear effect, but the intensity is not proportional to the increase in the amount of addition. When montmorillonite was added continuously at 8%, the stability of the mixture decreased, However, it is still greater than the strength of the base asphalt mixture. The line decreases and then increases with the increase of OMMT dosage in Figure 6(2), and basically remains stable. The minimum residual stability corresponds to 4% of the added amount, which still meets the specification requirements. In summary, the addition of organic montmorillonite can significantly improve the water stability of asphalt mixes, and the improvement is most obvious when the addition amount is 6%.

5.5. Fatigue Life of Asphalt Mixture

Asphalt pavement is constantly subjected to pressure and tension during use. It is easy to produce cracks under the pressure of tension. The ability of asphalt mixture to withstand tensile action is one of its important road properties. Indirect tensile test can better characterize the tensile properties of asphalt mixture. At present, indirect tensile tests are mostly used to study the tensile properties of asphalt mixtures. Since asphalt mixtures are temperature sensitive materials, indirect tensile tests at different temperatures and loading rates are used to analyze and evaluate the cold crack resistance of asphalt mixtures.

The relationship between fatigue life and stress of asphalt mixtures can be expressed by the fatigue formula.

$$P_f = R[\frac{1}{\alpha_0}]^i \tag{13}$$

In the formula, P_f represents the number of times of repeated load action when the specimen is fatigued in the process, and α_0 represents the total stress applied in the process. The others are coefficients determined by experiments.

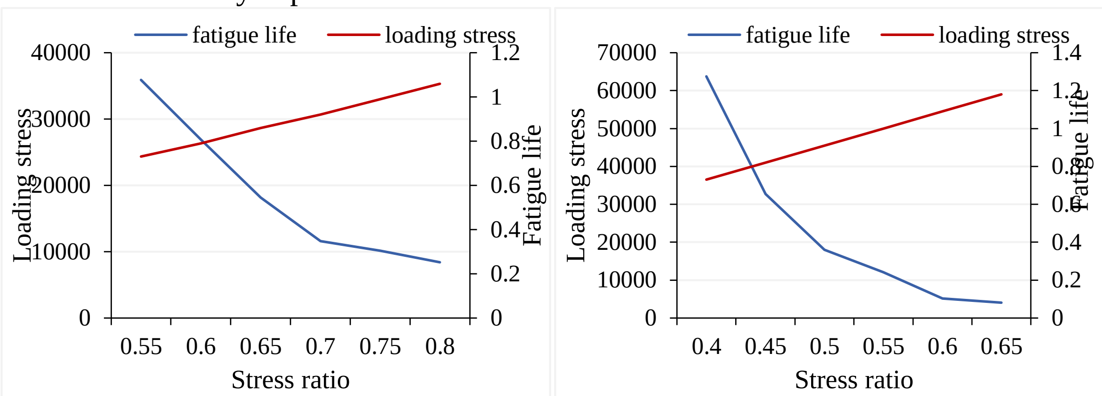


Figure 7. Indirect tensile fatigue of unmodified asphalt at 5 ℃

Figure 7 shows the variation of indirect tensile fatigue at 5 ℃ for the unmodified asphalt mix and the OMMT modified asphalt. The trend of the data in the figure shows that the tensile ratio of the modified asphalt mixture is lower than that of the original asphalt matrix.

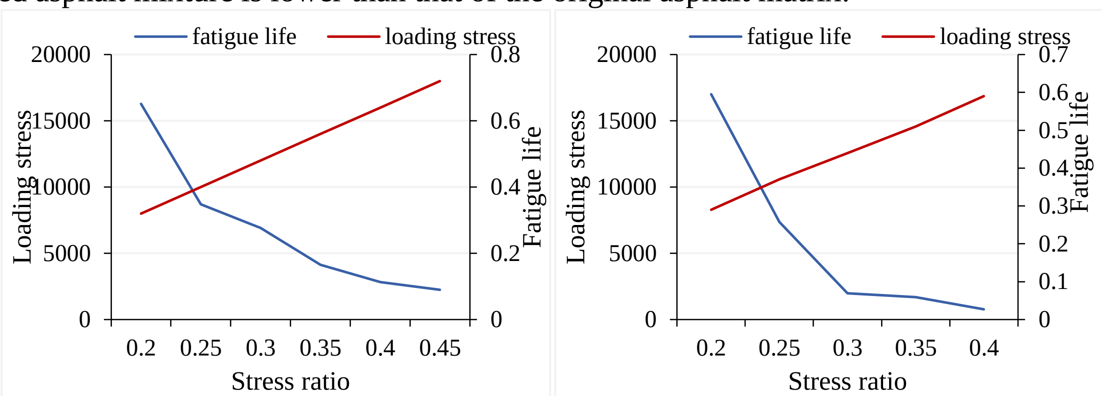


Figure 8. Indirect tensile fatigue of OMMT-modified asphalt at 20 ℃

Figure 8 shows that the nano-montmorillonite fatigue life of modified asphalt mixes is significantly higher than that of unmodified asphalt mixes, indicating that the addition of nano-montmorillonite can improve their fatigue life. The improvement of fatigue life was also more obvious at lower stress levels. At an applied stress of 1 MPa, the fatigue life of the modified asphalt mixture was lower than that of the unmodified mixture. In particular, at the test temperature of 20 ℃, the fatigue life of nano-montmorillonite modified asphalt mixture was lower than that of unmodified mixture.

The calculation process of the regression coefficient of the fatigue formula is:

The fatigue formula of the matrix at 5 ℃ is expressed as:

$$P_f = 9673.9 \times \left(\frac{1}{\alpha_0}\right)^{4.1} \tag{14}$$

The fatigue formula of the matrix at 20 ℃ is expressed as:

$$P_f = 1010.9 \times \left(\frac{1}{\alpha_0}\right)^{2.5} \tag{15}$$

The fatigue formula of asphalt with MMT added at 5 ℃ is:

$$P_f = 10204.7 \times \left(\frac{1}{\alpha_0}\right)^{5.8} \tag{16}$$

The fatigue formula of asphalt with MMT added at 20 ℃ is:

$$P_f = 71.3 \times \left(\frac{1}{\alpha_0}\right)^{4.5} \tag{17}$$

The results of least squares fitting of the fatigue formula parameters for unmodified asphalt and nanomontane-modified asphalt mixes can be obtained. It can be seen from Table 7 that the fatigue life of the nano-montmorillonite modified asphalt mixes was significantly improved compared to the unmodified asphalt mixes. In addition, it was found that the improvement in fatigue life of nano-montmorillonite modified asphalt mixes became better as the nano-montmorillonite content increased. The table also shows that the improvement effect of nano-montmorillonite is more pronounced at lower stress levels.

Table 7. Regression coefficients

type of material	Regression coefficients			
		R	n	K^2
matrix	5℃	9673.9	4.1	0.98
	20℃	1010.9	2.5	0.99
MMT	5℃	1024.7	5.8	0.989
	20℃	71.3	4.5	0.97

6. Conclusion

In this paper, modified asphalt containing different amounts of nano-montmorillonite was prepared. The performance changes of asphalt and asphalt binder before and after aging were investigated. The residual permeability, softening point elevation, viscosity and residual ductility of the asphalt binder, which affect the pavement performance, were comparatively analyzed. The results showed that the softening point and viscosity of the asphalt increased and the pinhole permeability decreased after the addition of montmorillonite. Montmorillonite significantly improved the high temperature properties of asphalt. It was found that the softening point and aging index of asphalt decreased with the increase of montmorillonite content. With the addition of nano-material modifier and the higher the total amount added, the content increased more obviously, indicating that the addition of nano-montmorillonite powder can improve the anti-aging performance of asphalt. Moreover, the ductility of modified asphalt was higher than that of base asphalt, and the residual ductility value increased with the increase of montmorillonite content. This indicated that the modified asphalt with nano-montmorillonite can improve the condition of the base asphalt after aging. The aging resistance was found to be better than that of asphalt.

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Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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