Volume 15, Issue 1, 152408 (1-12)

International Journal of Industrial Chemistry (IJIC)

https://dx.doi.org/10.57647/j.ijic.2024.1501.08

Performance of composite modified asphalt based on nano organic montmorillonite and silica

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Original Research

Received:
12 September 2023
Revised:
1 November 2023
Accepted:
18 November 2023
Published online:
15 March 2024

Abstract:

Asphalt pavement will inevitably face the problems of thermal aging and ultraviolet aging, so in order to improve the aging performance of asphalt and improve its service life, the modified asphalt based on nano organic monundedillonite and silica is proposed. Compared with the matrix asphalt, the penetration, ductility, softening temperature, and viscosity of modified asphalt were improved. The lowest penetration was 64 dmm, while the highest ductility, softening temperature, and viscosity were increased to 11.6cm, 54.1 °C, and 1970cp. Meanwhile, when the temperature was 64 °C, its irreversible creep compliance did not exceed 0.8 kPa^{-1}. When the temperature was −12 °C, the creep rate did not exceed 0.45. All were below the matrix asphalt. For the thermal aging performance, compared to matrix asphalt, the complex shear modulus aging index was decreased. The complex shear modulus aging index of short-term and long-term thermal aging was reduced by 44% and 23% respectively. For ultraviolet light aging performance, the growth rate of Brinell rotation viscosity for OMMT/SiO_2 modified asphalt did not exceed 0.7. The above results indicate that nano organic montmorillonite and SiO_2 can effectively improve the physical properties, thermal aging resistance, and ultraviolet light aging performance of asphalt.

Keywords: Organic montmorillonite; SiO_2; Modified asphalt; Old thermal performance; Rheological properties

1. Introduction

Asphalt, as a product of petroleum distillation, is widely used in bridge and road construction. More than 80% of urban roads worldwide use asphalt as the construction material. As an organic compound, asphalt is mainly composed of asphaltene and resin. Next are high boiling mineral oil and small amounts of oxygen, sulfur, and chlorine compounds. Due to the influence of its composition, asphalt is susceptible to factors such as high temperature, light, and water vapor, leading to asphalt aging. Therefore, to improve the service life of asphalt pavement, the aging resistance of asphalt should be generally improved [1, 2]. The commonly used methods to modify the aging resistance are adding antioxidant, antioxidant and modifier. The main principle is to retard the aging rate by isolating oxygen or ultraviolet light (UV) radiation. Although various modifiers can improve high-low temperature (HLT) performance, they are often difficult to simultaneously improve HLT performance. The modified asphalt gradually disappears after being subjected to UV, temperature, and load. Asphalt will still experience aging issues [3–6]. Nanomaterials undergo a series of changes in their polymers, leading to significant changes in their properties. Therefore, nanomaterial modified asphalt has become a current research hotspot. Nanomaterials improves the HLT performance of asphalt simultaneously. It also alters the asphalt structure at the microscopic level. Therefore, improve asphalt performance, and extend the operation life, a modified asphalt based on nano organic montmorillonite (OMMT) and SiO_2 is proposed in the study. The innovation of this research is that the use of OMMT to improve the thermal aging resistance of asphalt, and the addition of nano SiO_2 to reflect UV light to improve the UV aging resistance of asphalt. In addition, the properties of OMMT / SiO_2 modified asphalt were tested, and the best ratio of modified asphalt was obtained.

The research has four parts. The first describes the research status of modified asphalt and nanomaterials. The second part designs a modified asphalt testing method for OMMT/SiO_2. The third part analyzes the experimental

Notation index

R_r	Resilience rate
γ_r	Strain that can be recovered
γ_0	Initial strain value
γ_p	Strain extreme value
J_{nr}	Do not restore the creep flexibility
γ_{nr}	Unrecoverable strain
τ	Worm loading stress
VAI	Adhesive aging index
V_0	Asphalt viscosity before aging
V	Aging of the asphalt viscosity
CAI	Complex-shear modulus aging index
G_0^*	Complex number modulus before aging
G*	Complex number modulus after aging
PAI	Phase-angle aging index
δ_0	Phase angle before aging
δ	Phase angle after aging

results. The fourth part summarizes the research.

2. Related works

Asphalt, as the most widely used road construction material, its performance is often closely related to the performance of the road. To improve the asphalt performance, many scholars adopt various methods to modify asphalt. There have been considerable achievements. Song proposed a modified asphalt based on nano alumina to improve the HLT performance of asphalt mixtures. The nano alumina improved the high-temperature and fatigue performance of asphalt mixtures, while the low-temperature performance slightly dropped [7]. Zhu et al. proposed a modified asphalt based on styrene butadiene styrene block copolymer to improve the aging and regeneration performance. Adding the 1, 2-polybutadiene content and polystyrene monomers was averse to the compatibility, but it improved the mechanical properties of the prepared HVA [8]. Das and Singh proposed a modified asphalt based on basalt hydrated lime to improve the low-temperature performance. The elemental properties of the binder and mineral filler, as well as the weight concentration of hydrated lime filler, had impacts on the thermal cracking resistance of VG-30 and PMB adhesives. The combination of hydrated lime filler and basalt filler improved the heat resistance and cracking resistance of VG-30 adhesive [9]. Yang et al. proposed modified asphalt based on aluminum hydroxide to improve the flame retardancy and smoke resistance. The added aluminum hydroxide increased the ultimate oxygen index of the matrix asphalt by 23.1%. Simultaneously, it improved the structural integrity and strength. Aluminum hydroxide could improve the flame retardant performance [10]. Song et al. proposed a modified asphalt based on crushed rubber and styrene butadiene styrene composite to improve the high-low temperature performance. CR/SBSMA had excellent high-low temperature performance (superior to SBSMA), which reached the basic binder level [11].

Nanomaterials are extensively applied in various fields due to their quantum size effects, surface effects, and small size effects. Mousavi MA and his team proposed a modified cement based on nano montmorillonite and functionalized multi walled carbon nanotubes to address the issue of cracking in cement matrices. The experimental results showed that after modification with nano montmorillonite and multi walled carbon nanotubes, the compressive strength of cement increased by 30% and the bending strength increased by 40%; And reduce the surface roughness of the cement slurry and refine the porosity [12]. Rao et al. proposed a carbon fiber composite material based on organically modified montmorillonite nanoclay to improve the properties of carbon fiber composites. The interlayer shear strength, bending strength, and bending modulus of the composite material were increased by about 29%, 12%, and 7%, respectively. The added nanoclay also increased the ablation rate of the composite material, which was due to the higher insulation efficiency of nanoclay [13]. Lin et al. proposed using OMMT to modify multi walled carbon nanotubes/natural rubber latex nanocomposites to improve their properties. Compared with the composite material without added montmorillonite, the tensile strength and ductility at break increased by 21.5% and 14.3%. The glass transition temperature slightly increased, and the thin films were uniformly dispersed in the rubber matrix [14]. To improve the self-healing ability of cement-based composite materials, Akn

Table 1. Performance indexes of each material.

Material	Performance index	Unit	Value
Matrix asphalt	Needle penetration (25 °C, 100 g, 5 s)	0.1 mm	90
	Indentation index	/	−0.73
	Softening point	°C	45
	Ductility (5 °C, 1 cm/min)	cm	13.3
	Density (15 °C)	g/cm^3	0.99
	Brinell rotational viscosity (135 °C)	Pa · s	390
Nano SiO_2	Particle size	nm	20
	SiO_2 content	%	99
	Specific area	m^2/g	180
	Stacking density	g/cm^3	0.15
	pH	/	6.5
Nano organic montmorillonite	10 °C volatiles	/	≤ 3.5
	Particle size (200 items)	%	≥ 97 %
	Specific gravity	g/cm^3	1.7
	Stacking density	g/cm^3	≤ 0.3
	XRD d001	nm	3.5

modified them with nano SiO_2. Compared with the water curing stage, the nano silica solution applied to the sample during the curing stage had more effective and faster recovery in mechanical and permeability of the composite material [15]. Yun et al. proposed a modified oil well cement based on nano SiO_2 and nano hexagonal boron nitride to improve the rheological properties and strength of oil well cement. From the experimental results, after 3 days of curing, the early compression, bending, and splitting tensile strength increased by 47.24%, 29.01%, and 53.22%. The synergistic effect of added nano SiO_2 and nano hexagonal boron nitride increased the density of early hydration products in cement [16].

Overall, the research on modified asphalt has been quite effective. However, most of them are aimed at improving the thermal aging resistance performance. There is still insufficient research on UV aging. Due to their unique properties, nanomaterials can often bring unexpected performance changes to the original materials. Therefore, to improve the thermal aging resistance and UV aging performance of asphalt, and to enhance its HLT performance, a modified asphalt based on OMMT/SiO_2 is proposed. It is expected to enhance the service period and performance of asphalt pavement.

3. Experimental materials and methods

Asphalt is an important building material in road and bridge construction. More than 80% of road surfaces worldwide are paved with asphalt. However, asphalt pavement is subject to long-term erosion from external factors such as water vapor and light. It is also affected by temperature and load, resulting in changes in asphalt microstructure and accelerating its aging rate. Therefore, to improve the aging resistance, a composite modified asphalt based on OMMT and silica is proposed. Then the performance is tested.

3.1 Materials

The materials include matrix asphalt, nano SiO_2 modified with silane coupling agents, and OMMT. Table 1 displays the performance indicators for each material.

The research equipment includes an oven (For melting or drying material), an oil bath (To keep the asphalt at a temperature in the molten state), a high-speed shear emulsifier (For mixed materials), a glass rod (For mixing bitumen to drain bubbles), an aluminum tube with one end sealed (The diameter and height are 25 mm and 140 mm, It is used to hold asphalt), scissors (For shear and solidification specimens), a dynamic shear rheometer (DSR) (For measuring asphalt rheological properties), a bending beam rheometer (BBR) (For testing the low-temperature rheological properties of bitumen), a pressure aging instrument (To simulate long-term thermal aging of asphalt), a UV climate resistance aging test chamber (For UV light experiments), and a straight tube UV radiation fluorescent lamp (For UV light aging).

3.2 Preparation of composite modified asphalt based on OMMT/Nano SiO_2

Nanomaterials are extensively applied due to their high specific surface area, good stability, and absorption capacity. To improve the anti-fatigue, anti-aging and anti-stripping properties, it is proposed to melt and blend the matrix asphalt, nano SiO_2 and OMMT to prepare modified asphalt. The details are as follows. Firstly, the matrix asphalt is placed

Table 2. Physical properties of modified bitumen with different ratios.

Asphalt	Needle penetration / dmm	Ductility / cm	Softening point / °C	Brinell rotational viscosity / cp
Matrix asphalt	86	9.7	46.7	398
0 % SiO_2, 3 % OMMT	73	9.2	47.5	582
3 % SiO_2, 2 % OMMT	82	10.6	50.2	665
3 % SiO_2, 3 % OMMT	70	10.0	53.1	785
3 % SiO_2, 4 % OMMT	70	9.2	52.2	912
4 % SiO_2, 0 % OMMT	84	11.6	47	464
4 % SiO_2, 2 % OMMT	76	11.2	50.8	766
4 % SiO_2, 3 % OMMT	68	10.5	54.1	831
4 % SiO_2, 4 % OMMT	68	8.6	53.1	1101
5 % SiO_2, 2 % OMMT	72	9.8	51.1	778
5 % SiO_2, 3 % OMMT	64	8.5	52.9	873
5 % SiO_2, 4 % OMMT	65	7.3	52.4	1970

in an oven and baked to a molten state at 170 °C. Then the nano SiO_2 and OMMT are placed separately in ovens and dried at 70 °C until the weight no longer changes [17–19]. The dried nano SiO_2 and OMMT are mixed in a certain ratio and stirred evenly. Next, the molten matrix asphalt is transferred to an oil bath and maintained at a temperature of 165±5 °C. The mixed nano SiO_2 and OMMT are placed in a molten matrix asphalt and stirred for 20 minutes. Then, the material was mixed using a high-speed shear emulsifier to obtain modified asphalt at a speed of 5000 r/min, oil bath temperature of 165–170 °C and shear time of 1 hour.

3.3 Experimental methods

The storage stability and rheological test methods are as follows. 50 g of modified asphalt in a molten state is placed in an aluminum tube with one end sealed. After cooling to room temperature, the open end of the aluminum tube is folded twice for sealing. Then it is placed in an oven and bake at 163 °C for 48 hours. Then the aluminum tube is placed in the refrigerator to solidify. The solidified asphalt is split into three equal parts. The asphalt at the bottom and top is softened in an oven to test its softening point. Rheological tests are conducted using DSR and BBR. The anti-rutting performance is tested using multiple stress creep experiments. When conducting multiple stress creep experiments, a comprehensive evaluation is conducted from two aspects: strain recovery rate and irreversible creep compliance [20–22]. The strain recovery rate is shown in equation (1).

$$R = \frac{\gamma_r - \gamma_0}{\gamma_p - \gamma_0} \times 100\% \qquad (1)$$

In equation (1), R represents the strain recovery rate. γ_r represents the strain that can be recovered. γ_0 represents the initial strain value. γ_p represents the extreme strain value. The irreparable creep compliance is shown in equation (2).

$$J_{nr} = \frac{\gamma_{nr} - \gamma_0}{\tau} \qquad (2)$$

In equation (2), J_{nr} represents the irreparable creep compliance. γ_{nr} represents an unrecoverable strain. τ represents creep loading stress.

The short-term thermal aging experiment is as follows. Firstly, the oven is preheated for 48 hours. Then 35 g of modified asphalt was put in a sample bottle and placed on a circular rack in an oven. The sample is heated by rotating at 15 r/min. The heating temperature is 163 °C. The heating is stopped when the speed reaches the set value. Then the sample is further rotated in the opposite direction of the hot air flow. The flow rate of hot air is 4000 ml/min. The overall duration of aged asphalt is 85 minutes. The overall heating time of asphalt shall not be less than 75 minutes. The performance of aged asphalt is tested using a DSR. The

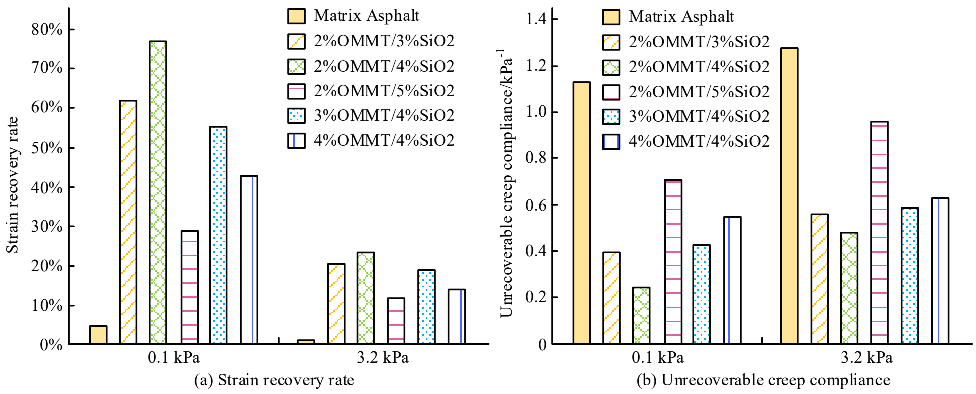


Figure 1. Results of multiple stress creep experiments.

performance is evaluated by viscosity aging index, complex shear modulus aging index (CAI), and phase angle aging index (PAAI). The viscosity aging index is shown in equation (3).

$$VAI = \frac{V - V_0}{V_0} \tag{3}$$

In equation (3), VAI represents the viscosity aging index. V_0 and V respectively represent the asphalt viscosity before and after aging. The CAI is shown in equation (4).

$$CAI = G^*/G_0^* \tag{4}$$

In equation (4), CAI represents the complex shear modulus aging index. G_0^* and G^* represent the complex moduli before and after aging, respectively. The PAAI is shown in equation (5).

$$PAI = \delta/\delta_0 \tag{5}$$

In equation (5), PAI represents the PAAI. δ_0 and δ respectively represent the phase angle before and after asphalt aging. The long-term thermal aging experiment is as follows. 50 g of modified asphalt is placed in a sample cup and aged continuously for 20 hours at 100 °C and 2.1 MPa. After aging is completed, the vacuum degassing device is used to remove bubbles and clean the asphalt with deionized water. Then it is placed in a constant temperature box. The performance testing and evaluation methods for long-term aging are consistent with those for short-term aging experiments. The UV aging experiment is as follows. A 10mm thick modified asphalt is laid on a sample tray with a diameter of 140 mm. Then it is placed in a UV climate aging test chamber and exposed to UV radiation for 7 days. The distance between the UV lamp and the sample tray is 20 cm. The test chamber temperature is 60 °C. The performance testing and evaluation method of UV aging experiment is consistent with that of thermal aging experiment.

4. Performance analysis of composite modified asphalt based on OMMT/nano SiO_2

4.1 Physical properties analysis of OMMT/nano SiO_2 composite modified asphalt

To analyze the effect of OMMT/nano SiO_2 on the physical properties of asphalt, the performance of modified asphalt with different ratios is explored. The softening point, penetration, and Brinell rotation viscosity are displayed in Table 2.

According to Table 2, in terms of penetration, compared with the matrix asphalt, the modified asphalt with different OMMT/SiO_2 ratios was decreased. The penetration rate of modified asphalt with 5%SiO2/3%OMMT was only 64 dmm. For ductility, the modified asphalt with the addition of 4%nanoSiO_2 alone showed an increase in ductility compared to the matrix asphalt, reaching 11.6 cm. After adding 3%OMMT alone, the asphalt ductility decreased to only 9.2 cm. When SiO_2 and OMMT were added simultaneously, the ductility decreased with the increase of OMMT content.

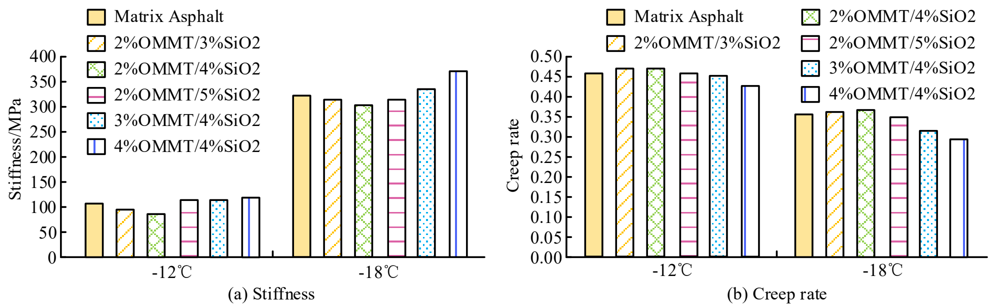


Figure 2. Results of the low-temperature bending beam rheology experiments.

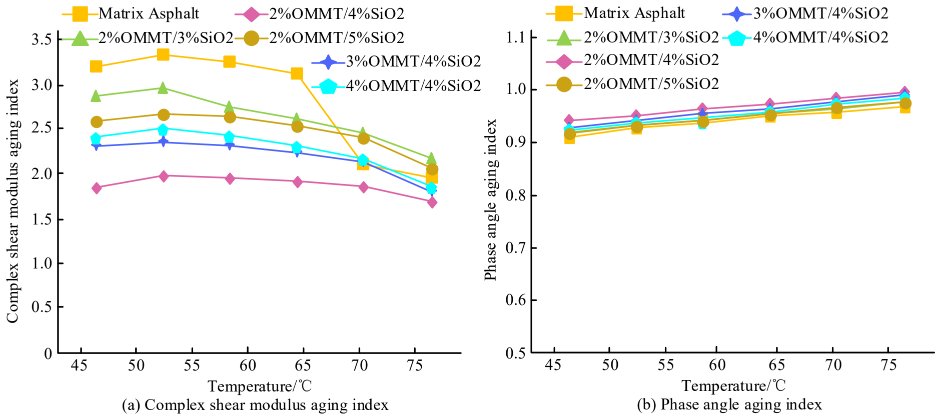


Figure 3. Results of the short-term thermal aging experiments.

When preparing modified asphalt, to ensure its ductility, the content of OMMT needs to be carefully selected. In terms of softening point temperature, different OMMT/SiO_2 ratios all triggered an increase. The modified asphalt with a 3%OMMT/4%SiO_2 ratio had the highest softening point at 54.1 °C. In terms of Brinell rotational viscosity, the viscosity also increased with the increase of OMMT/SiO_2 ratio. The viscosity was highest at 1970 cp with a 4% OMMT/5% SiO_2 ratio. Therefore, the OMMT/SiO_2 can raise the penetration, ductility, softening temperature, and viscosity, enhancing the recovery ability of asphalt under stress influence. To further verify the high-temperature resistance to rutting, multiple stress creep experiments are conducted on modified asphalt at 64 °C. Figure 1 displays the experimental results. The stress conditions for the multi stress creep test of modified asphalt are set according to the "SBS Modified Asphalt Multi Stress Creep Recovery Test (MSCR) Regulations" implemented in 2019. According to Figure 1 (a), the strain recovery rate of the matrix asphalt was about 6% when the stress was 0.1 kPa. The OMMT/SiO_2 modified asphalt exceeded the unmodified asphalt samples. For Figure 1 (a), the modified asphalt with 3% OMMT/5% SiO_2 was the lowest, about 30%. According to Figure 1 (b), the irreversible creep compliance of the matrix asphalt was approximately 1.16 kPa^{-1} when the stress was 0.1 kPa. The irreversible creep compliance of OMMT/SiO_2 modified asphalt did not exceed 0.8 kPa^{-1}. The resistance to permanent deformation of OMMT/SiO_2 modified asphalt is markedly raised. To test the low-temperature efficiency, low-temperature bending beam rheological experiments are conducted on it. Figure 2 displays the results.

According to Figure 2 (a), at −12 °C, the stiffness of modified asphalt with 2%OMMT/3%SiO_2 and 2%OMMT/4%SiO_2 ratios decreased slightly. The stiffness of the modified asphalt with other ratios outperformed the matrix asphalt. The maximum stiffness reached 119 MPa. In Figure 2 (b), at −12 °C, the creep rate of modified asphalt with 2%OMMT/3%SiO_2 and 2%OMMT/4%SiO_2 ratios slightly increased. The other modified asphalt was below the matrix asphalt. The creep rate with 4%OMMT/5%SiO_2 was the lowest, only 0.426. The above results indicate that the appropriate OMMT/SiO_2 modified asphalt can optimize the low-temperature efficiency.

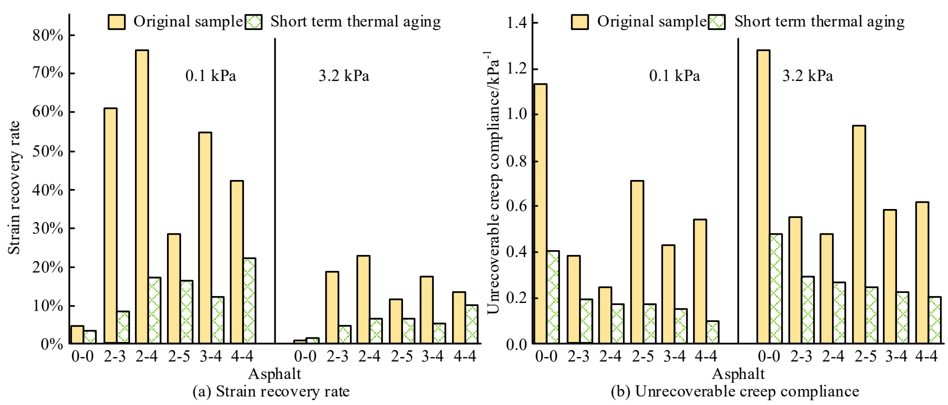
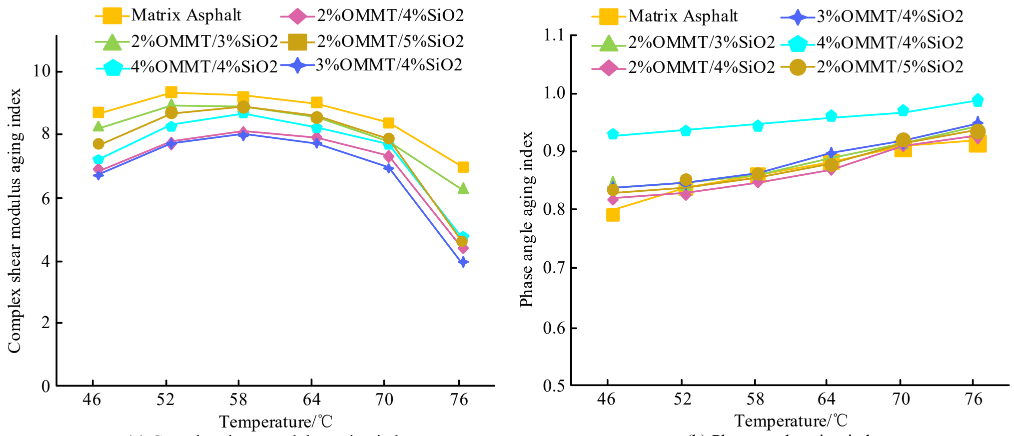
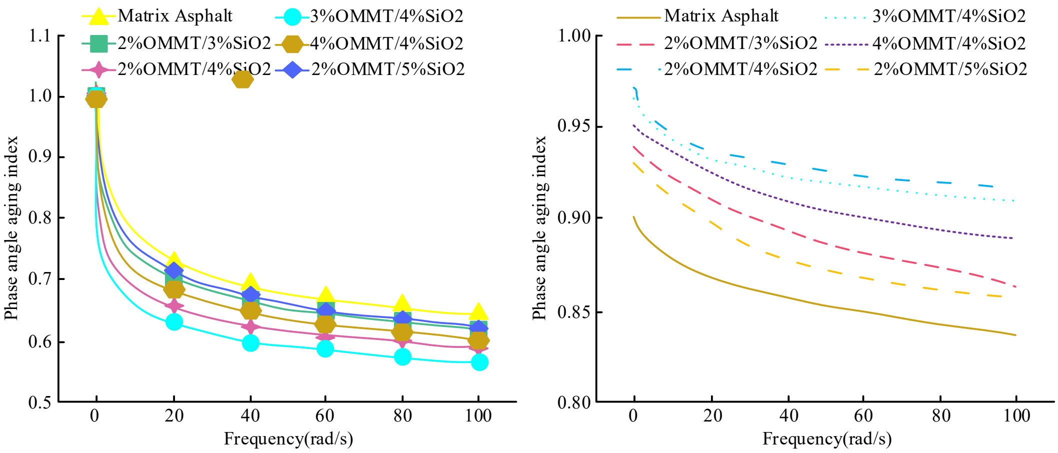


Figure 4. High temperature performance with short-term thermal aging.



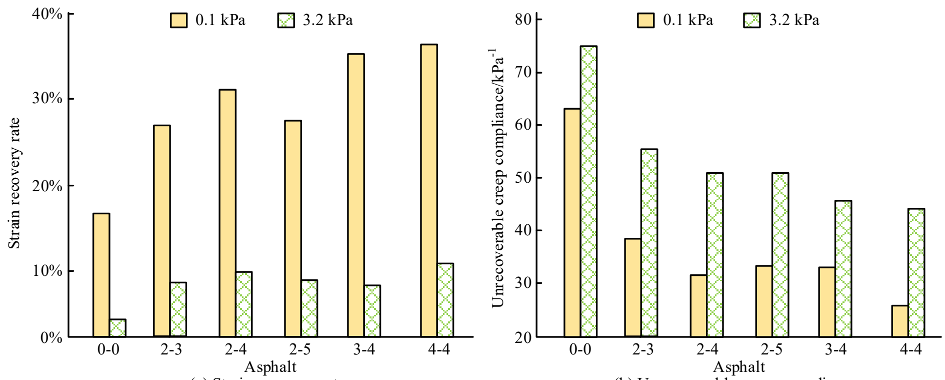
(a) Complex shear modulus aging index (b) Phase angle aging index

Figure 5. Results of the long-term thermal aging experiment.



(a) The relationship between complex shear modulus aging index and frequency (b) The relationship between phase angle aging index and frequency

Figure 6. Relationship between the aging index and the scan frequency.



(a) Strain recovery rate (b) Unrecoverable creep compliance

Figure 7. High temperature performance of modified asphalt with long-term thermal aging. Note: The x-y on the horizontal axis represents modified asphalt containing x% OMMT and y% silica.

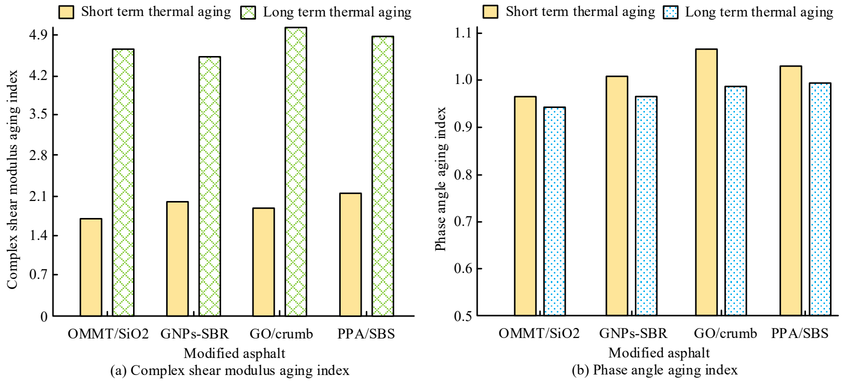


Figure 8. Aging index of different modified asphalt after thermal aging.

4.2 Thermal aging performance analysis of OMMT/-nano SiO_2 composite modified asphalt

Asphalt may age under high temperature and atmospheric conditions, leading to pavement failure. Therefore, to discuss the aging performance, short and long period thermal aging experiments are conducted. Figure 3 shows the short period thermal aging results.

From Figure 3 (a), compared with unmodified asphalt, the CAI of modified asphalt under various OMMT/SiO_2 ratios was decreased. The modified asphalt with 2%OMMT/4%SiO_2 decreased by 44%. According to Figure 3 (b), the PAAI of modified asphalt outperformed the matrix asphalt under various OMMT/SiO_2 ratios. The PAAI of 2%OMMT/4%SiO_2 modified asphalt increased by about 6%. From the above results, OMMT/SiO_2 can optimize the short-term thermal aging performance. After short-term thermal aging, the high-temperature performance is displayed in Figure 4.

In Figure 4 (a), for the deformation recovery rate, compared with the original sample, each asphalt sample was

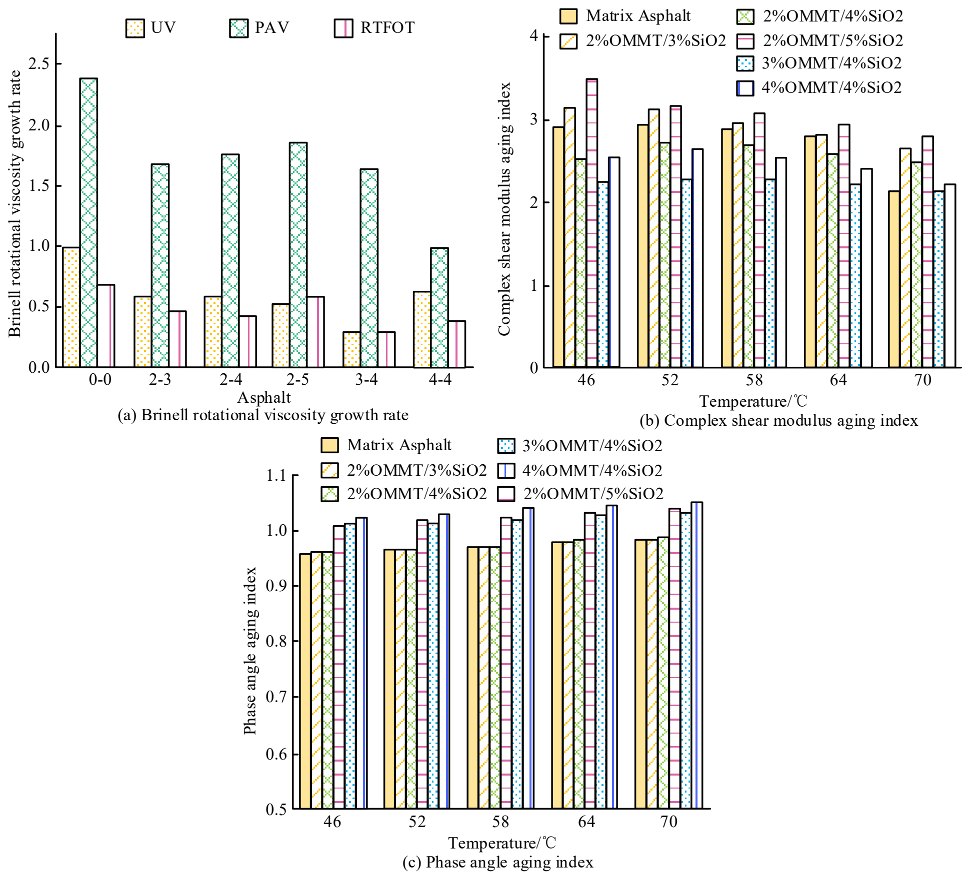
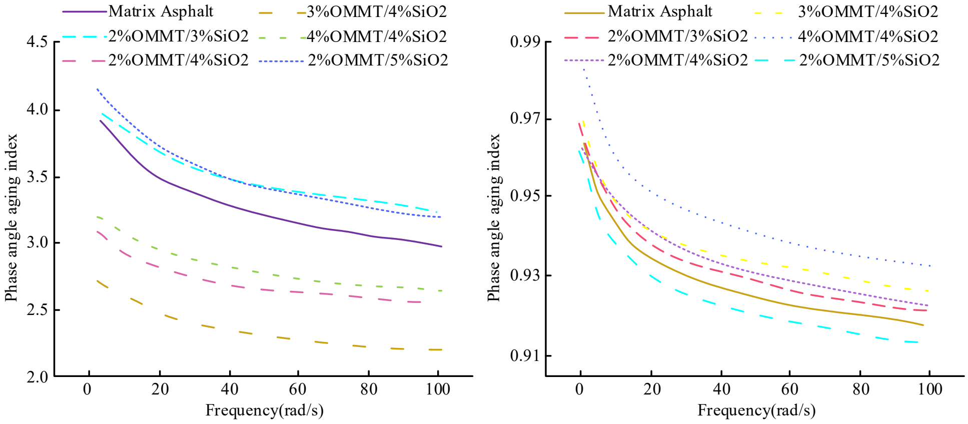


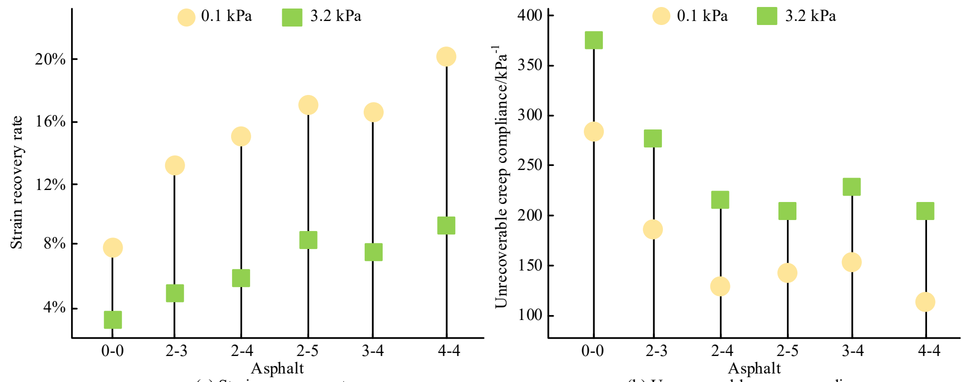
Figure 9. Growth rate of rotational viscosity and aging index after UV aging.



(a) The relationship between complex shear modulus aging index and frequency

(b) The relationship between phase angle aging index and frequency

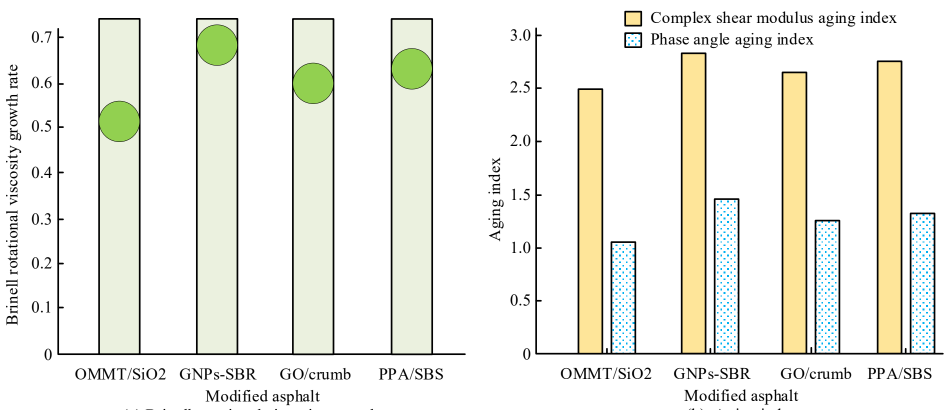
Figure 10. Relationship between the aging index and the scan frequency.



(a) Strain recovery rate

(b) Unrecoverable creep compliance

Figure 11. Results of multiple stress creep recovery experiments of UV-aged modified bitumen.



(a) Brinell rotational viscosity growth rate

(b) Aging index

Figure 12. Growth rate and UV aging index of different modified asphalt.

decreased. However, the OMMT/SiO_2 modified asphalt exceeded the original sample. The deformation recovery rate under a stress of 0.1 kPa remained basically above 10%. In Figure 4 (b), after electrical thermal aging, the irreversible creep compliance of each asphalt sample was decreased. The irreversible creep compliance of OMMT/SiO_2 modified asphalt was below the matrix asphalt. Under a stress of 0.1 kPa, it generally remained below 0.2 kPa^{-1}. Therefore, OMMT/SiO_2 can raise the short-term thermal aging resistance of asphalt. The results of the long period thermal

aging experiment are shown in Figure 5.
From Figure 5 (a), the CAI of modified asphalt under various OMMT/SiO_2 ratios was below the matrix asphalt. The modified asphalt with 3%OMMT/4%SiO_2 showed the greatest reduction in the CAI, with a decrease of about 23%. According to Figure 5 (b), the PAAI of modified asphalt outperformed the matrix asphalt under various OMMT/SiO_2 ratios. The PAAI of 4%OMMT/4%SiO_2 modified asphalt increased by about 19%. From the above results, OMMT/SiO_2 can raise the short-term thermal aging performance. Figure 6 presents the impacts of aging index and scanning frequency.
In Figure 6 (a), the CAI of each asphalt sample decreased with increasing scanning frequency. The CAI of modified asphalt with 3%OMMT/4%SiO_2 was consistently below the other asphalt samples. When the scanning frequency was 100 rad/s, its CAI was 0.58. In Figure 6 (b), the PAAI of each sample decreased with the increase of scanning frequency. The PAAI of 2%OMMT/4%SiO_2 was the highest. When the scanning frequency was 100 rad/s, its PAAI was 0.93. After long period thermal aging, the high-temperature performance is presented in Figure 7.
In Figure 7 (a), compared with the matrix asphalt, the modified asphalt with various OMMT/SiO2 ratios had a higher deformation recovery rate after aging. When the stress was 3.2 kPa, the modified asphalt with 4%OMMT/4%SiO_2 had the highest deformation recovery rate, which was about 12%. In Figure 7 (b), when the stress conditions are the same, the irreversible creep compliance was below the matrix asphalt. The modified asphalt with 4%OMMT/4%SiO_2 had the lowest irreversible creep compliance at 0.1 kPa, only about 25 kPa^{-1}. From the above results, OMMT/SiO_2 improves the thermal aging performance over a long period of time. The aging index of different modified bitumen after thermal aging is shown in Figure 8.
As shown in Figure 8 (a), in terms of short-term thermal aging, the complex shear modulus aging index of OMMT/SiO_2 is around 1.8, which is lower than other modified asphalt. In terms of long-term thermal aging, the complex shear modulus aging index of OMMT/SiO_2 is the lowest, around 4.8. According to Figure 8 (b), the phase angle aging indices of OMMT/SiO_2 for short-term and long-term thermal aging are 0.97 and 0.95, respectively, which are lower than those of other modified asphalt. It can be seen that modified asphalt based on OMMT/SiO_2 has better thermal aging resistance.

4.3 UV aging performance analysis of OMMT/nano SiO_2 composite modified asphalt

To discuss the UV aging performance, aging experiments are conducted using a UV climate resistant aging test box. The growth rate and aging index of Brinell rotation viscosity after UV aging are shown in Figure 9.
In Figure 9 (a), compared to the matrix asphalt, the growth rate of Brinell rotation viscosity of OMMT/SiO_2 modified asphalt after UV aging was smaller, not exceeding 0.7. The OMMT/SiO_2 improves the UV aging performance. In addition, among the three aging methods, the growth rate of Brinell rotational viscosity was the smallest under UV aging. According to Figure 9 (b), among the modified asphalt with different ratios, the CAI of 3%OMMT/4%SiO_2 modified asphalt was the smallest. In addition, the CAI of 2%OMMT/3%SiO_2 and 2%OMMT/5%SiO_2 was increased compared to the matrix asphalt. According to Figure 9 (c), the PAAI of modified asphalt exceeded the matrix asphalt under various OMMT/SiO_2 ratios. The PAAI of 2%OMMT/5%SiO_2 modified asphalt increased by about 7%. The above results indicate that OMMT/SiO_2 can alter the UV aging resistance of asphalt. Some ratios may even reduce the UV aging resistance. The relationship between aging index and scanning frequency is displayed in Figure 10.
In Figure 10 (a), the CAI of each asphalt sample decreased with increasing scanning frequency. The CAI of modified asphalt with 3%OMMT/4%SiO_2 was consistently below the other asphalt samples. When the scanning frequency was 100 rad/s, its CAI was 2.3. In Figure 10 (b), the PAAI of each sample decreased with the increase of scanning frequency. The PAAI of 4%OMMT/4%SiO_2 was the highest. When the scanning frequency was 100 rad/s, its PAAI was 0.94. The multiple stress creep recovery experiment of modified asphalt aged by UV is shown in Figure 11.
In Figure 11 (a), compared with the matrix asphalt, the different OMMT/SiO_2 ratios had a higher deformation recovery rate after aging. When the stress was 3.2 kPa, the modified asphalt with 4%OMMT/4%SiO_2 had the highest deformation recovery rate, which was about 8%. In Figure 11 (b), when the stress conditions were same, the irreversible creep compliance was below the matrix asphalt. The modified asphalt with 4%OMMT/4%SiO_2 had the lowest irreversible creep compliance, which was only about 120 kPa^{-1} at 0.1 kPa. The OMMT/SiO_2 can raise the UV aging performance of asphalt. The Brinell rotational viscosity growth rate and UV ageing index of different modified bitumen is shown in Figure 12.
According to Figure 12 (a), it can be seen that the growth rates of Brinell rotational viscosity of OMMT/SiO_2, GNps/SBR, GO/crumb, and PPA/SBS modified asphalt are 0.51, 0.67, 0.60, and 0.63, respectively, with OMMT/SiO_2 having the lowest growth rate. As shown in Figure 12 (b), the UV complex shear modulus aging index and phase angle aging index of OMMT/SiO_2 modified asphalt are around 2.5 and 1.1, respectively, which are lower than those of other modified asphalt. The above results indicate that the anti UV aging performance of OMMT/SiO_2 modified asphalt is superior to other modified asphalt.

5. Conclusion

In order to improve the service life of the road surface, a modified asphalt based on OMMT/SiO_2 was proposed. The experimental results show that the penetration, ductility, softening temperature, and viscosity of OMMT/SiO_2 modified asphalt have all been improved; The highest elongation, softening temperature, and viscosity can be increased to 11.6 cm, 54.1 °C, and 1970 cp. The irreversible creep compliance of OMMT/SiO_2 modified asphalt does not exceed 0.8 kPa^{-1}; When the temperature is -12 °C, the creep rate does not exceed 0.45. The complex shear modulus aging index of short-term and long-term thermal aging can be reduced by 44% and 23%, respectively; The growth rate of Brinell rotation viscosity of OMMT/SiO_2 modified asphalt did not exceed 0.7, which was lower than that of the base asphalt. The above results indicate that OMMT/SiO_2 can effectively improve the physical properties, thermal aging resistance, and UV aging performance of asphalt. However, in some cases, it may have a negative impact on the UV aging performance of asphalt. Therefore, careful selection of OMMT/SiO_2 ratio is necessary when configuring modified asphalt. Although some progress has been made in the study of OMMT/SiO_2 modified asphalt, there is a lack of research on other modification processes due to the fact that only one modification process, melt blending, was used in the experiment. Therefore, in the future, research will be conducted on the effects of different modification processes on the performance of OMMT/SiO_2 modified asphalt to determine the optimal modification process.

Ethical Approval
This manuscript does not report on or involve the use of any animal or human data or tissue. So the ethical approval is not applicable.

Funding
The research is supported by: National Natural Science Foundation of China, Decaying prediction of aging performance of hot recycled asphalt and mixture under exposure situation in northwest China. (Grant No: 52268070); Research project of Gansu Provincial Department of Transportation, Evaluation and application of aging resistance of thermal reclaimed asphalt pavement in Gansu Province, (No. 2023-02).

Authors Contributions
Authors have equally contributed in preparing the manuscript.

Availability of Data and Materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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