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Study on the Basic Properties of Silane Coupling Agent Modified Foamed Asphalt in the Monsoon Freezing Zone

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Abstract

In order to evaluate the basic performance of silane coupling agent-modified foamed asphalt under the monsoon freezing zone.The basic properties of matrix asphalt (AH90), foamed asphalt (FAH90) and silane coupling agent-modified foamed asphalt (MFAH90) after salt-freeze-thaw cycling were evaluated using needle penetration, softening point and ductility tests.The results show that the softening points of all types of asphalt gradually increase with the increase in the number of salt-freeze-thaw cycles, which enhances the high-temperature stability of asphalt to a certain extent.The high temperature performance of asphalt after salt-freeze-thaw cycle in descending order is: MFAH90>FAH90>AH90.Needle penetration of all types of asphalt showed a decreasing trend, and the viscosity of asphalt gradually increased.The ductility of all types of asphalt after different numbers of salt-freeze-thaw cycles is greater than 100cm, which meets the specification requirements.

Keywords

Monsoon Freezing Zone; Silane Coupling Agent; Foamed Asphalt; Basic Properties.

1. Introduction

Road pavement construction is a major source of energy consumption and carbon emissions. Asphalt pavements are widely used in various types of highways due to their advantages, including driving comfort and dust-free surfaces. The primary component of these pavements is asphalt mixture, which can be classified into hot mix asphalt (HMA) and warm mix asphalt (WMA) based on the construction process.

Currently, HMA is the most commonly used material in highway pavement construction. However, it requires high-temperature conditions (150°C–180°C) for production and placement. During mixing and compaction, HMA generates significant amounts of harmful emissions, including asphalt fumes and carbon dioxide (CO_2). These emissions not only pose health risks to construction workers but also contribute to environmental pollution and exacerbate the greenhouse effect.In contrast, WMA is produced and compacted at temperatures approximately 30°C lower than HMA, significantly reducing the release of asphalt fumes, CO_2, and other hazardous gases. As a result, WMA presents fewer health hazards to workers and has a lower environmental impact, making it a more sustainable alternative in pavement construction [1-3].

With the widespread adoption of warm mix foamed asphalt (WMFA) mixtures, extensive engineering practice and research have demonstrated that their water stability requires further improvement.

In China's northeast monsoon freezing region, characterized by high summer temperatures, extreme winter cold, and heavy snowfall, accumulated snow severely disrupts road traffic. To

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mitigate this issue, snow-melting salts are frequently applied to road surfaces during winter [4, 5]. However, under these harsh environmental conditions, asphalt pavements suffer significant deterioration due to combined salt erosion and water damage, primarily manifested as surface loosening, potholes, and cracking. These defects markedly reduce the service life of asphalt pavements and compromise traffic safety.Freeze-thaw cycles, as an intensified form of moisture damage, further limit the applicability of foamed asphalt mixtures in monsoon freezing zones. Consequently, enhancing the water stability of foamed asphalt mixtures through material modification has emerged as a critical research priority in asphalt pavement engineering.

Silane coupling agent as a commonly used modifier to improve the bonding between materials [6, 7]. In this paper, Silane coupling agent was used as a modification material for foamed asphalt.To assess the fundamental performance of silane coupling agent-modified foamed asphalt in monsoon freezing zone conditions, we conducted a series of standardized tests on three asphalt variants: base asphalt (AH90), conventional foamed asphalt (FAH90), and silane coupling agent-modified foamed asphalt (MFAH90). The evaluation employed three key rheological property tests - penetration, softening point, and ductility - following exposure to salt-freeze-thaw cycling conditions.

2. Materials and Method

2.1. Materials

The test matrix asphalt is 90# road petroleum asphalt (AH90), Its technical indicators are shown in Table 1. Foamed asphalt (FAH90) is foamed by adding 1.8% to 90# asphalt, Silane coupling agent modified foamed asphalt (MFAH90) is modified by adding 1.8% to 90# and then 0.5% Silane coupling agent.

Table 1. 90# asphalt technical indicators

Experimental projects	Measured value	Normative value
Needle penetration (25°C, 5s, 100g)/0.1mm	93	80-100
Ductility (15°C)/cm	>150	>100
Softening Point/°C	45.5	42-55
Solubility/%	99.97	>99.0
Flash point (open)/°C	306	>230
Density (25°C)/kg/m^3	1001.0	-
Wax content (distillation method)/%	1.91	<3.0

2.2. Method

(1) Preparation of specimens

On the basis of references and previous experience, salt solution erosion and freeze-thaw cycle were used to simulate the environmental characteristics of the Northeast Quarter Frozen Zone with low winter temperatures and snow-melting salt spread on the road surface, and salt-freeze-thaw cycle was applied to AH90, FAH90 and MFAH90 ,and are shown in Fig. 1-4.

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Fig 1. Freeze-thaw cycle tester **Fig 2.** Snow-melting salt solution

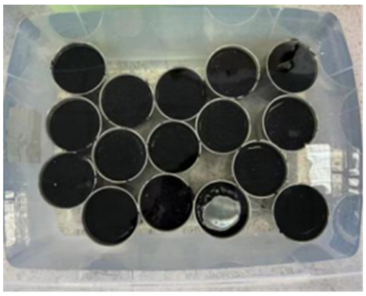


Fig 3. Asphalt immersed in salt solution **Fig 4.** Asphalt placed in freeze-thaw cycler

(2) Basic Characteristics Test

According to ***Test Procedures for Asphalt and Asphalt Mixture in Highway Engineering (JTG E20-2011)***, the softening point, needle penetration and ductility of matrix asphalt, foamed asphalt and Silane coupling agent modified foamed asphalt were determined respectively,as shown in the Fig.5-7.

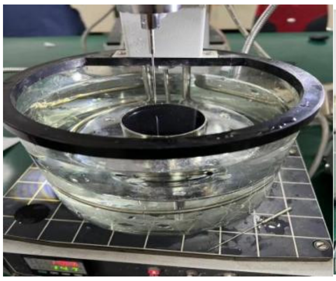


Fig 5. Needle penetration test apparatus **Fig 6.** Softening point tester

Fig 7. Ductility Test Apparatus

3. Result

(1)High temperature stability

The size and change rule of asphalt softening point after different salt-freeze-thaw cycles are shown in Fig. 8.

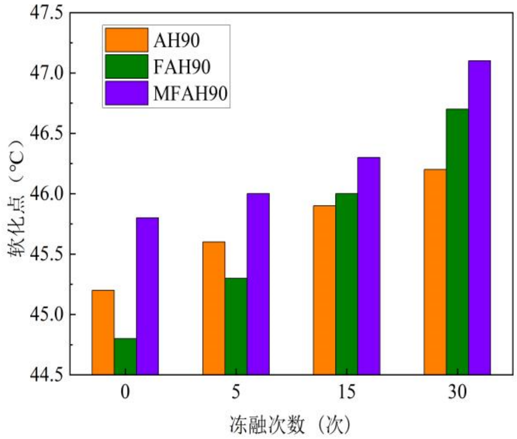

Fig 8. Softening points of various types of bitumen after salt-freeze-thaw cycles

The softening points of all types of bitumen showed a gradual increase with the increase in the number of salt-freeze-thaw cycles.After 5 freeze-thaw cycles, the softening point of AH90 increased by 0.8%, FAH90 by 1.1% and MFAH90 by 0.4%.After 15 freeze-thaw cycles, the softening point of AH90 increased by 1.5%, FAH90 by 3.3% and MFAH90 by 1.1%.When freeze-thaw cycling was done up to 30 times, the softening point increased by 2.2% for AH90, 4.2% for FAH90 and 2.8% for MFAH90.It indicates that all types of asphalt have a similar pattern of change in softening point after salt-freeze-thaw cycle, and the softening point is slightly increased, which improves the high temperature stability of asphalt to a certain extent.

(2)Viscosity

The size and change rule of asphalt Needle penetration after different salt-freeze-thaw cycles are shown in Fig. 9.

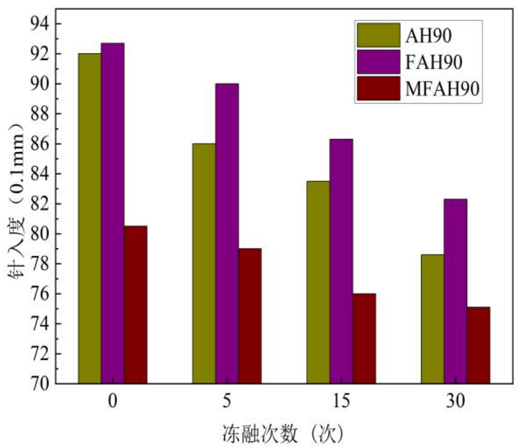

Fig 9. Needle penetration of various types of bitumen at 25°C

As the number of salt-freezing and thawing cycles increases, the needle penetration of all types of asphalt shows a gradual decrease, which may be attributed to the hardening of asphalt under low-temperature freezing.After freeze-thaw cycling up to 30 times, the needle penetration decreased by 14% for AH90, 11.2% for FAH90 and 6.7% for MFAH90.AH90 showed the greatest reduction in needle penetration, followed by FAH90, and MFAH90 showed the least reduction.

(3)Low Temperature Performance

The ductility of all types of asphalt after different number of salt - freeze-thaw cycles is more than 100cm, which meets the specification requirements.

4. Conclusion

In order to evaluate the basic performance of silane coupling agent-modified foamed asphalt under the monsoon freezing zone.The basic properties of matrix asphalt (AH90), foamed asphalt (FAH90) and silane coupling agent-modified foamed asphalt (MFAH90) after salt-freeze-thaw cycling were evaluated using needle penetration, softening point and ductility tests.The following conclusions can be drawn:

(1) The softening points of all types of bitumen showed a gradual increase with the increase in the number of salt-freeze-thaw cycles.

(2) As the number of salt-freezing and thawing cycles increases, the needle penetration of all types of asphalt shows a gradual decrease.

(3)The ductility of all types of asphalt after different number of salt - freeze-thaw cycles is more than 100cm, which meets the specification requirements.

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