

Research on the Influence of Rainfall Infiltration on the Stability of Urban Road Base Mixtures

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Research Article

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Abstract

To investigate the influence of rainfall infiltration on the stability of urban road base mixtures and to reduce premature damage to pavement structures caused by rainwater, laboratory tests and image processing techniques were employed in this study. The water stability and water damage mechanisms of warm-mix foamed asphalt (WMA) mixtures and conventional hot-mix asphalt (HMA) mixtures were systematically analyzed under different immersion conditions. The results indicate that rainwater infiltration reduces the effective stress within the mixture, leading to strength loss and increased deformation. Under the combined effects of water erosion and pore water pressure, the water stability of the road mixtures exhibits a declining trend as the deterioration caused by rainwater gradually accumulates. The failure load of HMA is higher than that of WMA, but HMA shows a greater strength reduction after immersion. The residual stability and freeze-thaw splitting strength ratio of both mixtures meet the specification requirements. The research findings can provide a reference for the design and construction of similar road base mixtures.

1. Introduction

Rainfall infiltration is one of the main environmental factors causing the deterioration of urban road base structures. After rainwater penetrates through pavement pores, cracks, and joints, the overall structural stability of the asphalt mixture and the chemical bonding between aggregates and asphalt decrease to varying degrees. Under repeated vehicle loading, dynamic water pressure further aggravates the internal structural damage of the mixture, eventually leading to loose aggregates, potholes, rutting, and other pavement distresses (Guo et al. 2021; Xiao et al. 2012; Marek and Anna 2013). Because of rainfall and climatic effects, pavement structures are often exposed to long-term dry–wet cycles. The damage to pavement structures is closely related to rainfall infiltration and temperature variation. Dry–wet cycles caused by rainfall, if not repaired in time, can significantly accelerate pavement deterioration. Many roads suffer from cracking and settlement due to rainfall, which affects the riding comfort and safety of vehicles.

Foamed asphalt is a commonly used binder in warm-mix technology. It is produced by injecting hot asphalt, water, and high-pressure air into an asphalt foaming device. Foamed asphalt mixtures are generally mixed with aggregates at a temperature about 30°C lower than that of HMA. Li et al. (2010) studied foamed asphalt-stabilized crushed stone mixtures with different cement contents and gradations. The results showed that the strength improvement of the asphalt mixture is closely related to cement content, and the suitable cement dosage was determined through tests. Liu et al. (2023) investigated the water stability of steel slag asphalt concrete using SBS-modified asphalt and Portland cement filler, providing theoretical and practical references for similar materials. Dang (2015) conducted tests on asphalt mixtures with different rubber particle contents and provided theoretical support for engineering applications. Zhang et al. (2022) analyzed the mechanical properties and mesostructure of permeable asphalt mixtures under different water temperatures using experimental evaluation and microscopic image processing. Yi (2023) applied surface free energy theory to quantitatively

characterize the adhesion and water damage resistance of asphalt–aggregate systems and proposed an optimization method for asphalt raw material combinations. Zhang (2019) used industrial CT to track the internal porosity of porous asphalt concrete and revealed the variation of air voids under freeze-thaw cycles.

Experimental evaluation methods based on stripping degree, such as the boiling test and photoelectric spectrophotometry, are commonly used to evaluate the water stability of asphalt mixtures. In this study, physical and mechanical indicators were used as evaluation criteria. Marshall tests and freeze-thaw cycle tests under different conditions were conducted to investigate the water stability of the mixtures. Through the analysis of water stability and water damage mechanisms, the damage mechanism of road mixtures under water-saturated conditions was explored, providing a basis for the practical application of asphalt pavement engineering.

2. Materials and Methods

2.1. Raw Materials

A 70-A grade road petroleum asphalt produced by a company in Fujian, China, was used in this study. Its technical properties are listed in Table 1.

Table 1
Technical properties of 70-A asphalt binder

Property	Value
Penetration (25°C)	5.47 mm
Ductility (5°C)	28.6 cm
Softening point (°C)	78.2
Kinematic viscosity (135°C)	2.31 Pa·s
Solubility (25°C)	99.81%
Elastic recovery (25°C)	98.1%
Note: The binder is a 70-A grade road petroleum asphalt produced in Henan, China.	

2.2. Aggregate Gradation

The AC-20 synthetic gradation was determined according to the range specified in the highway asphalt pavement design specification. The gradation was designed through laboratory sieve analysis of crushed stones of different sizes. The results are shown in Table 2.

Table 2
AC-20 aggregate gradation design

The following sieve hole pass rates/%												
Upper limit (%)	100	100	90	82	70	46	36	28	22	16	12	7
Synthetic gradation (%)	100	93.6	86.7	77.2	62.9	41.3	26.1	17.8	13.1	8.8	6.8	5.3
Lower limit (%)	100	90	75	63	51	33	23	17	11	6	4	3
Note: AC-20 denotes asphalt concrete with a nominal maximum aggregate size of 20 mm. The synthetic gradation was determined by laboratory sieve analysis.												

2.3. Test Program

According to the Test Specifications for Highway Engineering Asphalt and Asphalt Mixtures (JTG E20-2011), Marshall tests and freeze-thaw splitting tests were carried out on the two types of asphalt mixtures. The Marshall test was conducted under a constant loading rate of 50 mm/min. During testing, the loading head was kept in contact with the upper steel ball. After the specimen was crushed, the residual stability (T), failure stability (Ms), and flow value (FL) were recorded. Test data with large errors were discarded, and the average values of the remaining data were used for analysis.

3. Results and Discussion

3.1. Marshall Stability and Flow Value under Different Immersion Conditions

The Marshall test results are summarized in Table 3.

No.	Test name	Immersion condition	Mixture type	Ms/kN	T/%	FI/0.1mm
1	Standard Marshall stability test	60°C, 40min	HMA	14.85	/	19
			WMA	14.17	/	25
2	Standard Marshall stability test	60°C, 48h	HMA	13.31	88.7%	29
			WMA	13.17	91.3%	33
3	Vacuum saturated Marshall test	Vacuum saturation 15 min, 60°C, 48 h	HMA	12.94	86.8%	36
			WMA	12.54	87.2%	42
4	Vacuum saturated Marshall test	Dry + vacuum saturation each 15 min, 60°C, 48 h	HMA	12.69	85.5%	38
			WMA	12.62	87.8%	43

3.1.1. Language

Declarations

Author Contribution

.All authors contributed to the study conception and design. Pei Yu performed the material characterization. Suqin Gao provided the equipment and carried out the material preparation. Pei Yu was responsible for data collection, review, and analysis, proposed the methodology, and wrote the first draft of the manuscript. All authors commented on previous versions of the manuscript and read and approved the final manuscript.

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