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Design and Evaluation of Ultra-Thin Overlay with High Viscosity and High Elasticity †

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Abstract: Ultra-thin asphalt overlay, which is considered one of the main pavement maintenance strategies, has been widely used to maintain and restore pavements. However, the structural properties of traditional ultra-thin overlay materials, such as anti-friction and anti-cracking pavement surfaces, do not last longer under the climate change and traffic loading conditions. This paper introduces an innovative design of ultra-thin asphalt overlays with high viscosity and high elasticity, which provide not only a long service life of anti-resistance and anti-cracking performance, but also lower traffic noise and smoother riding quality. The process of designing such ultra-thin lift overlays involves multi-objective optimization of the overlay's structural and functional performances, including the quality and quantity of asphalt additives, gradation of coarse aggregates and materials' engineering, and cohesive and adhesive properties of asphalt overlays. During the lab tests prepared for this study, the compound-modified asphalt was prepared by modifying base asphalt with the high viscosity and high elasticity modifier. The gradation design was performed to improve coarse aggregate voids' filling and the density of the mixture, and the trackless tack coat emulsified asphalt was used as an adhesive layer material. Laboratory tests were conducted to evaluate the performance of the asphalt mixture and bonding effect of trackless tack coat emulsified asphalt. Results showed that the high viscosity and elasticity ultra-thin overlay exhibited excellent performance in terms of skid resistance and noise reduction. The interlocking effect of the coarse aggregate skeleton and the optimal asphalt film contribute to the resilient and durable properties of an ultra-thin asphalt overlay.

Keywords: asphalt pavement; asphalt mixture; ultra-thin overlay; high viscosity; high elasticity; skid resistance; molecular structure-activity; gradation design

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1. Introduction

Among the various pavement maintenance technologies, ultra-thin overlay has been increasingly used because of its engineering economy and construction convenience compared to traditional maintenance technologies such as micro-surfacing, slurry seal, and hot in-place recycling. Currently, the main ultra-thin overlay technologies include Nova Chip, UTAC, BBTM, etc. Ultra-thin asphalt concrete and super-thin asphalt concrete were firstly proposed in France. Subsequently, it has been widely used in many countries, including the United States, China, Australia, and South Africa [1]. Huang et al. carried out the performance evaluation of UTA-10 asphalt mixture and applied it to the maintenance engineering of cement bridge deck pavement [2]. Various types of ultra-thin overlay were constantly proposed, including warm mix ultra-thin overlay, cold mix ultra-thin overlay, and anti-icing ultra-thin overlay. Mixture design methods and asphalt modification techniques were studied [3–8].

Recently, more research projects have focused on the development of functional ultra-thin overlay. Li et al. proposed a colored ultrathin overlay which had good skid-resistance, water permeability, and, most importantly, a cooling effect [9]. Budiarto et al. proposed an ultra-thin surfacing hot mix asphalt (UTSHMA) with strong water permeability resistance [10]. Other functional ultra-thin overlay technologies such as porous ultra-thin overlay (PUAO) and self-healing ultra-thin overlay were also tested.

In summary, substantial studies have been conducted to develop ultra-thin overlay technologies and achieved many positive results. However, research on forming a comprehensive performance evaluation method and customized design method has rarely been reported. The purpose of this study is to verify the application of high-viscosity and high-elasticity asphalt in ultra-thin overlay and propose a design and evaluation method considering the durability of skid resistance and crack resistance.

2. Materials and Methods

2.1. Materials

The HVHE (high-viscosity and high-elasticity) asphalt was prepared by modifying base asphalt with HVHE modifier. The technical indexes and test result of the HVHE asphalt were listed in Table 1. The trackless tack coat emulsified asphalt was used as adhesive layer material to resist damage during construction and improve interlayer bonding. Basalt aggregates are used as coarse aggregates to ensure slip resistance. Limestone aggregates are used as fine aggregates to enhance the adhesion of asphalt mortar. The aggregates met the technical specifications of JTG E20-2011 [11].

Table 1. Technical indexes and test result of the HVHE asphalt.

Technical Indexes		Unit	Results	Requirements	Test Protocols
Penetration (25 °C)		0.1 mm	61.9	40–80	T 0604-2011
Soft point		°C	92	≥90	T 0606-2011
Ductility (5 °C)		cm	45.4	≥40	T 0605-2011
Brinell rotational viscosity (60 °C)		Pa·s	>580,000	≥300,000	T 0620-2000
Elastic recovery		%	99	≥95	T 0662-2000
Evaporated residue	Quality loss	%	0.44	±1.0	T 0610-2011
	Penetration (25 °C)	0.1 mm	91	≥80	T 0604-2011
	Ductility (5 °C)	cm	33	≥25	T 0605-2011

2.2. Methods

Gradation Design of UT-10

The thickness of the ultra-thin overlay ranges from 1.5 to 2.5 cm. A gradation with a maximum nominal particle size of 10 mm was applied. Based on both OGFC-10 and SMA-10 mixtures, nine gradations, as shown in Figure 1, were developed to determine the range of the UT-10 mixture gradation. Five asphalt aggregate ratios were set from 5.2% to 7.2% with an interval of 0.5%. The immersion rutting test was conducted to determine the optimum air void ratio. The texture depth decay test and the TSRST test were carried out to obtain the optimum asphalt content.

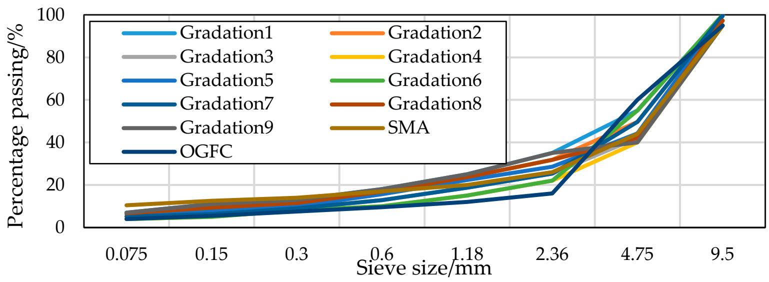

Figure 1. Nine preset gradations of UT-10.

3. Results and Discussion

3.1. Determination of Air Void Ratio

The results of the immersion rutting test are shown in Figure 2. They showed that the rutting deformation of Gradation 1, 2, 8, and 9 was around 2 mm, which is much larger than other gradations. The air void ratio of these four gradations ranged from 8% to 12%, indicating that it was difficult to drain water after it entered the semi-connected voids, and with the application of vehicle loads, water damage occurred, resulting in a larger rutting deformation. Therefore, the air void ratio of UT-10 mixture was determined to range from 12% to 15%.

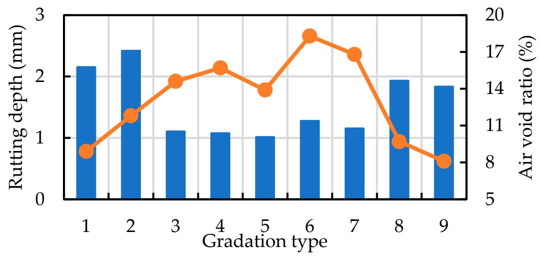

Figure 2. Results of the immersion rutting test.

3.2. Determination of Asphalt Aggregate Ratio

The results of the texture depth decay test are shown in Figure 3. They indicated that the texture depth attenuation increased with the rise in asphalt aggregate ratio, showing a slow growth trend at the three asphalt aggregate ratios of 5.2%, 5.7%, and 6.2%, and the anti-slip performance showed significant decay when the asphalt aggregate ratio exceeded 6.7%.

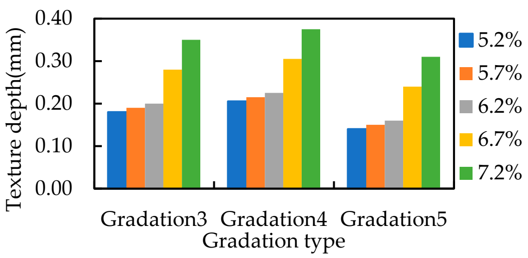

Figure 3. Results of the texture depth decay test.

The results of the TSRST test are shown in Figure 4. They indicated that the fracture temperature increased with the rise in asphalt aggregate ratio, and the anti-slip performance showed significant decay when the asphalt aggregate ratio exceeded 6.7%. For Gradation 3 and 5, when the asphalt aggregate ratio reaches 6.7%, the fracture temperature instead showed a slight increase.

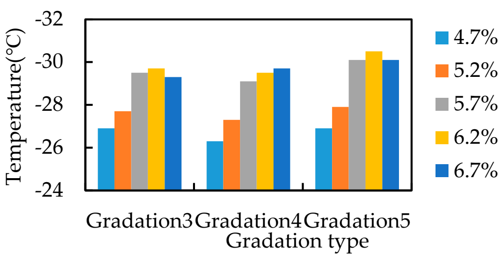

Figure 4. Results of TSRST test.

Based on the results of the texture depth decay test and the TSRST test, the final determined asphalt aggregate ratio of UT-10 mixture ranged from 5.2% to 6.2%.

3.3. Evaluation of Mixture Performance

The results of the evaluation tests are shown in Table 2. It can be seen that the performance of the HVHE mixture with gradation 5, 5.7% asphalt aggregate ratios, and 13.9% air void ratio fully meets the technical requirements, and has excellent high- and low-temperature performance.

Table 2. Results of the evaluation tests.

Technical Indexes	Unit	Results	Requirements
Leakage loss	%	0.1	≤0.3
Cantabro loss	%	1.71	≤8
Residential stability	%	87.0	≥85
TSR	%	81.6	≥80
Dynamic stability (60 °C)	loads/mm	6631	≥3200
Bending strain (−10 °C)	με	3864	≥2500

4. Conclusions

This study proposed an innovative design of ultra-thin asphalt overlays with high viscosity and high elasticity. The air void ratio and asphalt aggregate ratio were determined by designed test programs. The performance of HVHE asphalt mixture was verified. Several conclusions can be drawn as follows:

1. The performance of HVHE asphalt with gradation 5, 5.7% asphalt aggregate ratios, and 13.9% air void ratio fully meets the technical requirements (JTG E20-2011); the Brinell rotational viscosity of HVHE asphalt reaches 580,000 Pa·s, exhibiting superior bonding properties;
2. When the air void ratio of the HVHE mixture is between 12 and 15%, based on the immersion rutting test, it can drain the rainwater in time and reduce the water damage under the vehicle loads;
3. Based on the texture depth decay test, When the asphalt aggregate ratio is between 5.2 and 6.2%, it can guarantee the simultaneous durability of skid resistance and crack resistance under low temperature of the HVHE;
4. Based on the TSRST test, The HVHE mixture exhibits excellent high- and low-temperature performance, showing promising applications in North America.

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