Maintenance and Rehabilitation

Research and Application of Ultra-Thin Wearing Course with Large Porosity in Maintenance Engineering

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Abstract

In order to improve the driving safety and the noise reducing function of existing pavement, an ultra-thin layer wearing course with large porosity are developed. They are considered to be used as an overlay in maintenance of asphalt pavement, and built with thickness between 10mm and 25mm. In this paper, research focuses on the surface with a maximum aggregate size 10mm. Properties of binder are investigated firstly. In consideration of certain extreme weather condition and heavy traffic load in China, only modified asphalt is taken into account. Technical indicators and rheological properties of SBS modified asphalt and high-viscosity modified asphalt are investigated. It finds that there is a prominent improvement of material performances by using high-viscosity modified asphalt. Mixtures with target air voids contents from 15% to 20% are designed. Important factors presenting the high temperature property, moisture feature, anti-raveling performance and long-term application performance are investigated in lab. Meanwhile, sound absorption is also observed for samples with different air voids content and layer thickness. Considering a better bonding property between the porous wearing course and the underlying structural layer, the bonding strength of different materials are also tested and compared. It shows that the asphalt rubber stress absorbing membrane interlayer both show prominent tensile and shear strength, and suggested to be used as bonding material for porous thin layer wearing course. In the end, trial sections were constructed in Jiangsu province of China. Feasibility of using the ultra-thin wearing course mixture is proved. The achievements from the study will provide technical support for the maintenance scheme of porous asphalt and dense asphalt with moderate surface damage. It will also improve the skid resistance and the noise reducing function of the pavement, and has better social and environmental benefits.

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1. INTRODUCTION

Thin layer wearing course is commonly used as noise reducing road surface in European countries such as Germany and the Netherlands, and is used as anti-skidding surface course in the United States. According to definitions in different areas, it generally refers to asphalt pavement with small size aggregate (maximum particle size is not higher than 10 mm), by thickness of 15-30 mm. It can improve the safety and service life of road structure. As for gap graded type of thin layer wearing course, the air voids content is generally not smaller than 14%, while for porous type, it is higher than 18% [1]. In China, Ultra-Thin Wearing Course is defined as a thin functional surface for noise reduction or skidding resistance, with thickness from 10-25mm. A porous ultra-thin wearing course (PUC) has the air voids contents not less than 18%, and connected air voids content is generally above 12%. The rainwater can be quickly discharged through the voids without being left in the road surface.

It is known that the most typical structural disease form of a porous asphalt pavement is raveling caused by strip of coarse aggregate [2]. This disease is also particularly prominent for ultra-thin wearing courses. Because of small nominal maximum particle size of aggregate and low embedding force of coarse aggregate in PUC, it is easier to destabilize and disperse under traffic loads and environmental factors. Therefore, asphalt binder is required to have strong encapsulation ability and high adhesion to coarse aggregate.

Based on improvement and optimization of European experience and according to climate and traffic characteristics of various regions in the country, Japanese road engineering community focused on study of binders and proposed high-viscosity modified asphalt (HVMA) [3]. The main component of high-viscosity modification additives (HVA) is thermoplastic rubber, which forms a polymer network structure between polymer in the HVA and the asphalt component [4]. In order to adapt to high temperature and heavy traffic conditions in summer, the HVMA materials were also developed and applied in China for construction of porous asphalt. And the dynamic viscosity at 60 °C can be over 100000 Pa·s [5]. Xu et al. observed high temperature performance of aged high-viscosity modified asphalt and its adhesion to coarse aggregate by means of multi-stress creep recovery as well as ultraviolet spectroscopy [6]. Qin et.al. used temperature sweep and frequency sweep tests to investigate influence of temperature and frequency on anti-rutting performance of high-viscosity modified asphalt, and it is considered that these methods are better in presenting a practical load in the road surface [7].

As a functional surface, the noise reducing properties have also attracted the attention of researchers. The acoustic properties of porous asphalt mixtures are generally analyzed from surface texture and noise absorption properties. Sanberg [8] studied the effects of noise texture and texture depth on porous asphalt pavement. Li et al. studied the combined effects of surface texture and sound absorption on noise level based on experimental data analysis and developed the prediction model for tyre/road noise for a thin layer surfacing. It finds that larger air voids content of thin layer surfacing can improve sound absorption and reduce noise level at high frequency (>1000Hz) [9, 10].

In China, it is considered to use PUC as an overlay in maintenance engineering of highways, which aims to improve driving safety and to reduce traffic noise of the lane. However, a challenge is that the durability of a PUC mixture decreased with an increasing air voids content. In order to improve the mechanical performance of PUC, high-viscosity modified asphalt was employed as the binder. Technical indicators and performances of SBS modified asphalt and those of HVMA were compared, as well as mixture and sound absorption properties were investigated by laboratory tests. And finally, an appropriate type of PUC mixture for highway maintenance engineering is obtained. Different types of bonding layer materials were investigated and compared. Application of this type of material was carried out in field engineering. The research results provide a road surface structure with functional and structural advantages for highway maintenance.

2. BINDER PROPERTIES

SBS modified asphalt is the commonly used binder for top surface on highway in China. In this study, the HVMA was prepared based on composite modification by blending SBS asphalt and HVA modifier. The ratio between the mass of SBS asphalt and HVA is 92:8.

2.1. Basic properties

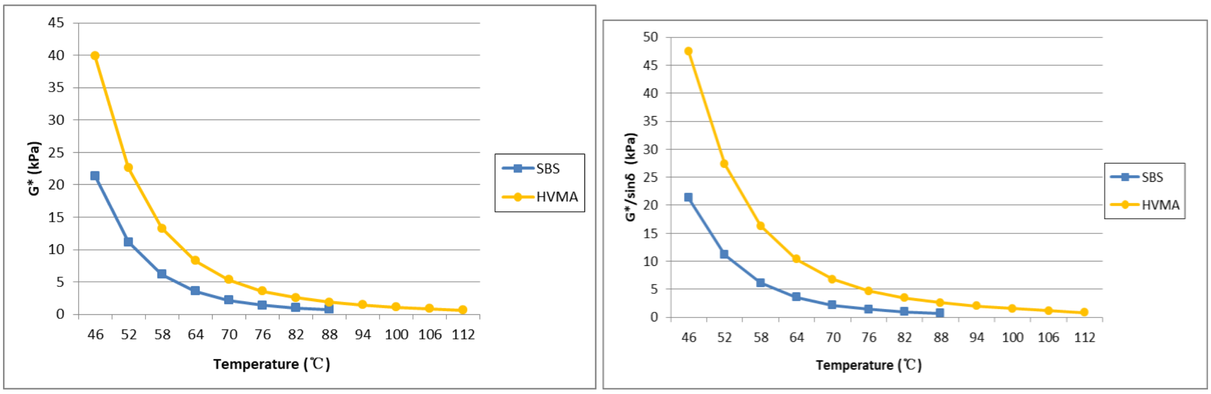
The basic technical indicators for SBS and HVMA asphalt are measured and compared. The test method is based on Chinese standard “Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering” (JTG E20-2011) and test results are shown in Table1. It can be seen that there is improvement for high temperature indicator (Needle Penetration at 25℃ and Softening point) as well as ductility of the binder after modified by HVA. Significant increase of dynamic viscosity at 60℃ is observed in HVMA. Existing studies show that [5], with a higher dynamic viscosity of asphalt at 60 °C, compressive strength, splitting strength and bending strength of porous asphalt mixture can be obviously increased. Brookfield viscosities are measured at different temperatures as production and compaction temperatures of SBS and HVMA binder are different. For HVMA, construction temperature is generally higher considering the workability.

Table 1. Technical indicators of SBS and high-viscosity modified asphalt

Asphalt performance indicator	Unit	SBS	HVMA
Needle Penetration, 25°C，100g，5s	0.1mm	54	48
Softening point（$T_{R\&B}$）	℃	86	91.5
Ductility （5°C，5cm/min）	cm	37	32
Dynamic viscosity（60°C）	Pa·s	13250	777548
Brookfield viscosity	Pa·s	2.382, at 135℃	1.069, at 170℃

2.2. Rheological Properties

Dynamic shear rheometer (DSR) is used for rheological properties investigation. The temperature sensitivity of different asphalt is analyzed by measuring complex shear modulus G*, phase angle δ and rutting factor G*/sinδ of asphalt. With a fixed loading frequency of 10 rad/s and stress level of 0.1kPa, tests are carried out at temperatures from 46 °C to the failure temperature of binder. Parallel plate of 25 mm is used, and the space between upper and lower parallel plates is fixed at 1 mm. The result complex shear modulus G* and rutting factor G*/sinδ in accordance with different temperatures are shown in Figure 1.



(a) G* (b) G*/sinδ

Figure 1: Test results of complex shear modulus G* and rutting factor G*/sinδ

Following analyses are carried out per Figure 1.

(1) Complex shear modulus

From Figure 1 (a), it can be seen that complex shear modulus G* of SBS modified asphalt and HVA modified asphalt are in good correspondence with test temperature. With the increase of temperature, complex shear modulus of both asphalts shows a downward trend. At the same temperature, the curves of complex shear modulus of HVA modified asphalt with temperature are above SBS modified asphalt, which presents a prominent high temperature performance.

(2) Rutting factor

The rutting factor G*/sinδ is used to evaluate resistance of asphalt materials to high temperature permanent deformation after ageing and short-term ageing. In Figure 1(c), rutting factors of both SBS modified asphalt and HVA modified asphalt show a downward trend. At the same temperature, rutting resistance of HVA modified asphalt is significantly higher than that of SBS modified asphalt. And the critical temperature of HVMA is 20℃ higher than that of a SBS asphalt. All the results show a superior high temperature performance of HVMA in comparison with SBS modified asphalt.

3. MIXTURE PERFORMANCE

3.1. Mixture Design

(1) Gradation

In this study, a PCU-10 mixture is designed for analysis and coarse aggregate size is from 4.75 to 9.5 mm. Considering that the range of 4.75-9.5mm gear aggregate is too large, it was decided to increase a 7.5mm mesh for the mixture design. Among them, 4.75-7.5mm and 7.5-9.5mm are mainly used as coarse skeleton structure to ensure the skeleton embedding, while 0-3mm fine aggregate mainly plays the role of filling the gaps. The target void contents are designed as 20%, 18%, and 15%, and grading curves for different air voids contents are shown in Figure 2. The gradations are marked as A, B and C.

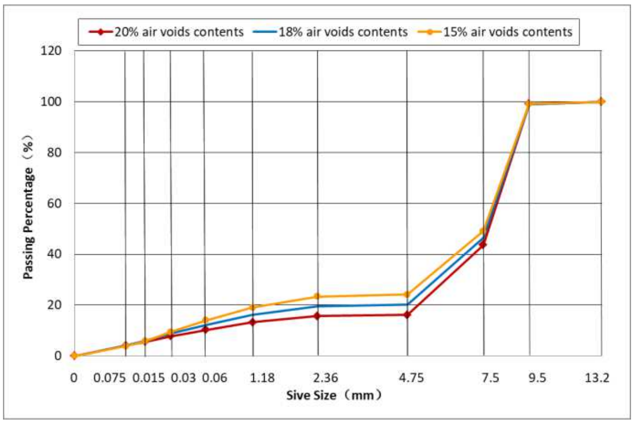


Figure 2: The gradation curve for PUC-10 mixture with different air voids content

(2) Asphalt content

Based on porous characteristics of ultra-thin wearing course of large voids, the combination of drainage and raveling test is used to determine the optimum asphalt content according to "inflection point" of the curve. In this study, for Gradation A, B and C, the optimum asphalt content is 4.7%, 5.0% and 5.1% respectively.

3.2. Freeze-thaw split tensile strength

The freeze-thaw split test is to determine the strength ratio of asphalt mixture test sample before and after water damage, so as to evaluate water stability of the asphalt mixture. The test was carried out for two groups of specimens. The first group was stored at room temperature. The second group was vacuumed for 15 minutes and then immersed in the water for 0.5 h. The bag was placed in an incubator at -18 ° C for 16 h, and then placed in a constant temperature water bath at 60 ° C for 24h. The test results are shown in Figure 3.

It can be seen from Figure 4 that the 20% and 18% void ratio PUC-10 asphalt mixture freeze-thaw splitting tensile strength ratio is slightly lower than the conventional 80% requirement of China Highway, and the 15% void ratio asphalt mixture meets the specification requirements. In response to this situation, we conducted repeated experiments through the following three scenarios to improve the performance:

a. Replace asphalt for another SBS modified asphalt

b. Replace mineral filler

c. Replace the filler with 50% hydrated lime

The results of freeze-thaw split test for the above three schemes are shown in Figure 4.

According to test results:

(1) By replacing the test raw material asphalt and mineral filler, the influence on performance is insignificant.

(2) Using 50% hydrated lime to replace original filler can increase the freeze-thaw splitting tensile strength ratio, but this may bring about changes in other test indexes of porous asphalt mixture, which should be based on the actual engineering technology.

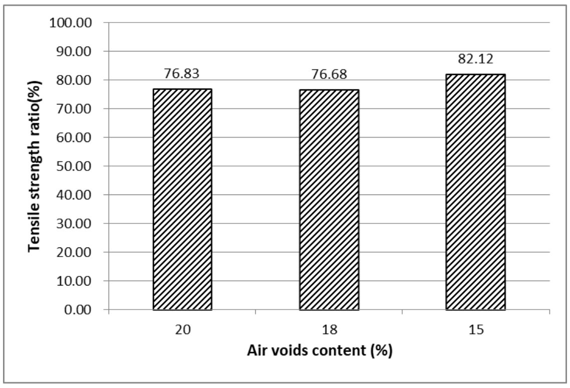


Figure 3: Residual split tensile strength for PUC-10 mixtures

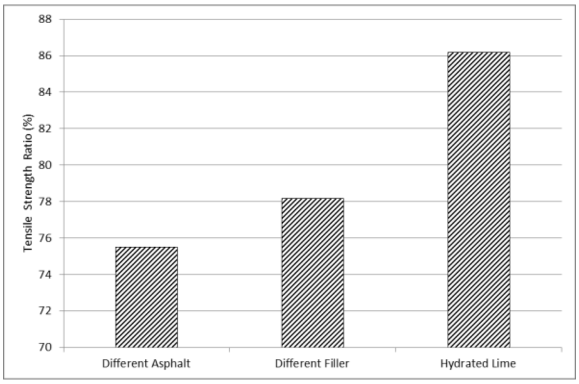


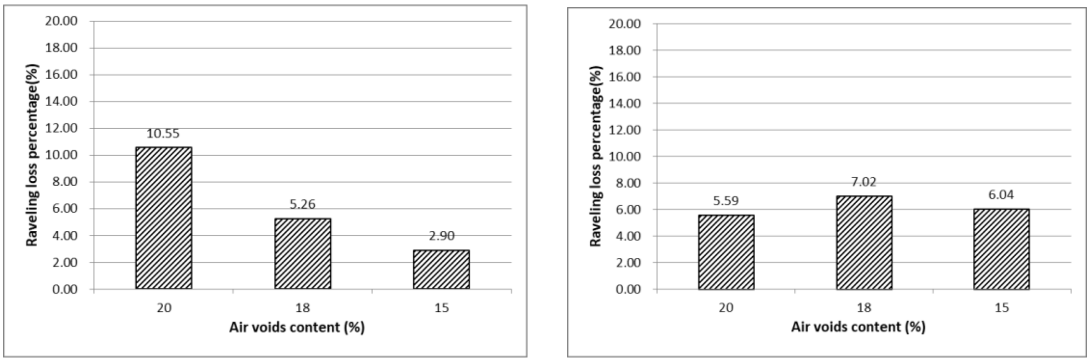
Figure 4: Residual split tensile strength for PUC-10 with material adjustment

3.3. Anti-raveling performance

Raveling is a significant disease of mixture with large porosity. The test was conducted by Los Angeles Abrasion Tester. Test results of standard raveling and immersion raveling are shown in Figure 5. It indicates that:

(1) The results of standard raveling test show that with decrease of void ratio, raveling loss of PUC-10 mixture decreases significantly, and raveling loss percentage of asphalt mixture of 15%, 18% and 20% can meet technical requirements of porous asphalt mixture in China, which is generally 15% for expressway.

(2) The results of water immersion raveling test show that PUC-10 mixture with 15%, 18% and 20% air voids content has little water immersion raveling loss, and correlation with void variation is not remarkable. Mixture with all air voids content show good performance for anti-raveling.



(a) Standard raveling measurement (b) Immersion raveling measurement

Figure 5: Raveling loss percentage for PUC-10 mixtures

3.4. Long-term aging performance

Asphalt mixture will gradually age in service process, and asphalt pavement damage often occurs in different periods. Therefore, it is necessary to conduct long-term aging test on porous asphalt mixture to analyze mixture performance.

In the test, PUC asphalt mixture was heated for 4 hours under the forced air condition of 135 ° C ± 3 ° C for short-term aging, and specimens were continuously heated in an oven at 85 ° C ± 3 ° C for 5 days. The test results are shown in Table 2.

It can be seen from Table 2 that after long-term aging, the immersion raveling rate increases by about 11%, and Marshall stability, residual stability, standard raveling loss, and freeze-thaw splitting residual strength were improved. All indicators meet the requirements of an experienced engineering requirement in China, which means the current design of PUC-10 material can adapt to environmental effects in long-term use.

Table 2. Test results of performances after long-term ageing

Performance	**Test results**		**Engineering Requirements**
	Before ageing	After ageing	
Marshall stability, kN	7.43	7.49	≥5.0
Residual Mashall stability percentage, %	94.30	100	≥85
Standard raveling loss percentage, %	10.55	7.3	≤15
Immersion raveling loss percentage, %	5.59	6.2	≤20
Residual Freeze-thaw split tensile strength ratio,%	86.5	88.6	≥80

3.5. Sound Absorption Performance

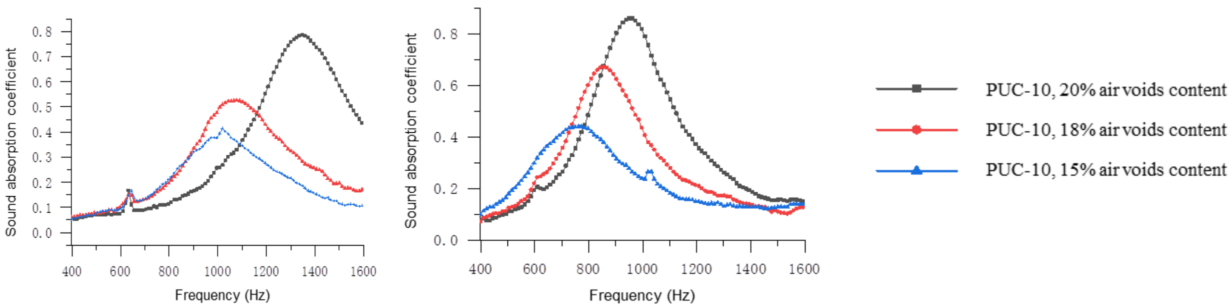
Aiming at main influencing factors of road surface noise reduction, sound absorption performance of porous thin layer pavement is analyzed. Specimens with thicknesses of 25mm and 40mm were respectively formed for comparing a thin layer surfacing and a course with typical thickness. The sound absorption coefficients are measured by impedance tube device. And sound absorption curves obtained are shown in Figure 6.

As can be seen from Figure 6:

(1) The sound absorption coefficient-frequency curves of different air voids contents all showed similar trends. As frequency increases, sound absorption coefficient of the mixture gradually increases, and gradually decreases after reaching the peak value.

(2) Within a certain thickness range, the peak frequency of the same thickness mixture is in range of 500~1400 Hz, and the peak of sound absorption coefficient becomes "high and wide" with increase of air voids content, which is very obvious for improvement of sound absorption effect of asphalt mixture. The peak value of curve increases as air voids content increases, and corresponding frequency of the peak also gradually shifts toward high frequency direction.

(3) In particular, when thickness is increased to a certain range, even if the thickness of mixture is kept constant, the peaks of sound absorption coefficient of mixture of different void ratios tend to gradually close together, so that the peak of sound absorption coefficient corresponds to tendency of the frequency to shift toward high frequency.

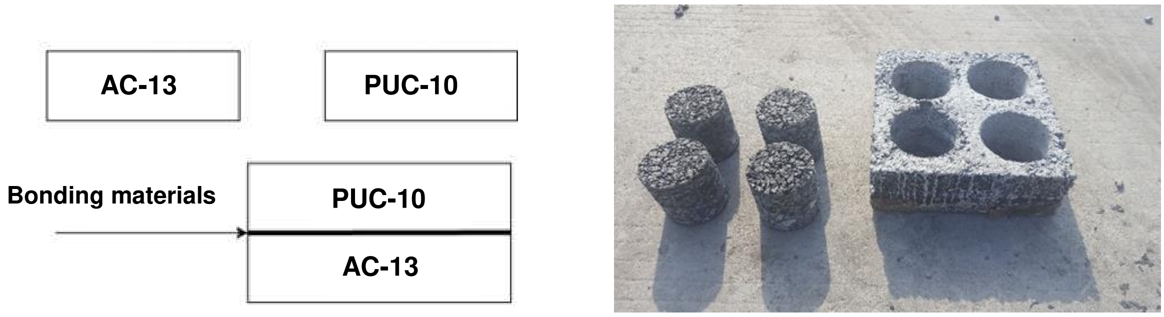


（a）PUC-10 with thickness 25mm （b）PUC-10 with thickness 40mm

Figure 6: Sound absorption curves for PUC-10 mixtures

4. INTERLAYER BONDING MATERIALS

For porous thin surfacing, as contact area with course underneath is smaller than that of dense graded pavement, the strength of interlayer bonding material is required to be higher. Three types of bonding materials are compared in this study, namely, including SBS modified emulsified asphalt commonly used in dense graded pavement, rubber asphalt (AR) stress absorbing membrane interlayer (SAMI) and SBS modified asphalt chip seal, which are generally used in maintenance engineering. The shear strength and tensile strength of bonding materials are used to evaluate performance of adhesive materials. The test temperature is 25°C , and loading force is applied at 50 mm/min. The forming process of specimens are: (1) AC-13 asphalt specimens are compacted in laboratory, the size of which is 300 mm × 300 mm × 50 mm; (2) bonding interlayer materials are uniformly coated on different specimens according to actual dosage; (3) a 50 mm PUC-10 mixture is added on the top of AC-13 specimens by compacting, and a double-layer specimen is formed; (4) drill core samples from double-layer specimens. The schematic of specimen preparation and pictures of samples are shown in Figure 7.



(a) Schematic of the double-layer specimen (b) Core samples from the double-layer specimen

Figure 7: Preparation of samples for tensile and shear strength

Test results of interlayer bonding strength of the three materials are shown in Table 3. The dosages for different materials refer to the engineering experiences in China. It can be seen from the table that when modified asphalt SAMI is used as adhesive layer material, its bonding strength is greater than that of SBS modified emulsified asphalt. The main reason is the interlocking between gravels and aggregate of the porous structure of the thin layer; and bonding force provided by more asphalt content is also one of the reasons. The interlayer bonding strength of AR-SAMI is greater than that of SBS chip seals, because viscosity of rubber asphalt is higher than that of SBS modified asphalt under the same conditions, so bonding force provided by rubber asphalt is also greater. Therefore, it is recommended to use rubber asphalt stress absorbing layer in practical application.

Table 3. Interlayer bonding strength of the three materials

Items	Interlayer bonding materials		
	SBS modified emulsified asphalt	**SBS-SAMI**	**AR-SAMI**
Material dosage	0.4 kg/㎡ for pure asphalt	Asphalt: 1.5 kg/㎡ ; Gravel size: 5~10mm; Gravel spreading area: 60%	Asphalt: 1.5 kg/㎡ Gravel size: 5~10mm; Gravel spreading area:60%
Shear Strength (MPa)	0.434	0.623	0.671
Tensile Strength (MPa)	0.267	0.380	0.433

5. TRIAL SECTION CONSTRUCTION

The porous asphalt pavement of coastal highways in Jiangsu province in China was constructed in 2005. It has been used in operation for more than 14 years. Field investigations showed that porous asphalt has been clogged to some extent. However, as rough texture of road surface helped to break the water film, it still has certain drainage function in rainy time. In order to improve safety performance in rainy days, it was planned to build PUC-10 porous ultra-thin wearing course for maintenance and repair of porous asphalt pavement. And this technology will be verified and summarized during service process. The specific maintenance section is K1125+200~K1124+190 from south to north, with total length of 1.0 km. The thickness of trial section is 25mm. Results of measurements on the mixture and pavement surface are shown in Table 4. It can be seen that performance of PUC-10 surface can meet requirements for road service. The long-term performance and functions of pavement will continue to be investigated in future studies.

Table 4. Measurement results on the newly paved PUC-10

Position	Lane	Thickness, mm	Air voids content, %	Compaction Degree, %	Permeability （ml/min）	British pendulum number （BPN）
K1125+000	Middle Lane	24.7	23.0	98.1	5556	57
K1124+700	Fast Lane	27.3	23.9	97.0	5310	61
	Middle Lane	27.2	22.7	98.5	5279	62
K1124+400	Fast Lane	26.5	23.3	97.7	5357	64
	Middle Lane	24.2	21.5	100.0	4700	65
	Heavy Lane	28.3	21.6	99.9	5187	60

(a) The PUC-10 surface (near) and the dense surface (far) in rain time (b) The surface appearance of PUC-10

Figure 8: The PUC-10 trial section

6. CONCLUSIONS AND RECOMMENDATIONS

In this paper, the comprehensive study on binder properties, mixture performances, interlayer bonding materials for a PUC-10 type of porous ultra-thin wearing course was carried out. And road surface performance was investigated by construction of a trial section in Jiangsu Province of China. The main conclusions and recommendations are as follows:

(1) In order to maintain the durability of a thin wearing course with large air voids content. It is suggested to use high-viscosity modified asphalt as a binder, which can improve dynamic viscosity at 60 ℃ and high temperature performance significantly.

(2) According to performance study on PUC mixture, for PUC type mixture with high-viscosity modified asphalt as binder, when the air voids content is 15%-20%, it can meet requirements of high temperature, low temperature, water damage resistance, raveling resistance and long-term aging performance in China.

(3) Air voids content affects mixture’s peak value and peak frequency of sound absorption coefficient, that is, when air voids content is larger, peak value is higher, as well as a lower peak frequency correspondingly.

(4) Different types of interlayer bonding materials are compared by evaluating tensile strength and shear strength. The results show that AR-SAMI is more suitable for using as the interlayer bonding material, due to high viscosity of rubber asphalt and interlocking contact with PUC-10 provided by the gravels.

(5) The preliminary application of PUC-10 porous ultra-thin wearing course technology was carried out in a trial section. It showed a prominent permeability, meanwhile its other performance can also satisfy the requirements for using in China. In-situ observation on trial section will be carried out, and construction techniques such as paving,

rolling and temperature control will be improved as well.

At present, wearing course with thinner layer thickness and small aggregate size are being studied. And the mixtures type PUC-8 or PUC-5 will also be tested and applied in the future work.

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