



Research on the Shear Strength of Porous Asphalt Overlay

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Abstract. To investigate the factors influencing the bonding strength between the PAC-13 overlay and the underlying layer, this study focused on a porous asphalt concrete (PAC) overlay project on the Yan-Jing Expressway. Six types of core samples were subjected to conduct shear strength test at three temperatures (25°C, 45°C, and 70°C). The study examined three factors: temperature, material type, and surface texture depth. Results showed that at an intermediate temperature (25°C), the shear strength of SBS modified emulsified asphalt was 75% of that of rubber asphalt, and the texture depth of the underlying layer significantly impacted shear strength, with the milled surface exhibiting a shear strength 0.73 MPa higher than that of the road marking surface. As temperature increased from 25°C to 45°C, shear strength decreased by over 40%, with the range of shear strength decreasing from 0.73 MPa at 25°C to 0.11 MPa at 45°C. To evaluate the interlayer contact area, MATLAB software was used to enhance and sharpen post-test images of the samples. The Otsu method was applied to convert these images into binary images, allowing for the calculation of the contact area between the PAC-13 overlay and the underlying layer. Results indicated that as temperature rose, the contact area of core samples decreased from 79% at 25°C to 66% at 45°C, and to 62% at 70°C. Based on these findings, the thermal stability of the waterproof and cohesive layer must be enhanced to prevent shear failure at high temperatures.

Keywords: Porous asphalt; Shear strength; Shear test; Waterproof and cohesive layer

1 Introduction

Asphalt mixtures are highly temperature-sensitive, with properties that transition from elastic to plastic at elevated temperatures. As a result, even minimal shear stress from vehicle loads can cause shear failure in the pavement, manifesting as rutting. In recent years, as carbon emissions have steadily risen, some regions in China have experienced prolonged high summer temperatures. Under these conditions, shear failure is likely to occur in the middle surface layer of the pavement due to vehicle loads, leading to

significant rutting damage. To mitigate shear failures in road surfaces caused by vehicular loads, researchers have primarily concentrated on developing shear testing methods and establishing indices to quantify shear resistance. In 1994, Southgate employed a triaxial shear test to design asphalt mixtures and proposed that pavement thickness could be validated using this method [1]. Davide Ragni et al. developed a test protocol to examine the damage characteristics of the interface bond using a cyclic shear load on a double-layered asphalt specimen, the results indicated that specimens with a tack coat at the interface exhibit significantly better shear fatigue life resistance than those without a tack coat [2]. J Zak proposed the Uniaxial Shear Tester (UST), which more accurately simulates the actual stress state of the road [3]. Regarding material properties, W Jiang et al. studied the bonding layer material in porous asphalt pavement. Their analysis of the shear strength of the bonding layer under various adverse conditions revealed that freeze-thaw cycles had a significant impact, with the shear strength decreasing by nearly 50% after two cycles [4]. Jiang et al. investigated the factors influencing the shear strength and cracking mechanism of asphalt mixtures through numerical tests of uniaxial penetration, and found that aggregate gradation and asphalt type had the most significant effects [5]. Song et al. investigated the interlayer bonding performance between open-graded friction course (OGFC) layers and underlying layers, focusing on the effects of tack coat application and underlying layer type [6]. The results revealed the significant influence of temperature, tack coat, and underlying layer type on the bonding and fracture behavior between layers. Some scholars studied shear stress based on the theory of artificial neural networks. AL-Jarazi et al. employed supervised machine learning to predict the interface fatigue life (IFL) and interface shear stiffness (ISS) of asphalt pavements [7]. Researchers, both domestically and internationally, have examined pavement shear strength from these perspectives and obtained a series of important findings.

Despite ongoing research, a comprehensive understanding of the shear strength of porous asphalt overlay, particularly with regard to the waterproof bonding layer, remains lacking. Unlike dense-graded asphalt pavement, porous asphalt overlay function as drainage layer and is composed of large-void asphalt mixtures, requiring a waterproof bonding layer to maintain adequate interlayer adhesion and shear strength between the overlay and the existing surface layer. This bonding layer is essential for ensuring both waterproofing and shear integrity in porous asphalt pavement. In terms of its intended purpose and required performance, the technical specifications for the waterproof bonding layer are considerably more demanding than those outlined in current Chinese standards for traditional bonding layers.

This study is based on the reconstruction project of the Yanjing Highway, which is in Jiangsu Province. Through shear testing of pavement core samples, it assesses the shear strength of the waterproof bonding layer and examines key influencing factors, including temperature, bonding layer material, and contact surface roughness.

2 Project Background

Yanjing Highway has been in operation for over 20 years, following its acceptance inspection in November 2001. The original pavement structure is shown in Table 1.

Table 1. Original Pavement Structure

Position	Thickness	Material
Surface layer	4 cm	Modified AK-13
Middle layer	6 cm	Superpave-20
Bottom layer	8 cm	AC-25
Base	40 cm	Cement stabilized crushed stone
Subbase	20 cm	Lime and fly ash stabilized soil

To enhance pavement conditions and ensure the pavement's serviceability, the highway section K89+430-K96+000 is prepared to be paved with a 4 cm PAC-13 overlay. The construction plan is: for sections with rutting depths less than 10 mm, considered as normal sections, the existing pavement will not be milled, and porous asphalt overlay will be directly applied. In these sections, the emergency lane will have a tapered overlay thickness, ranging from 40 mm on the inner side to 25 mm on the outer side. For sections with rutting depths between 10 mm and 15 mm, classified as deep-rutting sections, the passing and driving lanes of the old road will be milled to a depth of 15 mm. In the emergency lane, milling will gradually taper from 15 mm to 0 mm over a 2-meter width, followed by the application of porous asphalt overlay.

The construction plan for the waterproof bonding layer is: spread 1.5 kg/m² of rubber asphalt crushed stone waterproof bonding layer on the passing lane and driving lane, with a thickness of 5 mm and a crushed stone spreading amount of 60% of the full paving; spread 0.3kg/m² (in terms of solid content) of SBS modified emulsified asphalt waterproof bonding layer on the emergency lane.

Due to the presence of road markings on the unmilled portions of the existing road surface, four distinct contact surface conditions are identified: milled, unmilled (directly applying overlay), gradient milled, and road markings. Gradient milled, given its shallow depth, can be regarded as a form of surface roughening treatment. Twenty-four core samples were cored from the passing lane, driving lane, and emergency lane. For these samples, shear tests were performed to study the effects of temperature, bonding layer material, and structural texture depth on shear strength. The core sampling plan is presented in Table 2.

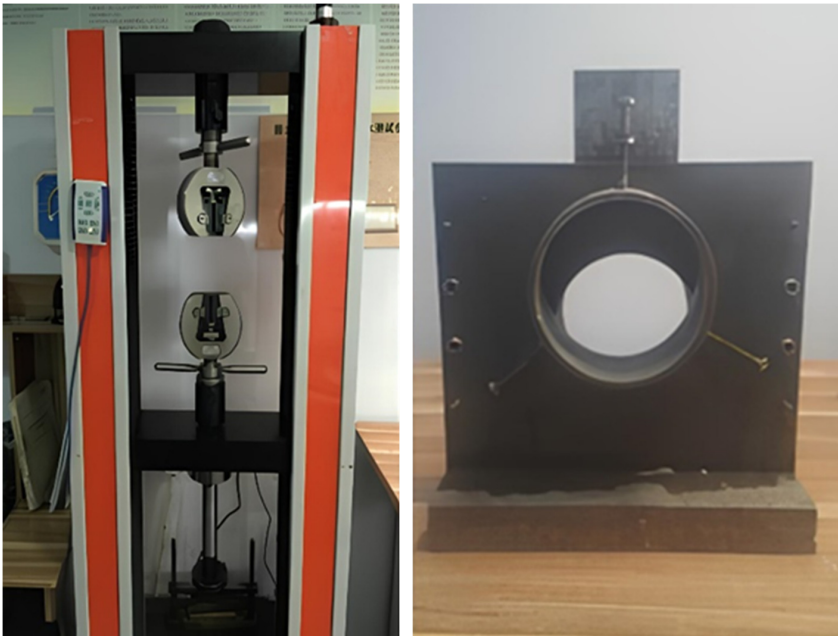
Table 2. Core sampling plan

Bonding layer type	Rubber asphalt with synchronized crushed stone		SBS modified emulsified asphalt			
Location	Passing Lane	Driving lane		Emergency lane		
Treatment plan	Milled	Un-milled	Road marking	Milled	Gradient milled	Unmilled

Number of core samples	6	4	3	3	4	4
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3 Test Method

Shear tests were conducted using the WDW-100 electronic universal testing machine at temperatures of 25°C, 45°C, and 70°C. The tests utilized the machine's stretching and compression functions, along with a custom-made fixture. The test equipment is shown in Fig. 1. The temperature is regulated using a temperature chamber, and the core sample is placed in the chamber for 5-12 hours before the test. The shear rate is 5mm/min, and the computer automatically records the data during the test.



(a) WDW-100 electronic universal testing machine; (b) Shear test clamp

Fig. 1. Test device and fixture

4 Results and Analysis

4.1 Effect of temperature

Tests were conducted at three temperatures from 25 °C to 70 °C. The test results are shown in Fig. 2.

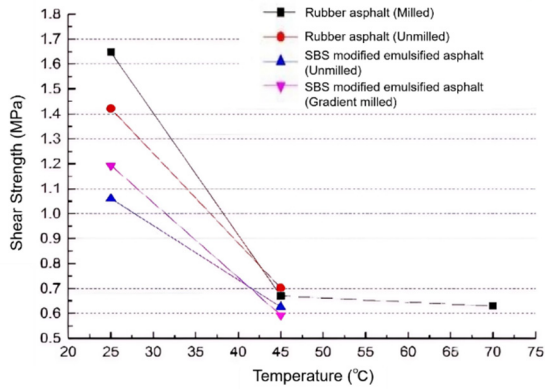


Fig. 2. Bond strength at different temperatures

It can be observed from Fig. 2 that temperature significantly affects the shear strength of the waterproof bonding layer. As the temperature increased from 25°C to 45°C, the shear strength of the bonding layer under all four conditions decreased markedly. Among these, the shear strength of the rubber asphalt waterproof bonding layer with milling treatment dropped from 1.6 MPa to 0.7 MPa, representing the largest decrease of 56%. The rubber asphalt (unmilled) showed the second largest decrease at 51%, while the other two conditions saw reductions of 50% and 41%, all exceeding 40%. The shear strength of the four core samples ranged from 0.73 MPa at 25°C to 0.11 MPa at 45°C. When comparing the shear strength of the rubber asphalt (milled) bonding layer at 45°C and 70°C, a 6% decrease was observed. This suggests that the temperature at 45°C has a considerable impact on the shear strength.

4.2 Effect of Bonding Layer Material

The bond strength of interlayer materials, including rubber asphalt and SBS modified emulsified asphalt, was compared. The test results are shown in Fig. 3.

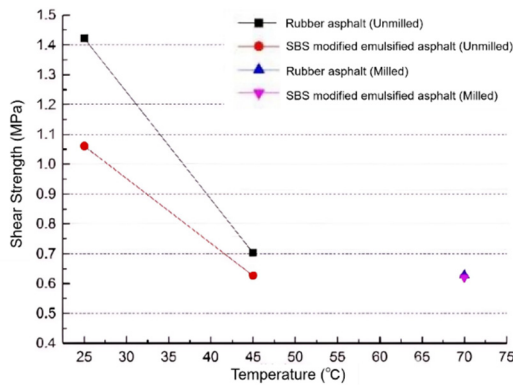


Fig. 3. Bond strength of different bonding materials

It can be observed that, under the same temperature and contact surface treatment conditions, the shear resistance of rubber asphalt is stronger than that of SBS modified emulsified asphalt. However, this difference diminishes significantly as the temperature increases. At 25°C, the shear strength of SBS modified emulsified asphalt is 75% that of rubber asphalt, while at 45°C, it rises to 89%. When comparing the two materials after milling treatment on the original road surface at 70°C, the shear strength difference between them is only 0.008 MPa. As the temperature rises, the viscosity of asphalt decreases significantly, causing both materials to lose much of their original interlayer bonding effect at high temperatures (70°C).

4.3 Effect of Surface Structure Texture Depth

Since the original pavement underwent different treatments before the PAC-13 overlay was applied, the interlayer contact conditions varied, resulting in different surface structural texture depths. Among the four interlayer contact conditions, the milled surface exhibited the greatest structural texture depth, followed by the gradient milled pavement, while the marked surface had the shallowest structural texture depth. It is generally understood that a greater structural texture depth enhances the interlocking effect between the overlay and the original pavement, thereby increasing interlayer friction and shear strength. This trend can be observed in Fig. 4.

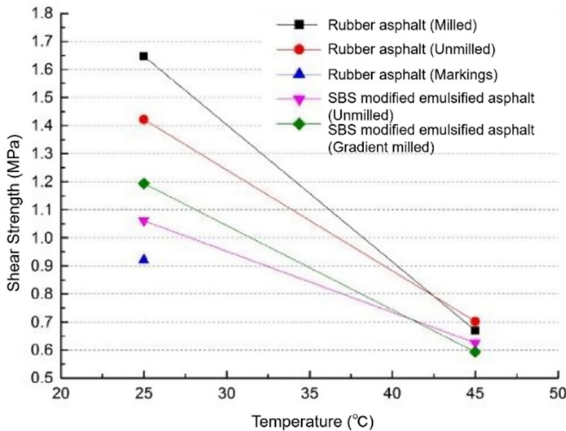


Fig. 4. Effect of structural texture depth

At 25°C, the shear strength of rubber asphalt follows the order: milling > no milling > marking. The shear strength of the milled surface is significantly stronger than that of the marked surface, with a difference of 0.7 MPa, and 0.2 MPa stronger than the unmilled surface. For SBS modified emulsified asphalt, the shear strength ranks as: roughening > no milling, with a difference of 0.1 MPa. This indicates that, at room temperature, greater texture depth results in stronger shear strength of the waterproof bonding layer. However, when the temperature rises to 45°C, the effect of texture depth on shear strength diminishes. In fact, for the same material, the shear strength of the

pavement paved after milling treatment is approximately 0.03 MPa lower than that of the unmilled pavement.

4.4 Analysis of Interlayer Contact Area

To examine the cross-section of the core sample after shear damage more closely, the cross-sectional image was processed using MATLAB image processing software and subsequently binarized. The images of the core sample section before and after binarization are shown in Fig. 5. After binarization, the pixel grayscale values were reduced to two states: 0 or 255, resulting in a black-and-white visual effect. Once the cross-sectional image was binarized, the percentage of the black region was calculated using a MATLAB function to determine the contact area between the PAC overlay and the original road surface. Each pixel of the binarized grayscale image was scanned, and the number of pixels with grayscale values below the threshold T was counted. Entropy calculations were performed on the total number of image pixels to determine the percentage of the black area on the shear failure surface. The contact between the PAC overlay and the original road surface on the shear failure surface was then evaluated based on this result.

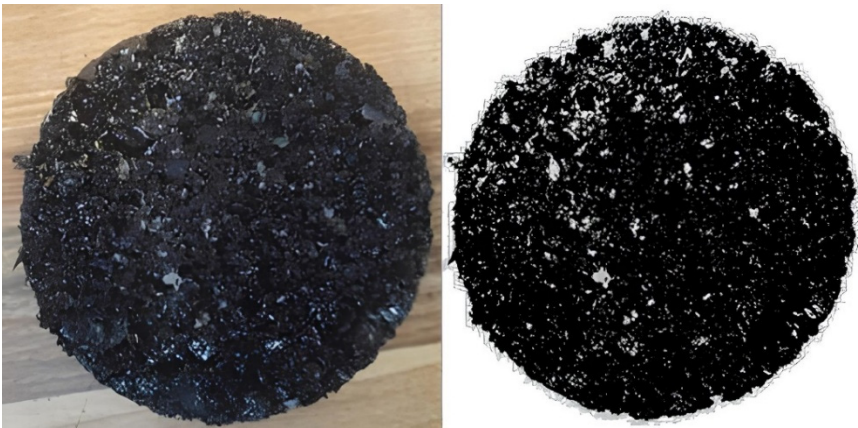


Fig. 5. Binarization of shear failure surface

The contact area of the rubber asphalt adhesive layer in the directly applied overlay was calculated and found to be as follows: at 25°C, the contact area was 79%; at 45°C, it decreased to 66%, a reduction of 13%; and at 70°C, it was further reduced to 62%. Since the porous asphalt overlay is a large-void top layer with a void ratio of 15% to 20%, its contact area with the original pavement is smaller than that of conventional densely graded pavements. As the temperature increases, the contact area decreases further. The viscosity of the asphalt decreases at higher temperatures, exhibiting plastic behavior, which leads to a further reduction in interlayer bonding strength, and consequently, a decrease in the shear strength of the pavement.

5 Conclusions

This study takes the reconstruction project of Yanjing Highway as the research background. The shear strength of the pavement core samples was determined through shear tests, and the factors influencing the shear strength of the waterproof bonding layer, including temperature, bonding layer material, and contact surface roughness were analyzed. The impact of applying porous asphalt overlay after milling the old road was also examined to assess how the milling process affects interlayer bonding. Additionally, MATLAB image processing software and the Otsu algorithm were applied to calculate the contact area of the bonding layer on the shear failure surface after binarizing the image. The main conclusions are as follows:

1. High temperature, adhesive layer material, and surface structural texture depth of the overlay all influence shear strength, with temperature having the most significant effect. At 45°C, the shear strength in the four cases decreased by 56%, 51%, 50%, and 41%, respectively. As the temperature increases, the difference in shear strength between core samples diminishes, with the maximum shear strength difference among the four core samples reducing from 0.73 MPa at 25°C to 0.11 MPa at 45°C.
2. At room temperature (25°C), the shear strength of rubber asphalt is stronger than that of SBS modified emulsified asphalt, with the latter's shear strength being 75% of that of rubber asphalt. However, as the temperature increases, the difference diminishes significantly, and at 70°C, the shear strength difference between the two materials is only 0.008 MPa.
3. At room temperature (25°C), the surface structure texture depth positively affects shear strength. Among the four contact surface conditions—milling, roughening, direct paving, and marking—the shear strength of the pavement with milling treatment is the highest, while the shear strength of the pavement with marking is the lowest. However, this effect diminishes at high temperatures.
4. Due to structural characteristics, the contact area between the porous asphalt overlay and the original pavement is 15% to 25% smaller than that of dense-graded asphalt mixtures. At high temperatures, the contact area of the bonding layer is further reduced. Additionally, as the viscosity of the asphalt decreases, the bonding strength of the waterproof bonding layer is significantly weakened. Therefore, for porous asphalt overlay, it is essential to enhance the waterproof bonding layer by increasing the amount of material, using high-viscosity asphalt, and considering the impact of temperature on shear strength to prevent shear failure at elevated temperatures.

Based on the findings of this study, the following suggestions for future research and improvements are proposed:

1. The effect of normal stress on shear strength was not considered in the experiment. Investigate the influence of normal stress on the shear strength between layers.
2. To improve the understanding of interlayer behavior, develop a mechanistic model for predicting interface debonding failure using computational analysis.
3. Further research is needed to assess the long-term shear stress resistance performance of PAC under varying traffic loads, climate conditions, and material aging.

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