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Bond condition between surface layer and immediate layer in porous asphalt pavement

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Abstract: Through the shear tests on composite specimens using four different kinds of tack coat material (epoxy resin, SBS modified emulsified asphalt, SBS modified asphalt and H# bridge waterproof material), the bond condition between layers of porous asphalt pavement under traffic load, temperature variation and moisture situation is evaluated. The test results show that the bond strength decreases with the rise in temperature, and the relationship between shear strength and temperature can be expressed by a logarithm curve at a high reliability. Under the action of traffic load, the value of shear strength of the mixture right under the centre of the wheel track is smaller than that of other parts of the pavement. It is also found that some effects concerning moisture have comparative effects on the bonding of the two layers. Given all the results achieved during the study, it will be quite rewarding to make rational comparisons during selecting the sound type of tack coat.

Key words: porous asphalt pavement; waterproof and cohesive layer; shear strength

Elastic layers system theory, which presumes that the bond condition between layers is completely continuous, is usually used to design the pavement structure in China. Once the bond condition changes, even if this change is small, the force situation between layers is prone to be changed. If continuity is not achieved between the surface layer and the intermediate layer, there will be occurrence of larger tensile stress under the surface layer. Ref. [1] has indicated that the stress between layers is quite sensitive to the bond condition of pavement, and the tensile stress at the bottom of layers increases evidently when the bond coefficient between layers changes, accordingly the fatigue life of pavement decreases seriously.

The surface layer of porous pavement is composed of a high porosity mixture, and the area of contact face between the surface layer and the immediate layer is only 75% to 85% of that of the dense-graded pavement. One of the most important problems is to ensure the continuity between the surface and intermediate layers for the sake of improving the wearing performance of the porous pavement. Therefore, the cohesive performance between the porous surface layer and the intermediate layer should be enhanced in porous pavement construction[2]. The cohesive strength at coalescent area of porous pavement is mainly provided by the bituminous mixture and tack coat.

Temperature, traffic load and water all show significant influences on bond condition between the surface layer and the intermediate layer of the porous pavement. The focus of this paper is on analyzing these influencing factors by laboratory testing, and doing research on the bond condition when using four different kinds of tack coat material as the waterproof and cohesive layer.

1 Materials

Four kinds of tack coat materials are chosen for experiment, which are epoxy resin, SBS modified emulsified asphalt, SBS modified asphalt and H# bridge waterproof material. The properties of all these tack coat materials can be seen in Tab. 1.

A kind of porous pavement structure used in some highway projects in China was taken for experiment, which used dense-graded hot asphalt mixture Superpave-20 as its intermediate layer and porous asphalt mixture PA-13 as its surface layer. On rainy days, the rainwater can penetrate the surface layer which has high porosity, and then it flows out of pavement along the surface of the waterproof and cohesive layer (see Fig. 1).

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Tab. 1 The properties of four kinds of tack coat materials

Item		Epoxy resin	SBS modified emulsified asphalt	SBS modified asphalt	H# bridge waterproof material
Bond strength (20 ℃)/MPa		2. 2	0. 63	0. 5	0. 71
Ductility	Ductility rate/%	593	146	284	300
	Elastic recover/%	95	80	98	96
Shear strength (20 ℃)/MPa		4. 85	0. 36	0. 48	1. 75
Heat endurance (140 ℃ flow or not)		Not	Not	Not	Not

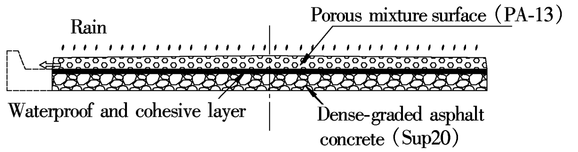

Fig. 1 The structure of porous pavement and raining indication

2 Methods

Under the action of temperature, water and traffic load, shear displacement appears at the contact face and leads to the breakage of the surface layer and premature damage such as upheaval, craze, track and so on[3]. Therefore, the waterproof and cohesive layer should have high cohesive performance. The property of tack coat material used in porous pavement plays an important role in the bond condition between the surface and intermediate layers.

Shear strength between layers is an important parameter that can reflect the bond condition perfectly. In this study, an experiment is designed to simulate actual pavement conditions by evaluating the capacity of shear resistance for composite specimens. In order to analyze these factors influencing the usage performance of porous pavement, temperature, water and traffic load are all taken into consideration in the design of the experiment. During specimen preparation, four kinds of tack coat material were used for the waterproof and cohesive layer to bond the surface layer and the intermediate layer. A self-made shearing tester was used to measure the shear strength between the surface layer and the intermediate layer at different temperatures.

Composite specimens composed of the lower layer of Superpave-20, the upper layer of PA-13 and the tack coat between them are fabricated. First, lower layer of 290 mm × 290 mm × 40 mm is made by the rolling formation method. After the lower layer cools down, the tack coat material is then spread evenly over the surface, which is conserved at 25 ℃ for a certain time considering the different requirements for the materials. Then the upper layer is paved using the same method as used on the lower layer. The composite specimens should be sawn to the size of 50 mm × 50 mm × 60 mm (see Fig. 2). However, the composite specimens cannot be sawn until the strength is developed.

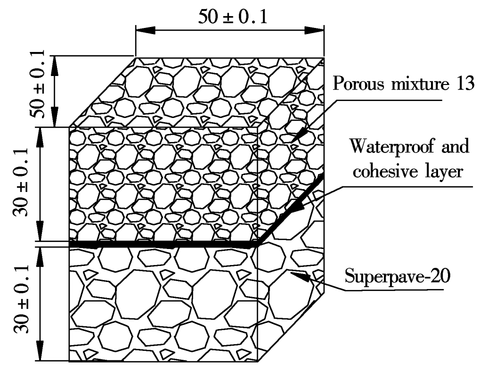

Fig. 2 Composite specimens prepared for experiment (unit: mm)

In the test, the tack coat is placed on the specimen at the optimum rate, which falls into the four different categories: 0. 5, 1. 0, 0. 6 and 1. 0 kg/m^2 while the material types are epoxy resin, SBS modified emulsified asphalt, SBS modified asphalt and H# bridge waterproof material, respectively.

The composite specimens, which have been prepared before testing, are put on the self-made shearing tester to measure the shear strength. The loading equipment can be seen in Fig. 3. Based on Ref. [4], the experiment uses 40° as the shearing angle, with a loading speed of 10 mm/min.

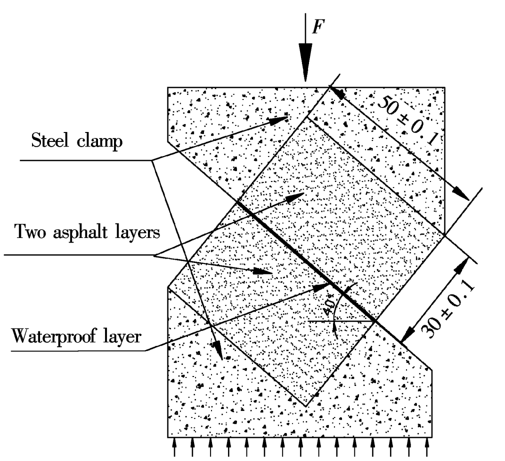

Fig. 3 Loading equipment used in experiment (unit: mm)

3 Influencing Factors of Bond Condition

3. 1 Temperature

Temperature is always one of the most important factors influencing usage performance of the asphalt pavement. Research indicates that the temperature gradient exists inside the pavement because of the difference in hot airflow, solar radiation and heat exchange speed of the asphalt mixture. As there exist many connective voids in the surface of porous asphalt pavement, the working condition of the intermediate layer and the waterproof layer has a higher temperature. For porous asphalt pavement, the temperature between the surface and intermediate layers T_{tc} can be obtained by Eq. (1)[5], which is used to calculate the temperature of the pavement layer below the surface layer in the superpave pavement.

$$T_{tc} = T_{max}(1 - 0.63d + 0.007d^2 - 0.0004d^3) \quad (1)$$

where T_{max} is the highest temperature of the pavement, and d is the depth of the pavement.

According to the actual temperature[6] measured on the pavement, the highest temperature can reach 65 ℃ in summer. If the depth of the surface layer is 4 cm, T_{tc} can be obtained by Eq. (1), $T_{tc} = 63.45$ ℃.

This basically accords with the actual temperature measured on the pavement[6].

Therefore, 60 ℃ is selected as the highest temperature for the shear test. And 0, 20 and 40 ℃ are also chosen for test to evaluate the influence of bond conditions with the change in temperature. The results are listed in Fig. 4.

Fig. 4 shows that temperature is obviously a factor that influences bond conditions. The bond strength will decrease with the rise in temperature. A conclusion can be drawn that the relationship between shear strength and temperature is close to a logarithm curve. In other words, the relationship between the logarithm value of shear strength and temperature is linear (see Fig. 5). The relationship can be regressed as

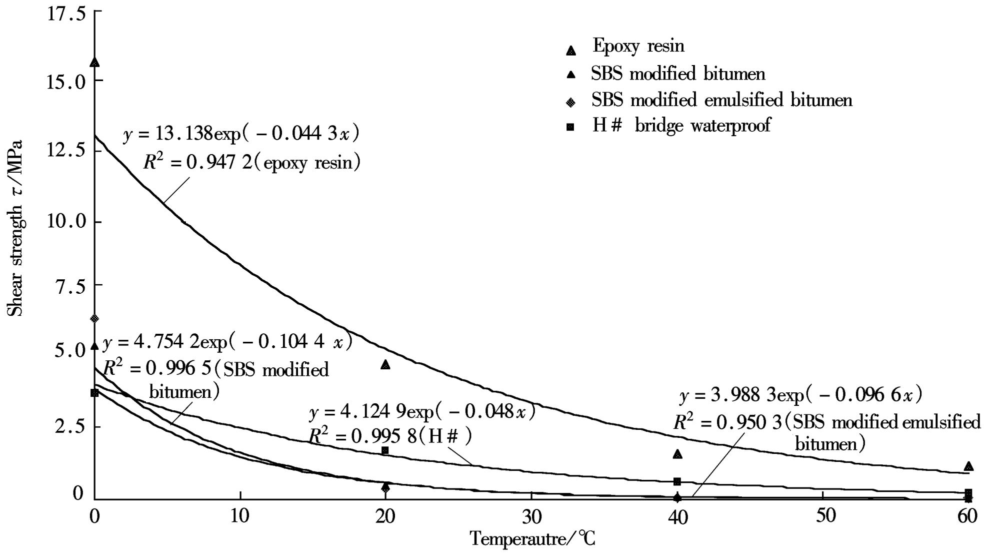

Fig. 4 The relationship between shear strength and temperature

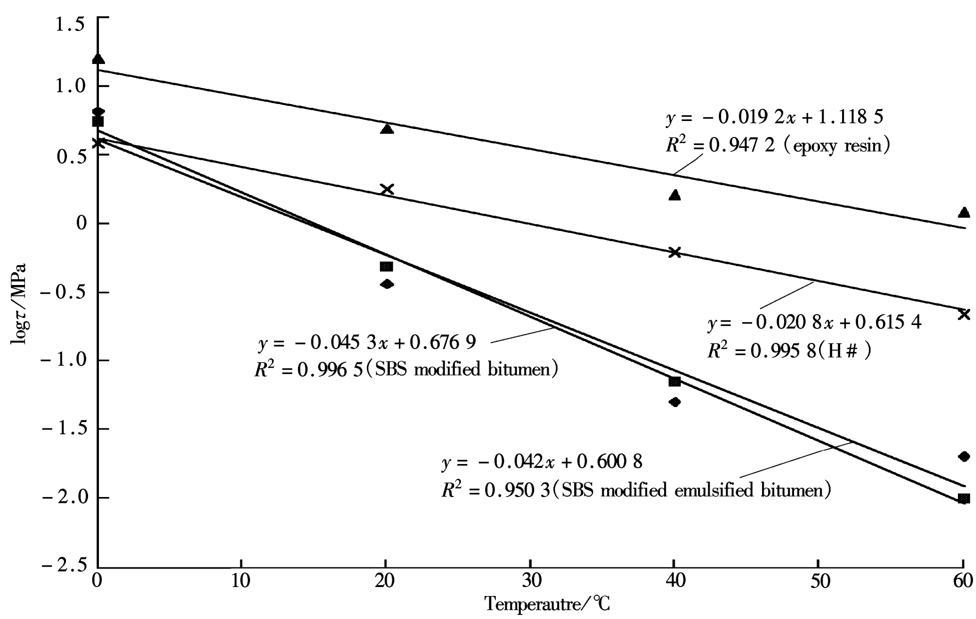

Fig. 5 The relationship between logarithm value of shear strength and temperature

$$\log\tau = kT + B \quad (2)$$

where k is the slope of the logarithm curve of temperature vs. shear strength, and B is the linear regression coefficient, $B = (T_2\log\tau_1 - T_1\log\tau_2)/(T_2 - T_1)$.

Eq. (2) obtained above can be used to calculate the shear strength under high temperature only if the value of k and shear strength under normal temperature are available, which can be helpful for the future study in this field, and as well as under low temperature. The cohesive performance of the tack coat used in porous pavement structure can be evaluated by measuring the value of k which means the temperature sensitivity ratio toward shear strength. The higher the value of k, the lower the temperature sensitivity of the tack coat and the better the cohesive performance of the tack coat.

3.2 Traffic load

The damage of pavement structure is mainly made by the joint action of vertical stress and horizontal stress under traffic load[7]. The surface layer of the porous pavement has a higher void percentage and a lower interface area with the intermediate layer, which the results in more serious stretch damage caused by traffic load.

In this research, composite specimens (290 cm × 290 cm × 8 cm), including the surface layer, the intermediate layer and the waterproof layer, are prepared in advance. Then specimens are placed in Hamburg Wheel Tracking Device (HWTD) under water at a temperature of 60 ℃, which is subjected to the rubber wheel for 20 000 cycles to simulate the actual influence that traffic loads have on the porous pavement. After the Hamburg wheel tracking test, the tested specimens are cut into small pieces (50 cm × 50 cm × 60 cm). These specimens are divided into three groups: wheel-trace edge, wheel-trace centre and uninfluenced edge. The results from comparing shear strength of the three groups of specimens are shown in Fig. 6.

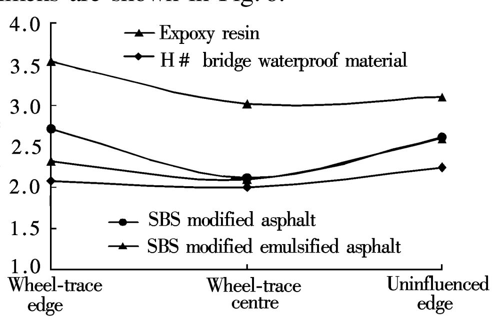

Fig. 6 Shear strengths of composite specimens after wheel tracking test

As shown in Fig. 6, traffic load has a significant impact on shear strength between layers of pavement. The value of shear strength of the mixture in the wheel-trace centre is smaller than that in the wheel-trace edge and the uninfluenced edge.

According to the previous researches[6, 8], the shear strength of the mixture in the traffic load action center area is smaller than that in the traffic load action edge area. That is because freedom bitumen and bonding agent in the intermediate layer under the traffic load action center area flow into the sides of the pavement under the action of the traffic load; consequently, the actual contact area between the surface and intermediate layers in the traffic load center area decreases and the close connection is weakened. Due to the transferred freedom bitumen and bonding agent, the oil aggregate ratio of the asphalt mixture in the wheel-trace edge area increases, and the shear resistance performance reduces. Therefore, as for porous asphalt pavement, high strength material should be chosen to improve bond performance and resist traffic load action[9].

3.3 Water

Analyzing the inner structure of porous pavement, it is found that plenty of water can accumulate between the connected pore space and the tack coat, and the bond condition between the surface layer and the tack coat is gradually destroyed under the dynamic hydraulic pressure. For the sake of finding the water influence upon the bond condition, the composite specimens which spread with four different kinds of tack coat materials are divided into three groups in this study. The specimens in first group are saturated in water under vacuum condition in order to simulate the rainwater damage to the pavement. The second group is put into a freeze-thaw circulation process to simulate frost heaving when water becomes ice at low temperature. The last group is unsettled. Then, shear strength tests are done with the three groups of specimens. The test results are shown in Fig. 7.

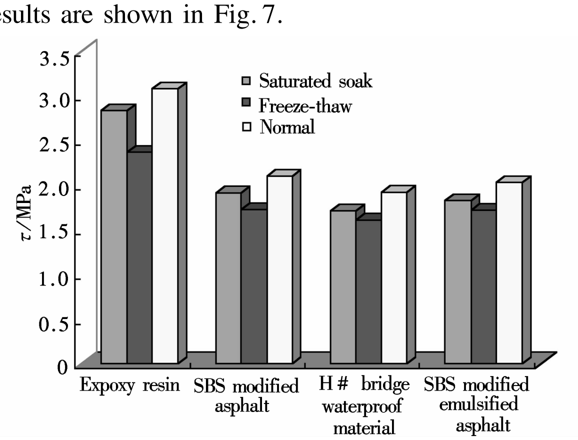

Fig. 7 Shear strengths after saturated soak or freeze-thaw

The test results indicate that water is one of the main factors which affects the bonding of the surface and the intermediate layers of the porous asphalt pavement. Saturated soak and freeze-thaw tests have comparatively obvious effects on the bonding of two layers. The reason is that saturated soak and freeze-thaw tests destroy the effective contact on the bonding surface. The shear strength descends about 20% to 30% after the freeze-thaw test and about 10% after the saturation. The 9% volume increases when water in the connected pore space turns into ice, thus causing the frost heaving effect in the freeze-thaw process. The effect causes part of the changes within the inner structure of the bonding surface between the surface and the intermediate layers and reduces the interaction between layers among the mixtures. And water corrosion also destroys the effective contact on the bonding surface. For the porous pavement, the pore cleaning of the surface layer should be enhanced to make a smooth drainage, and the saturation time of the pavement should be reduced after rain. At the same time, snow cover should be cleaned in time to reduce the destruction to the layer combination of the pavement.

4 Conclusions

1) The porous mixture is composed of a framework-void structure, the coalescent area between the surface layer and the immediate layer is smaller than that existing in dense-grade pavement. Therefore, the bond condition between the porous surface layer and the intermediate layer is important for pavement usage performance.

2) Shear strength between layers is an important parameter that can reflect the bond condition well. And this parameter can be used to evaluate the bond condition of porous pavement impacted by different external factors.

3) Temperature is always one of the most important factors influencing usage performance of the asphalt pavement. A conclusion can be drawn that the relation between shear strength and temperature is close to a logarithm curve. The value of k which means the slope of the logarithm curve of temperature versus shear strength can be employed to evaluate the cohesive performance of the tack coat used in porous pavement structure.

4) Traffic load has a significant impact on shear strength which represents the bond condition. Therefore, as for the porous asphalt pavement, high strength material should be chosen to improve bond performance and to resist traffic load influences.

5) The test results indicate that water is one of the main factors which affects the bonding of the surface and the intermediate layers of the porous asphalt pavement. Saturated soak and freeze-thaw tests have comparatively obvious effects on the bonding of the two layers. For the porous pavement, the pore cleaning of the surface layer should be enhanced to allow for a smooth drainage, and the saturation time of the pavement should be reduced after rainfall.

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排水性沥青路面上中面层层间结合状况研究

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摘要:通过环氧树脂、SBS 改性乳化沥青、SBS 改性热沥青和 H# 桥面防水材料等 4 种粘结层材料组合试件的剪切试验,对影响排水性路面的行车荷载、温度和水等外部因素进行了研究和分析. 试验结果表明,温度升高会造成层间结合能力的降低,层间剪切强度与温度之间的关系接近一条对数曲线. 在实际路面中,行车荷载作用中心区域下的剪切强度较其他部位要小. 冻融和饱水等水损害都明显地降低了路面抗剪强度,破坏了上中面层间的层间结合. 荷载、温度和水等因素的作用会对层间结合状况产生一定的不利影响,需要通过优选粘结层材料来提高排水性路面的耐久性.

关键词:排水性沥青路面;防水粘结层;剪切强度

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