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Research Article

Effects of Continuous Laydown and Compaction on Interlayer Shear Bonding of Asphalt Layers

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Traditional discontinuous paving technology of asphalt pavement is to pave and compact with two different gradation asphalt mixtures in the upper and lower layers, respectively, so the interlayer contact state of asphalt mixture is the major issue of pavement structure. Meanwhile, the continuous paving technology is to pave and compact with two different gradation asphalt mixtures in the upper and lower layers simultaneously, which can solve the issue of interlayer contact appropriately. In order to contrast the shear performance of the structural layer based on continuous and discontinuous paving technology, in this project, through simulating site construction, the double-deck Marshall and rut specimens are prepared based on two different gradation asphalt mixtures simultaneously, and the mechanical and interlayer shear performances of asphalt mixtures under continuous and discontinuous paving technology are tested at room temperature, low temperature, and freeze-thaw. The test results show that the mechanical and interlayer shear performance of continuous paving asphalt mixtures is better than that of discontinuous paving asphalt mixture. The findings can provide a certain technical basis for the design of continuous paving asphalt pavement.

1. Introduction

Traditional asphalt pavement with discontinuous paving and compact technology, due to the fact that the asphalt mixture in each layer has long spaced time, the thickness of the layer is thinner, the temperature of the mixture is lost faster, and compaction time is short and effective, leads to the structure of asphalt mixture being mutually independent and lack of interlayer connectedness and integrity. Asphalt pavement based on continuous paving technology is a new technique for asphalt pavement construction, which is to pave and compact with two different gradation asphalt mixtures in the upper and lower layers simultaneously and make it not only become a coordinated integrity but also have high construction efficiency [1, 2]. At the same time, it can also save material costs, improve the interface state between layers, and improve the durability of asphalt pavement.

The quality of interlayer bonding in asphalt pavement is one of the important factors that influence the service times of asphalt pavement, especially on the sections of large longitudinal, small radius, acceleration, and braking, where pavement structure will cause a larger horizontal load. When the loads are repeated more than a certain number of times, the shear stress generated in the intrinsic of asphalt pavement structure exceeds the shear strength of asphalt mixture, which can lead to fatigue damage and shearing damage in asphalt pavement [3–6]. In the study of the shear resistance of asphalt mixture, Wang [7] used the shear test to compare the shear strength of the double layer paving and the traditional paving core sampling specimens and the laboratory specimens. The results show that the double layer paving can significantly improve the bonding energy between the asphalt pavement layers. Raab [8] systematically summarized the interlaminar shear test method, systematically discussed the factors that may affect the bond strength between layers, and determined the standard evaluation method and the test idea of the interlayer bond strength. Wu [9] determined that the size of interlaminar shear strength of asphalt pavement is related to the test temperature, test speed, stress applicable to the interface, and the age of the sample. Zhang [10] holds that the interlayer shear strength increased with the decreased test temperature, increased

traffic load (within design limit), and increased test confinement pressure. Santagata et al. [11] hold that the void fraction and contact roughness are the main factors that affect the pavement bond performance. Under the different vertical pressure, oil content, temperature, and different loading rates, Guan et al. [12] tested the shear modulus of three different material combinations by using the self-designed direct shear test. Under different temperatures and different levels of oil spraying, Fu et al. [13] used oblique shear apparatus to determine the shear strength of specimens. It is found that the interlaminar shear strength decreases with high temperature, and the appropriate layer of oil spray can increase the shear strength between layers.

Therefore, in order to contrast the shear performance of the structural layer based on continuous and discontinuous paving technology, through the preparation of double-deck Marshall and rut specimens with two different gradation asphalt mixtures simultaneously, this study is to test the mechanical and interlayer shear performance of asphalt mixture based on continuous and discontinuous paving technology in three different test conditions (room temperature, low temperature, and freeze-thaw conditions). The findings can provide a certain technical basis for the design of continuous paving asphalt pavement.

2. Material Design

2.1. Asphalt. The virgin asphalt 90# (25°C penetration is about 80–100/0.1 mm) was selected in this test, and the indexes of the asphalt are shown in Table 1 [14].

2.2. Aggregates. The three kinds of dense-graded asphalt concrete are applied in test, which are AC13, AC16, and AC20, respectively [15, 16]. Two types of specimens are designed, which are the structure of AC13/AC16 and AC16/AC20 (shown in Figure 1). Test results of the aggregates are shown in Table 2, and the aggregate gradation for three kinds of asphalt mixture is shown in Table 3.

2.3. Proportion Design of Mixture. Through the proportion design of three kinds of asphalt mixtures according to the Marshall method, the optimum asphalt contents are, respectively, 5.4% for AC13, 5% for AC16, and 4.4% for AC20. The volumetric properties of the above asphalt specimens are shown in Table 4.

3. Preparation of Specimen and Test Methods

3.1. Preparation of Specimen. The diameter of Marshall specimen is 101.6 mm and the height is 63.5 mm. The diameter of the designed double-deck Marshall specimen is invariant and the height is 100 mm (upper layer is 50 mm; lower layer is 50 mm). The double-deck Marshall specimen is prepared based on Marshall compaction method. The process of making double-deck Marshall specimens based on continuous and discontinuous paving technology is shown in Figure 2. The making method of discontinuous paving specimen is to simulate site construction, which is to compact the asphalt mixture in lower layer firstly and cool it down to room temperature, and then compact the asphalt mixture in upper layer. In order to simulate compaction method in construction site, the continuous paving specimen is compacted for 150 s at one side (do not flip the specimen in the compaction process). Meanwhile the discontinuous paving specimen is to be compacted for 75 s firstly at lower layer and then for 75 s at upper layer (do not flip the specimen in the compaction process). Therefore, both compaction numbers of the two type specimen are 2×75 s [17, 18].

The double-deck Marshall specimens based on continuous and discontinuous paving technology are shown in Figure 3. The rut test specimen and beam specimen are shown in Figure 4.

3.2. Test Methods

3.2.1. Tests of Mechanical Performance

(1) Rut Test. Rut test specimens ($300 \times 300 \times 50$ mm) are made by wheel rolling method. The load wheel pressure of the asphalt mixture rut test equipment is 0.7 ± 0.05 MPa, and the round rolling speed is 42 times/min. The dynamic stability of specimens is tested at 60°C. The specimen and test equipment are shown in Figure 5.

(2) Bending Test. The cutting technique is used to make the asphalt mixture beams based on the double-deck rut specimen which are sized at $250 \times 60 \times 70$ mm. The loading rate of the test is at 50 mm/min and the test temperatures are room temperature, low temperature, and freeze-thaw, respectively. The specimen and test equipment are shown in Figure 6.

(3) Split Test. The test adopted the double-deck Marshall specimen and the test temperatures are room temperature, low temperature, and freeze-thaw, respectively. The specimen and test equipment are shown in Figure 7.

3.2.2. Adhesion Tests

(1) Interlayer Adhesion Test. The adhesion strength of interlayer between two mixtures is mainly investigated in the test and not the adhesion strength in the mixture itself. Therefore, the project developed a modified interlayer adhesion test for evaluating the characteristics of the interlayer to carry out the comparative study on interlayer adhesion performance of asphalt pavement based on continuous and discontinuous paving technology. The interlayer adhesion test is to rotate the specimen for 90 degrees from the original splitting direction, the loading rate of the test is at 1 mm/min, and the test temperatures are at room temperature, low temperature, and freeze-thaw condition, respectively. Working state of the split shear test is shown in Figure 8.

According to the definition of shear strength, the modified split shear strength is calculated by equation (1).

$$\tau = \frac{F_s}{A_s} = \frac{4F_{\max}}{\pi D^2}, \quad (1)$$

where τ is split shear strength (MPa); F_S is shear force (N); A_S is shear area (mm^2); $F_{\max}$ is maximum test force (N); and D is specimen diameter (mm), 101.6 mm.

Table 1: Performance index of virgin asphalt (90#).

Indexes	Unit	Standards	Measured value	Test methods
Penetration (25°C, 5 s, 100 g)	0.1 mm	80~100	93	T0604
PI		−1.5~+1.0	−0.77	T0604
Softening point (T&B)	°C	43	44.5	T0606
Ductility (10°C)	cm	45	90.7	T0605
Ductility (15°C)	cm	100	>100.0	T0605
Dynamic viscosity (60°C)	Pa.s	160	198	T0620

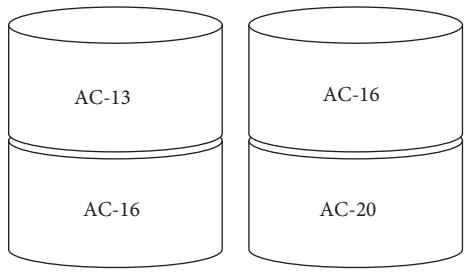


Figure 1: Structure of specimen.

Table 2: Technical indexes of aggregate.

Indexes		Measured value	Standards	Test methods
Coarse aggregate	Los Angeles wear value (%)	24	≤28	T0317
	Crushing value (%)	12.3	≤28	T0316
	Asphalt adhesion	5	>grade 4	T0616
	Percentage of lamellar carpolite (%)	14.7	≤15.0	T0312
	Mud content (%)	0.4	≤1	T0333
	Water absorption ability (%)	0.4	≤2.0	T0307
Fine aggregate	Mud content (%)	1.9	≤3	T0333
	Sand equivalent (%)	68	≥60	T0334
Mineral powders	Water content (%)	0.5	≤1	T0332
	Hydraulic coefficient	0.6	≤1	T0353

Table 3: Gradation composition of aggregates.

	Percentage of passing sieve (%)											
Sieve size (mm)	0.075	0.15	0.3	0.6	1.18	2.36	4.75	9.5	13.2	16	19	26.5
AC13/	6	10	13.5	19	26.5	37	53	76.5	95	100	—	—
AC16/	6	9.5	12.5	17.5	24.5	34	48	70	84	95	100	—
AC20/	6	10	15	21	27	37	48	62	71	82.5	95	100

Table 4: Volumetric properties of single layer mixture specimens.

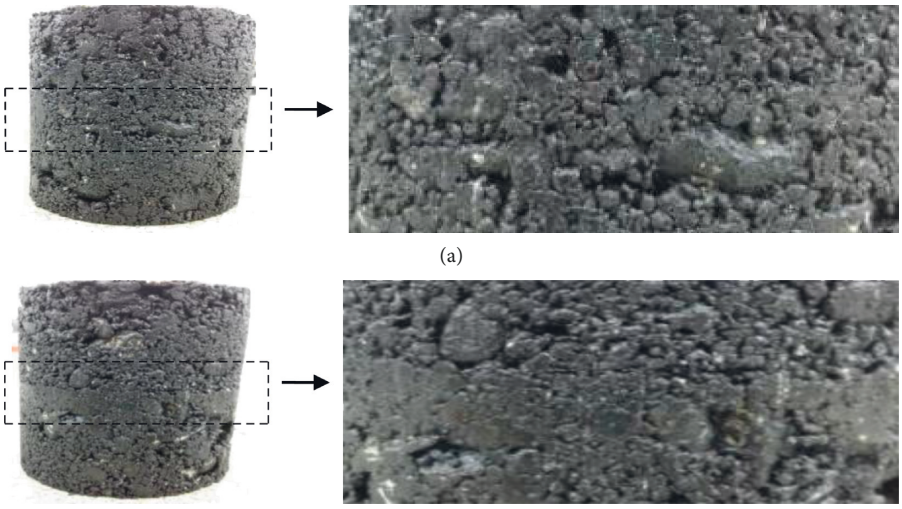
	OAC (%)	G_{mb} (bulk density)/(g/cm^3)	G_{mm} (maximum density)/(g/cm^3)	V (%)	VMA (%)	VFA (%)
AC 13	5.4	2.364	2.530	6.576	13.914	52.739
AC 16	5.0	2.359	2.538	7.053	13.846	49.062
AC 20	4.4	2.358	2.547	7.432	13.422	44.630

(2) Direct Shear Test. In order to reflect the actual stress conditions of the interlayer under vehicle load, the direct shear test was carried out on self-developed shear machine in laboratory (shown in Figure 9). The loading rate of the test is at 1 mm/min. The specimen is subjected to the stress which is perpendicular to interlayer and the shear strength is parallel to the interlayer during the load process. The test indexes are the same as the split shear test and the test temperatures are room temperature, low temperature, and freeze-thaw, respectively.

The shear strength of direct shear test is calculated by equations (1) and (2).

(a) (b)

Figure 2: Mixture of single layer and double layer. (a) Single layer. (b) Double layer.



(a)

(b)

Figure 3: Discontinuous and continuous Marshall specimens. (a) Continuous paving. (b) Discontinuous paving.

(a) (b) (c)

Figure 4: Rut and beam specimens. (a) Rut specimen (single-deck). (b) Rut specimen (double-deck). (c) Beam specimen.

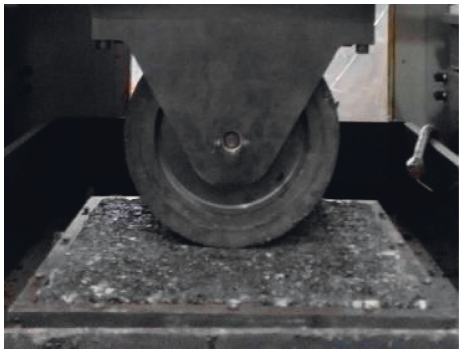


Figure 5: Rut test.

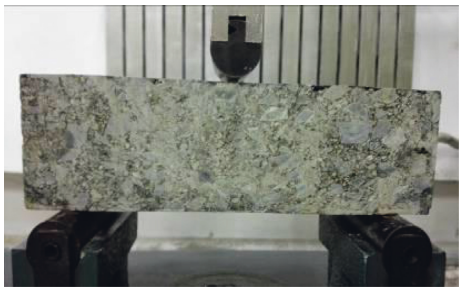


Figure 6: Bending test.

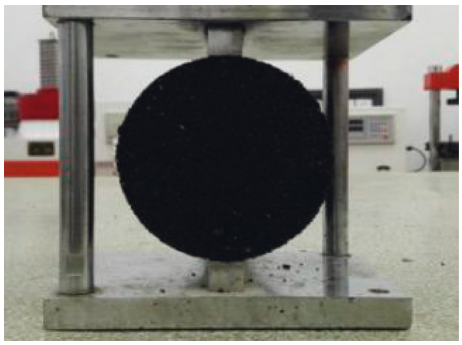


Figure 7: Split test.

$$F_s = F \sin 45^\circ, \tag{2}$$

where F is failure load (N).

4. Test Results

4.1. Tests Results of Mechanical Performance. The test results of mechanical performance are shown in Table 5. The standard deviations of test results are shown in Table 5. The sample number of measurements is three samples.

Through analysis of the data in Table 5, the conclusions can be obtained as follows:

(1) The results of rut test show that the specimen's ability to resist high temperature rut based on continuous paving technology is better than that of specimen based on discontinuous paving technology. At the point of ability to resist high temperature rut, AC13/AC16 specimen is better than AC16/AC20 specimen

(2) The results of bending test show that the continuous paving specimens are better than discontinuous paving specimens at the point of flexural-tensile strength based on specimens with the same gradation combination, and AC13/AC16 specimen is better than AC16/AC20 specimen. The flexural-tensile strength of continuous paving specimens is better than that of discontinuous paving specimens at different temperatures. With the test temperatures of room temperature, low temperature, and freeze-thaw, the flexural-tensile strength is progressively lowering. The gap in flexural-tensile strength of specimens with two paving methods is the most obvious at low temperature

(3) The results of split test show that the shear strength of specimens based on continuous paving technology is better than that of specimens based on discontinuous paving technology at room temperature. The split shear strength of AC16/AC20 specimens based on continuous and discontinuous paving technology shows little change at low temperature

4.2. Tests Results of Shear Performance

4.2.1. Results of Shear Test at Room Temperature. Results of shear test at room temperature are shown in Table 6. The standard deviations of test results are shown in Table 6. The sample number of measurements is three samples. It can be seen from Table 6 that the shear strength of the specimen based on continuous paving technology is bigger about 1-2 times than that of specimen based on discontinuous paving technology. The influence of different gradation combinations on continuous paving specimen is small because the double layer of continuous paving specimen is paved and compacted simultaneously, which leads to the interlayer bonding strength between upper and lower layers become large. For discontinuous specimens, the result is opposite, which is because the bonding of asphalt in interlayer is subdued relatively and mainly depends on the interlock strength from aggregate in interlayer.

4.2.2. Results of Shear Test at Low Temperature. Results of shear test at −10°C are shown in Table 7. The standard deviations of test results are shown in Table 8. The sample number of measurements is three samples. It can be seen from Table 8 that the shear strength at low temperature is better than that at room temperature. The reason is that water vapour forms ice crystals in the specimen pore at low temperature; the ice crystals provide a certain carrying capacity which leads specimens at low temperatures to be harder to break than specimens at room temperature [19, 20]. The gap among the results of shear test at low temperature by continuous and discontinuous paving specimens is larger because the ice crystals have the smooth style, and the interlayer of discontinuous paving specimens

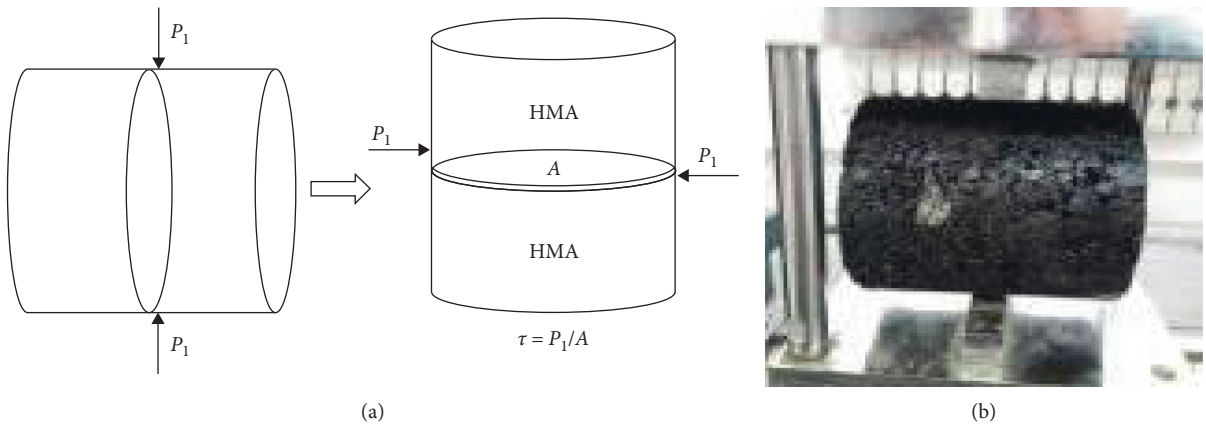


Figure 8: Working state of interlayer adhesion test. (a) Stress diagram of interlayer adhesion test. (b) Working state of interlayer adhesion test.

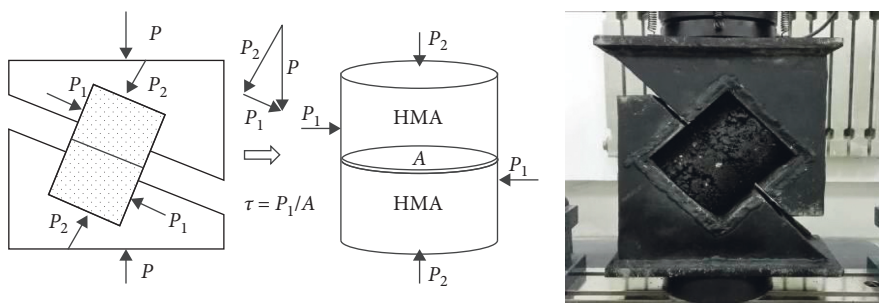


Figure 9: Working state of direct shear test. (a) Stress diagram of direct shear test. (b) Working state of direct shear test.

Table 5: Results of test.

Types of specimen		AC13/AC16		AC16/AC20	
		Continuous paving	Discontinuous paving	Continuous paving	Discontinuous paving
Rut test (dynamic stability (kN))	60°C	2520	2258.8	2405.1	2122.9
	Standard deviation	145	143.9	133.8	93.4
Bending test (bending strength (MPa))	Room temperature	5.628	4.846	5.415	4.752
	Standard deviation	0.394	0.219	0.461	0.163
	Low temperature	16.876	14.216	16.354	14.208
	Standard deviation	0.773	0.976	0.664	0.763
	Freeze-thaw	1.424	1.152	1.337	1.05
	Standard deviation	0.112	0.056	0.054	0.068
Split test (split strength (MPa))	Room temperature	0.778	0.620	0.796	0.532
	Standard deviation	0.026	0.039	0.054	0.041
	Low temperature	2.007	1.672	1.771	1.793
	Standard deviation	0.096	0.099	0.097	0.102
	Freeze-thaw	0.414	0.155	0.279	0.285
	Standard deviation	0.021	0.011	0.015	0.012

Note: AC13/AC16 (AC16/AC20): upper layer AC13 (AC16)/lower layer AC16 (AC20).

Table 6: Results of shear test at room temperature.

Specimen type		Continuous paving		Discontinuous paving	
		13/16	16/20	13/16	16/20
τ (MPa)	Split shear	0.252	0.222	0.121	0.089
	Standard deviation	0.013	0.009	0.008	0.004
	Direct shear	0.717	0.837	0.448	0.608
	Standard deviation	0.041	0.041	0.018	0.021

Table 7: Results of shear test at freeze-thaw condition.

Specimen type		Continuous paving		Discontinuous paving	
		13/16	16/20	13/16	16/20
τ (MPa)	Split shear	0.116	0.048	0.016	0.014
	Standard deviation	0.006	0.003	0.001	0.001
	Direct shear	0.409	0.349	0.124	0.156
	Standard deviation	0.021	0.018	0.006	0.003

Table 8: Results of shear test at low temperature.

Specimen type		Continuous paving		Discontinuous paving	
		13/16	16/20	13/16	16/20
τ (MPa)	Split shear	1.828	1.897	1.230	0.772
	Standard deviation	0.091	0.083	0.053	0.043
	Direct shear	6.733	6.079	5.27	5.317
	Standard deviation	0.241	0.304	0.271	0.199

has a larger trend of slippage at low temperature, which makes the specimens more vulnerable.

4.2.3. Results of Shear Test at Freeze-Thaw Condition. Results of shear test at freeze-thaw condition are shown in Table 7. The standard deviations of test results are shown in Table 7. The sample number of measurements is three samples. It can be seen from Table 7 that the shear strength of specimens interlayer is reduced at high degree after a freeze-thaw cycle. On the aspect of the capacity resisting the water-induced damage and the temperature change, the continuous paved specimens are obviously better than that of the discontinuous paving specimens. That is because there are larger void space and poor condition of compaction on the interlayer of discontinuous paving specimens, which leads to water infiltrating into interlayer more easily. The ice crystals have greatly disintegrated the carrying capacity of the internal structure at low temperature so that the shear strength of discontinuous paving specimen is reduced at high degree after the freeze-thaw cycle.

4.2.4. Results of Shear Test of Asphalt Mixture. Carrying out the shear test of asphalt mixture (not the interlayer) is to research the shear performance of the mixture itself. The method and test condition to make specimens are the same as double-deck specimens and the results of shear test of asphalt mixture are shown in Table 9. It can be seen from Table 10 that, on the basis of comparison on different gradation combination, the test results of asphalt mixture itself in shear performance at different temperatures are shown as follows:

$$\begin{aligned}&\text{Freeze} - \text{thaw condition} < \text{room temperature}\\&\quad < \text{low temperature}.\end{aligned} \tag{3}$$

The AC20 specimens have stronger shear capacity than that of the other two specimens at low temperature, which is because the coarser the grain size is, the bigger ice crystals in the specimen pore become, which can provide a stronger carrying capacity. The AC16 specimens do even better in the shear test at room temperature and freeze-thaw condition. On the ratio of the shear strength at freeze-thaw condition and room temperature, all are close to 30%.

5. Analysis of Shear Test Data

5.1. Analysis of Split Shear Test Data. Interlayer adhesion test results are shown in Table 9. The standard deviations of test results are shown in Table 9. The sample number of measurements is three samples.

5.1.1. Comparison of Test Results from Gradation. From Figure 10, the split shear strength of continuous double-deck specimens based on the same gradation is larger than that of discontinuous double-deck specimens. The split shear strength of AC13/AC16 is larger than that of AC16/AC20.

Table 9: Summary of interlayer adhesion test results.

Specimen type		13/16		16/20		AC13	AC16	AC20
		Bonding layer				Not bonding layer		
		C. pave	Disc. pave	C. pave	Disc. pave			
τ (MPa)	Room T.	0.252	0.121	0.222	0.089	0.255	0.293	0.314
	Standard deviation	0.028	0.014	0.026	0.011	0.021	0.016	0.024
	Low T.	1.828	1.230	1.897	0.772	1.690	1.813	1.829
	Standard deviation	0.13	0.09	0.148	0.062	0.11	0.16	0.15
	Freeze-thaw	0.116	0.016	0.048	0.014	0.083	0.108	0.098
	Standard deviation	0.014	0.003	0.009	0.0028	0.019	0.01	0.011

Table 10: Results of shear test of asphalt mixture.

	AC13			AC16			AC20		
	Room T.	Low T.	Freeze-thaw	Room T.	Low T.	Freeze-thaw	Room T.	Low T.	Freeze-thaw
τ (MPa)	0.255	1.690	0.083	0.293	1.813	0.108	0.314	1.829	0.098
Standard deviation τ (MPa)	0.013	0.083	0.004	0.021	0.091	0.005	0.031	0.086	0.005

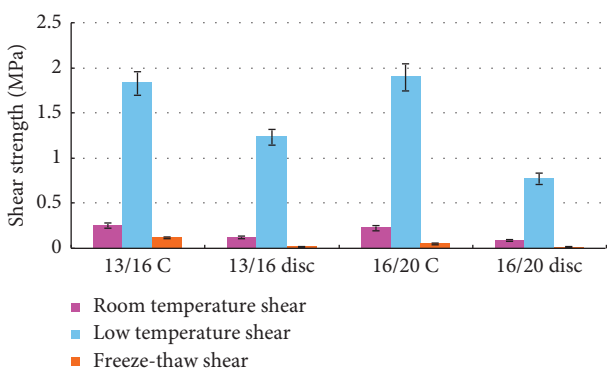


Figure 10: Comparison of test results from gradation.

5.1.2. Comparison of Test Results from Test Conditions. From Figure 10, the split shear strength of the specimens at low temperature is the highest, and that at freeze-thaw condition is the lowest. There is a wide gap in the split shear strength of two paving technologies at low temperature. By the comparison of the test results between room temperature and freeze-thaw conditions, the split shear strength of AC13/AC16 continuous double-deck specimen, relative to that at room temperature, has the lowest percentage decline (approaching 50 percent) and the decline of the other specimen is over 50 percent. The ratio of split shear strength at room temperature and low temperature, respectively, is around 1 : 9.

5.1.3. Comparison of Test Results from Load-Displacement Curves. From Figure 11, after the shear stress at room temperature reaches the maximum, the shear stress decreases slowly with the displacement increasing (Figure 11(a)), while the shear stress plummets down rapidly after reaching the maximum at low temperature (Figure 11(b)). In the shear test at low temperature, the form of damage to the specimen is brittle fracture.

5.1.4. Comparison of Test Results from Modes of Specimen Damage. From Figure 12, the fracture surface of continuous paving double-deck specimens is not the interlayer but the slant which is 10–15 degrees in the vertical direction. Meanwhile, the fracture surface of discontinuous paving double-deck specimens is the interlayer. That is, the interlayer bonding of continuous paving double-deck specimens is better.

5.1.5. Comparison of Test Results from Asphalt Mixture. From Figure 13, the test results from asphalt mixture itself are regular; the shear strength ratio at different temperatures is the following:

$$\text{Room temperature : low temperature : freeze-thaw condition} = 3 : 18 : 1. \tag{4}$$

The ice crystals in the specimen pore have a certain resistance at low temperature, which leads the shear strength to become larger.

5.2. Analysis of Direct Shear Test Results. The direct shear test results are shown in Table 11. The standard deviations of test results are shown in Table 11. The sample number of measurements is three samples.

5.2.1. Comparison of Test Results from Gradation. Test results of different gradation are shown in Figure 14. From Figure 14, for the same gradation specimens, the direct shear strength of the continuous paving specimens is greater than that of the discontinuous paving specimens because the continuous paving technology makes aggregate of upper and lower layers connected much better, which increases the interlayer shear performance. The direct shear strength of AC13/AC16 is smaller than that of AC16/AC20 because the skeleton structure of coarse aggregate plays a major role,

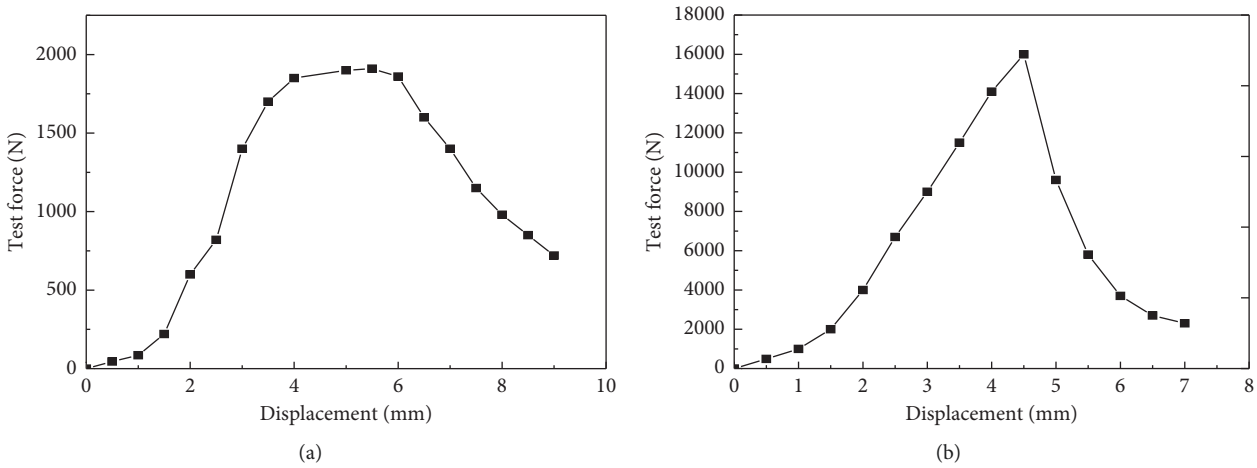


Figure 11: Comparison of test results from load-displacement curves. (a) Room temperature. (b) Low temperature.

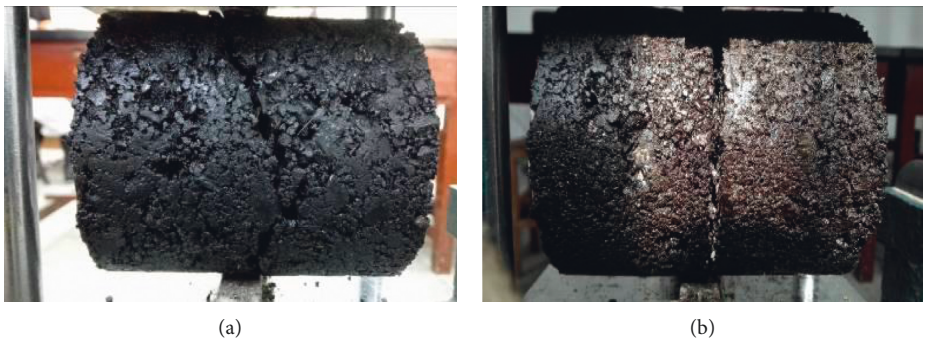


Figure 12: Comparison of test results from modes of specimen damage. (a) Continuous paving. (b) Discontinuous paving.

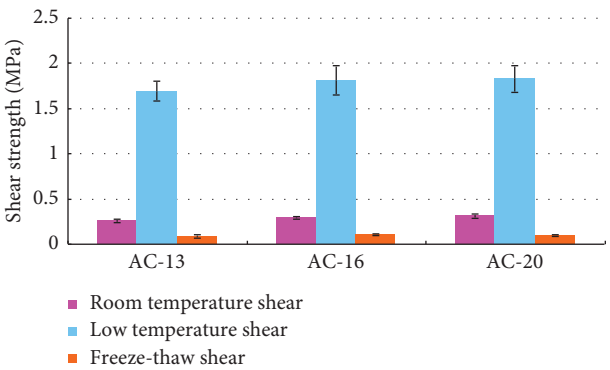


Figure 13: Comparison of test results from asphalt mixture.

Table 11: Summary of direct shear test results.

Specimen type		AC13/AC16		AC16/AC20	
		C. pave	Disc. pave	C. pave	Disc. pave
τ (MPa)	Room T.	0.717	0.448	0.837	0.608
	Standard deviation	0.061	0.042	0.075	0.059
	Low T.	6.733	5.27	6.079	5.317
	Standard deviation	0.44	0.33	0.45	0.35
	Freeze-thaw	0.409	0.124	0.349	0.156
	Standard deviation	0.043	0.012	0.033	0.021

which leads to the increase of damage load and shear forces. So the direct shear strength of AC16/AC20 is larger.

5.2.2. Comparison of Test Results from Temperature Conditions. Test results from different temperature conditions are shown in Figure 14. From Figure 14, the direct shear strength at low temperature is the highest, and that at freeze-thaw condition is the lowest. By the comparison of the test results between room temperature and freeze-thaw conditions, the direct shear strength of AC13/AC16 continuous paving double-deck specimens at freeze-thaw conditions, relative to that at room temperature, has the lowest percentage decline (approaching 50 percent), and the decline of the other specimens is over 50 percent. The ratio of direct shear strength between room temperature and low temperature is around 1 : 9; the reason is that moisture in the specimen pore forms ice crystals at low temperature and increases the interlayer connection performance. Meanwhile, after freeze-thaw treatment, the internal structure of

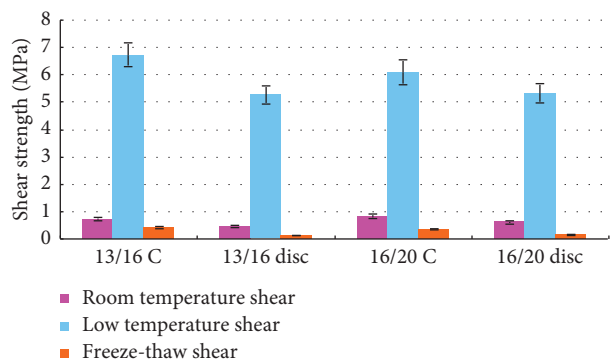


Figure 14: Comparison of gradation.

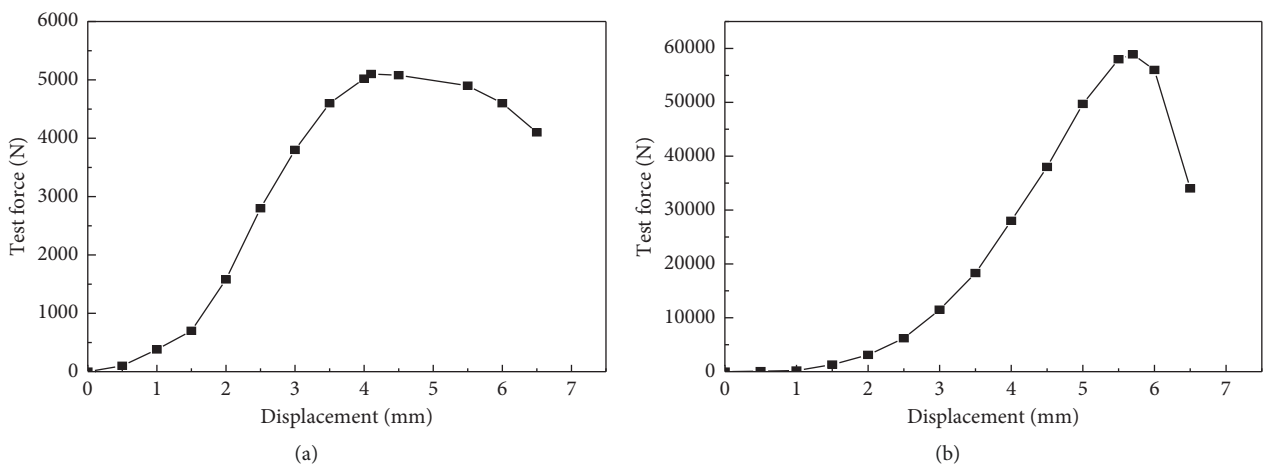


Figure 15: Comparison of test results from load-displacement curves. (a) Room temperature. (b) Low temperature.

the specimen is destroyed and the interlayer connection performance decreases naturally.

5.2.3. Comparison of Test Results from Load-Displacement Curves. From Figure 15, after the test force at room temperature reaches the maximum, the test force decreases slowly with the displacement increasing (Figure 15(a)), while the test force plummets down rapidly after reaching the maximum at low temperature (Figure 15(b)). In the shear test at low temperature, the form of damage to the specimen is brittle fracture.

5.2.4. Comparison of Test Results from Modes of Specimen Damage. From Figure 16, there is no fracture surface produced when the damage of the continuous specimens happens, while the discontinuous specimens generate tiny fracture surface in that condition and the fracture surface is the connection interface of upper and lower layers, which shows that the interlayer bonding of the continuous paving asphalt pavement is better.

5.3. Comparative Analysis on Two Shear Tests

5.3.1. Comparative Analysis on Test Results. Both interlayer adhesion test results and direct shear test results show that the interlayer shear strength of the continuous paving double-deck specimens is larger than that of the discontinuous ones, but the range is different. Split shear test results show that the shear strength of AC13/AC16 is larger than that of AC16/AC20, while the direct shear test results show that the shear strength of AC13/AC16 is smaller than that of AC16/AC20, which is because the split shear test has no horizontal pressure. The dense structure based on fine aggregate of AC13/AC16 specimens plays a major role and the frame structure based on coarse aggregate plays a secondary role; that is, the cohesion (C) plays a major role and angle of internal friction (ϕ) plays a secondary role. During the direct shear test, the specimens are subjected to not only shear forces but also vertical pressure; at this moment, the angle of internal friction (ϕ) plays a major role, while the cohesion (C) and tightness play a secondary role.

5.3.2. Comparative Analysis on Load-Displacement Curves. The comparison between Figures 11 and 15 shows that, in the conditions of room temperature and low temperature, the test force in direct shear test decreases slower than that in split shear test while the displacement increasing after the test force reaches the maximum. This is because the compressive strength of the specimen continues to resist loads after the shear failure under the direct shear test, resulting in slower force's decline.

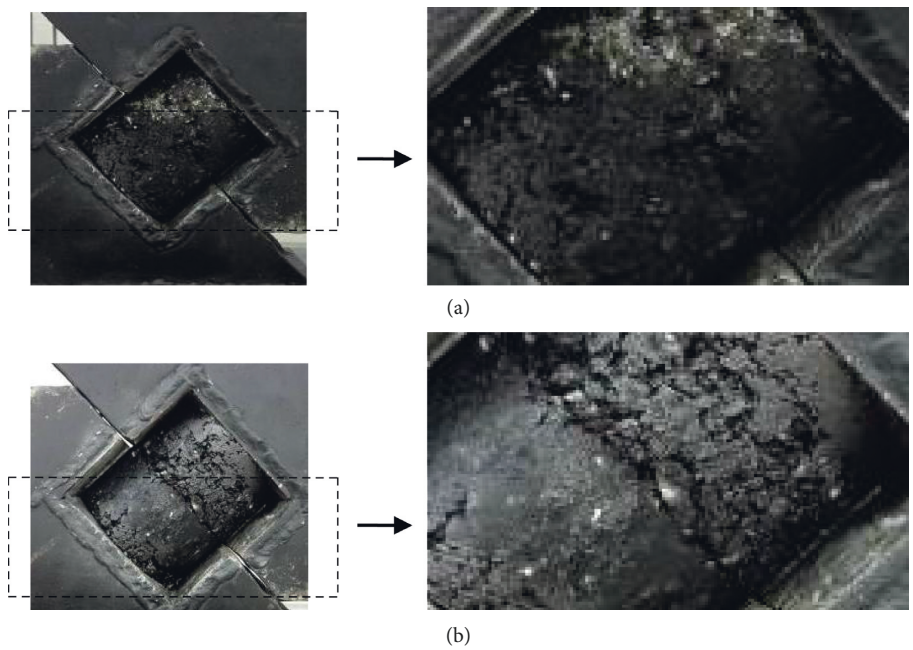


Figure 16: Comparison of test results from modes of specimen damage. (a) Continuous paving. (b) Discontinuous paving.

5.3.3. Comparative Analysis on Modes of Specimen Damage. The comparison between Figures 12 and 16 shows that, in the case of continuous and discontinuous paving technology, the fracture surface of the specimen under the direct shear test is much smaller than that under the shear test and does not even have a fracture surface after the test force reaches the maximum during the test loading process. This is because the compressive strength of the specimen resists loads completely after the shear failure under the direct shear test; the specimens are not subjected to shear stress, resulting in slower stress's decline. So the specimens have only smaller depredation and not even a depredation.

6. Conclusions

(1) The research results show that the interlayer shear strength of the continuous paving asphalt mixture can be improved to a certain extent compared with the discontinuous paving asphalt mixture

For the gradation combination of AC13/AC16 specimens at room temperature, the shear strength of the continuous paving specimens is two times bigger than that of the discontinuous paving specimens and the direct shear strength is 1.6 times bigger than that of the discontinuous paving specimens

For the gradation combination of AC16/AC20 specimens at room temperature, the shear strength of the continuous paving specimens is 2.5 times bigger than that of the discontinuous paving specimens and the direct shear strength is 1.4 times bigger than that of the discontinuous paving specimens

(2) From the results of shear test for asphalt mixtures by different paving methods, the shear strength at different temperatures basically conforms to the following rules:

freeze-thaw < normal temperature < low temperature

From the results of shear test for asphalt mixtures based on the same materials, the shear strength at different temperatures basically conforms to the following rules:

normal temperature: low temperature: freeze-thaw = 3 : 18 : 1

(3) The mechanical performance of asphalt mixture by different paving methods is sensitive to freeze-thaw shear. The freeze-thaw shear strength of AC13/AC16 continuous specimens is 50% lower than that at room temperature, while the other three specimens declined by more than 50%. This conclusion has some guiding significance for the gradation design of asphalt mixture in low temperature regions; for example, in low temperature regions, the AC13/AC16 continuous type is relatively superior to the AC13/AC16 discontinuous type and the AC16/AC20 continuous and discontinuous types. When designing the asphalt pavement structure, the most unfavorable freeze-thaw design method can be considered and the AC13/AC16 continuous type should be applied in asphalt pavement.

Data Availability

The data used to support the findings of this study have not been made available.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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