Review Article

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Interface bond condition of cement concrete pavement with an asphaltic interlayer

Abstract

For the sake of promoting interface bond condition of cement concrete pavement, the effect of an asphaltic interlayer on the bond between substrate and overlay was investigated in this paper by the self– made shear apparatus. Besides, the effects of three potential factors on the interface bond, such as substrate age, substrate type and overlay thickness were also discussed in the research. The results show that the AC– 5 interlayer could reduce the shear bond strength and stiffness by 38.8% and 62.9% separately. Substrate age, substrate type, and overlay thickness have an influence on the shear bond strength.

Keywords: cement concrete pavement, interface bond, asphaltic interlayerM substrate type and age, overlay thickness

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Introduction

According to the Chinese speculation on the structure design of concrete pavement, overlay and substrate are assumed to be bonded smoothly. However, for most of the concrete pavements, the crack of slab results from the stiff constraint of substrate on the overlay under the coupling effect of temperature and vehicle. In fact, Yi[1], Wu[2], Pigeon[3] claimed there was a complicated bonding condition in the interface between substrate and overlay and there is a weak transition layer with a certain thickness in the interface, which induce the separation of substrate and overlay and the following crack of overlay through traditional mechanical and fracture mechanical analysis. Until now, someone like Zhao[4] & Beushausen[5] have done some research on the impact factor of transition layer but factors like substrate type and age, and overlay thickness were seldom studied. In order to improve the bonding condition between the substrate and overlay, it is an effective way to set an interlayer on the substrate. Stott[6] & Yao[7] specified the separation effects of some inter layers like geotechnical cloth and slurry seal by tests but the effect of asphaltic interlayer was seldom studied. In terms of the material of asphaltic interlayer, Wu[8] & Zhang[9] chose asphalt concrete of large particle such as AC–13 and AC–16. In fact, it is more reasonable to choose one of small particle as the interlayer for the purpose of water proof and separation. According to current status of lacking the study on the effect of interlayer of small particle asphalt concrete, this paper introduced its orthogonal test results. Three potential factors, substrate age, substrate type, and overlay thickness were tested.

Test design

Impact factors

The test focuses on the influence of the asphaltic interlayer, substrate type and age and overlay thickness on the bonding condition of concrete pavement. Generally, as an asphaltic interlayer, its surface texture depth must be small enough to separate overlay from substrate, its air voids fewer to keep the water from permeating the substrate and its water–stability good enough to adapt to the water environment. That's to say, it required the asphaltic interlayer has finer aggregate, higher mineral powder content, higher asphalt content and less air voids. In this study, AC–5 was chosen. Besides the asphaltic interlayer, influence of other factors on the bonding condition is needed to study, which in turn helps us understand the working principle of asphaltic interlayer. In this study, two common substrates, lean concrete base and cement treated base, were taken into consideration. And different substrate ages, seven days (the shortest curing age according to the Chinese speculation) and twenty days, were studied. Last, the overlay thicknesses, 5cm and 20cm, were discussed. The factors and its levels are shown in Table 1.

Table1 Factors and levels of the test

Factors	Level 1	Level 2
A Substrate Type	Lean Concrete (LC)	Cement Treated Base (CTB)
B Substrate Age	7d	20d
C Asphaltic Interlayer	None	AC– 5
D Overlay Thickness	5cm	20cm

Design of form header

The test was planned orthogonally. Based on the amount of factors and levels, an orthogonal table L_8 (2^7) was used in the test. The form header is shown in Table 2.

Table 2 Design of form header

Form header	A	B		C			D
Column Number of L_8 (2^7)	1	2	3	4	5	6	7

Test plan

According to the design of form header, the numbers in the orthogonal table are replaced by the corresponding levels of factors. There are eight groups in tests. The test plan is shown in Table 3.

Test index

In this study, the shear bond strength and stiffness are used to assess the bonding condition. Shear bond strength is the ratio of maximum shear force and interface area. Shear bond stiffness is the ratio of shear bond strength to interface area.

Test method– vertical shearing test

In the test, eight slabs were constructed, which correspond to eight test groups in the Table 3. The thickness of substrate and interlayer were 5cm and 2cm respectively. After being cured for several days, each slab was drilled to get eight cylindrical specimens with diameter of 150 mm. These specimens were tested with MTS and vertical shearing instrument. The shearing box of vertical shearing instrument consisted of a fixed semicircular iron box and a movable circular iron box. The shearing interface between these two boxes was vertical. The vertical shearing instrument is shown in Figure 1. No parallel force was loaded and normal shear displacement was controlled as 1.0 mm/min. For the samples with asphaltic interlayer, the shearing interface is between asphaltic interlayer and overlay. The weight of overlay which would be loaded is around 21.2N and the maximum of shearing force in the test is between 3000N and 20000N. Thus, the effect of the mass of the sample on the measured load can be neglected to some extent.

Table 3 Test plan

Group number	Substrate	Substrate	Asphaltic	Overlay
	Type	Age	Interlayer	Thickness
1	LC	7d	None	5 cm
2	LC	7d	AC– 5	20 cm
3	LC	20d	None	20 cm
4	LC	20d	AC–5	5 cm
5	CTB	7d	None	20 cm
6	CTB	7 d	AC– 5	5 cm
7	CTB	20d	None	5 cm
8	CTB	20d	AC– 5	20 cm

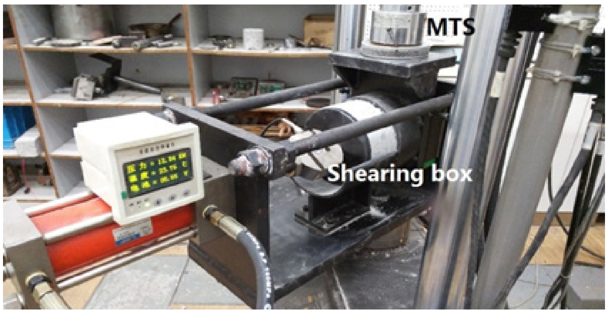

Figure 1 Vertical shearing instrument.

Analysis of test results

Test results

For eight groups the shear bond strength, displacement and stiffness are shown in Figure 2– 4 respectively. The values which are not between Q1–1.5IQR and Q3+1.5IQR is thought to be outliers and would be deleted (Q1, Q3, IQR represent upper quartile, lower quartile and quartile). Average of each group was used to fill the missing values caused by the outliers or the damaged specimen during the drilling.

Shear bond strength

Table 4 shows the analysis of variance in the shear bond strength. As shown in Table 4, under significance level of 0.05, factor B, C, D are significant and under significance level of 0.1, factor A, B, C, D are significant. Table 5 shows the shear bond strength of four factors. The shear bond strength of lean concrete is 526.89 KPa, which is higher than that of cement treated base, 434.80 KPa. The shear bond strength of 7d curing time is 630.64KPa, which is higher than that of 20d curing time, 331.05 KPa. In terms, the shear bond strength of asphaltic interlayer is 596.63KPa is higher than the one without asphaltic interlayer, 365.06KPa. The shear bond strength of 5cm–thick overlay is 410.21 KPa, which is higher than that of 20cm–thick overlay, 551.47 KPa.

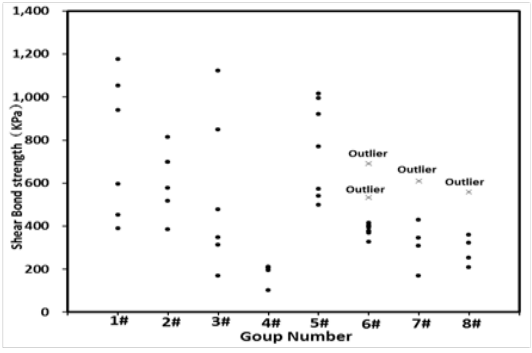

Figure 2 Shear bond strength of test specimens.

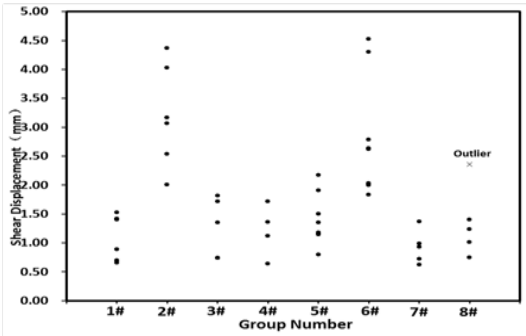

Figure 3 Shear displacements of test specimens.

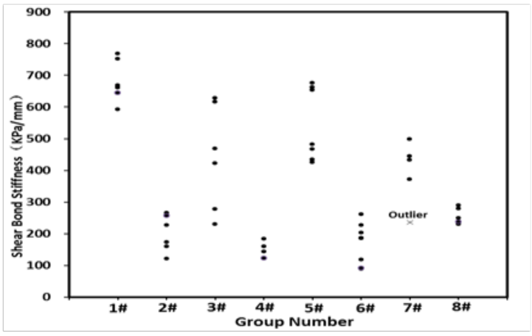

Figure 4 Shear bond stiffness of test specimens.

Shear bond stiffness

Table 6 shows the analysis of variance in the shear bond strength. As shown in Table 6, under significance level of 0.05, factor B, C, A×B, A×C, B×C are significant. However, based on the value 'F', compared with the asphaltic interlayer (factor C), substrate type and age (factor A and B), and overlay (factor D) thickness make less influence to the shear bond stiffness. Table 7 shows the shear bond stiffness of four factors. In terms of asphaltic interlayer (factor C),

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the shear bond stiffness without asphaltic interlayer is 525.55 KPa/mm, which is higher than that with an asphaltic interlayer, 195.07 KPa/mm.

Table 4 Analysis of variance in the shear bond strength

Source	SS	DF	MS	F Ratio	Significance
A	135710.29	1	135710.29	2.97	*
B	1436152.6	1	1436152.61	31.48	***
C	857950.53	1	857950.53	18.8	***
D	319268.99	1	319268.99	7	**
A×B	13471.11	1	13471.11	0.28	None
A×C	13036.59	1	13036.59	0.27	None
B×C	18515	1	18515	0.38	None
e1	45022.69	3	15007.56	0.31	
e2	1688752.8	35	48250.08		
e	1733775.5	38	45625.67		

Table 5 The shear bond strength of levels of four factor (KPa)

Factors	A	B	C	D
Level 1	526.89	630.64	596.63	410.21
Level 1	434.8	331.05	365.06	551.47
R	92.1	299.6	231.56	141.26

Table 6 Analysis of variance in the shear bond stiffness

Source	SS	DF	MS	F Ratio	Significance
A	4599.1	1	4599.1	0.59	None
B	94532	1	94532	12.03	**
C	2E+06	1	2E+06	222.34	***
D	0.01	1	0.01	0	None
A×B	72807	1	72807	9.26	***
A×C	46472	1	46472	5.91	**
B×C	148478	1	148478	18.89	***
e	298652	38	7859.3		

Table 7 The shear bond stiffness of levels of four factor (KPa/mm)

Factors	A	B	C	D
Level 1	368.79	398.74	525.55	360.3
Level 2	351.83	321.88	195.07	360.32
R	16.95	76.87	330.48	0.02

Curves of shear test

As shown in Figure 5, for the samples without an asphaltic interlayer (slab 1,3,5 and 7), before reaching the maximum force, the shear force increases linearly and after reaches the peak, the shear force decreases to a small one immediately. The samples seem brittle. Whereas, the samples with an asphaltic interlayer (slab 2,4,6 and 8) seem flexible, which shear force decreases slowly after the sliding starts between layers. The shearing failure between samples with asphaltic interlayer and ones without asphaltic interlayer is different in the increasing velocity, the decreasing velocity and the shear bond displacement. If an asphaltic interlayer is flexible enough, it would weaken the constraint on the overlay slab and then reduce the crack and the other failures of overlay slab. At this point, it is available to set an asphaltic interlayer to improve the performance of cement concrete pavement.

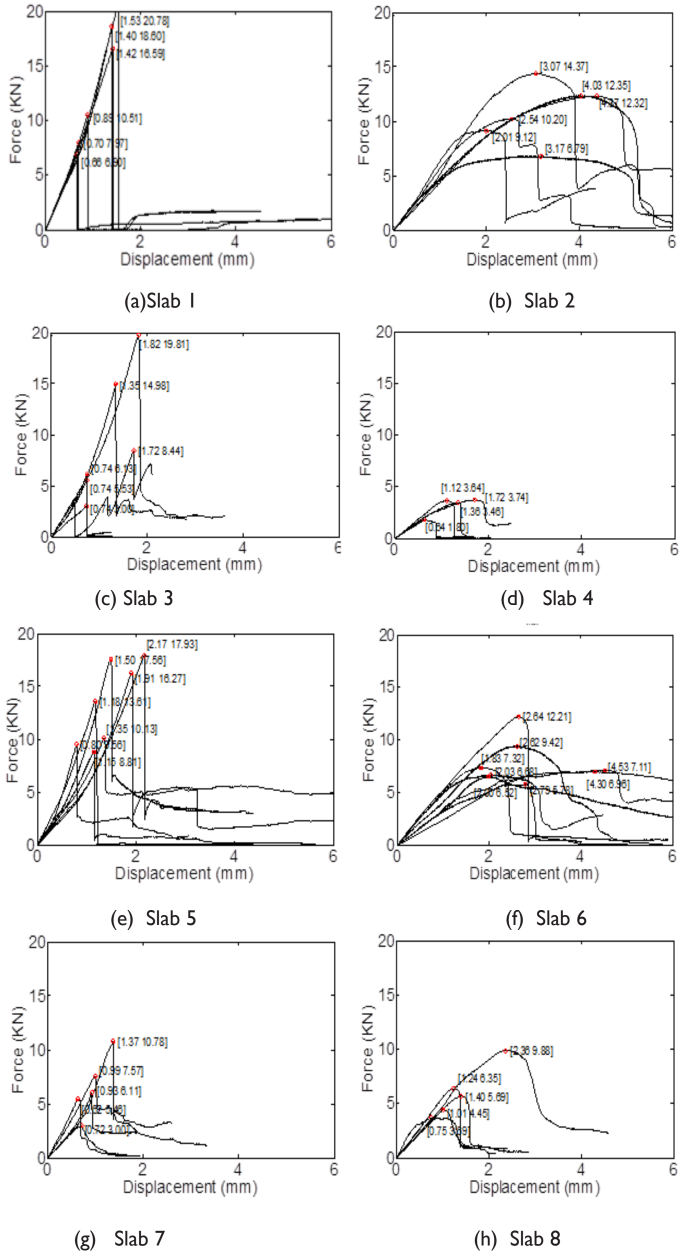

Figure 5 Curves of shear test.

Factors analysis

Substrate type

Compared with the lean concrete base, the shear bond strength of cement treated base decreases by 17.5%. Because the strength of overlay is higher than substrate, the initial interface detach starts at the material approaching to the substrate, which means that the shear bond strength depends on the strength of substrate. The infiltration

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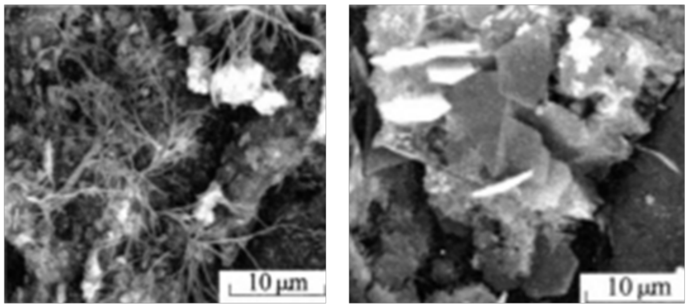
test shows that cement treated base is totally permeable with water permeability coefficient of 923.08 ml/min and the lean concrete is almost impermeable. And the sand equivalent test shows that the surface texture depth of cement treated base with value of 1.48 mm is higher than the lean concrete with value of 0.5mm. Although these would result in more overlay mortar permeating the cement treated base and then increase its strength, the substrate is still weaker than the lean concrete owing to unconsolidated surface of cement treated base. Thus, the shear bond strength of lean concrete is higher than the cement treated base. Besides, in comparison with the specimen with lean concrete base (Figure 6a), the one with cement treated base (Figure 6b) has a rougher interface after the detachment of overlay and substrate. It means the surface of cement treated base still has more pores and its effective contact area is smaller than that of lean concrete base, which will result in lower shear bond strength.

(a) Lean concrete base (b) Cement treated base

Figure 6 Interface between overlay (up) and substrate (down).

Substrate age

Substrate age has a significant influence on the shear bond strength and stiffness. Compared with the substrate of 7– day curing time, the shear bond strength and stiffness of the 20– day curing substrate decrease by 47.5% and 19.3% separately. Cement treated base and lean concrete base both consist of cement and aggregate. Hydration reaction plays a vital role in the strength of substrate. And the bond strength mainly comes from the interlocking and cohesion. Cohesion mainly consists of chemical bonding. As for the substrate with a short curing time, most of the cement would not finish the hydration reaction. If overlay is constructed on substrate at the young age, cement of both overlay and substrate would react together and the products enable them to firmly connected, and that's to say, the chemical bonding between overlay and substrate is stronger. By contrast, the hydration reaction in the long curing substrate has stopped or would be at a slow rate, which weakens the connection between substrate and overlay. In addition, Li[10] found that microstructure and hydration reaction products of concrete would change with curing age. Through scanning electronic microscope, the microstructure of 28– day curing concrete (Figure 7b) was denser and the amount of product was higher in comparison with the 3 day curing concrete (Figure 7a). The pore ratios of the former and latter were 11.02% and 13.64% respectively. Thus, for the substrate, the longer curing time, the less mortar of overlay permeating into the pore. This would result in the weaker interlocking. And at last, the lower cohesion and interlocking between overlay and substrate would result in smaller shear bond strength. What's more, for the old substrate, it would seldom shrink. So when overlay is constructed on the old substrate, there would be plenty of micro– cracks in the interface because of the shrink of overlay in the early period.[11]

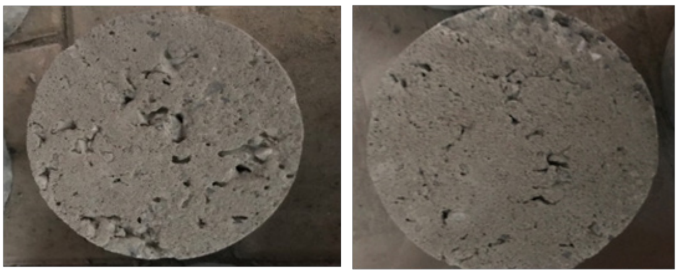


(a) days (b) 28 days

Figure7 Microstructure of concrete of different ages under the scanning electron microscope.

Overlay thickness

Overlay thickness has a significant influence on the shear bond strength. Compared with 5cm– thick overlay, the shear bond strength of 20cm– thick one increases by 34.4%. The thicker the overlay is, the more pressure at the bottom of overlay, which makes it easier for the mortar to flow into the substrate or the asphaltic interlayer. Once this mortar solidifies, the shear bond strength comes into being. In addition, during the construction of overlay, it is unavoidable to produce some bubbles in the cement concrete. Those bubbles at the bottom of overlay would affect the shear bond strength. However, if the overlay is thick enough, those bubbles would disappear owing to the great pressure from the overlay, which keeps interface from the stress concentration and then enlarges the shear bond strength. Some interface of broken specimen could serve as evidence. Compared with 5 cm– thick overlays (Figure 8a) the pores at the bottom of 20cm– thick (Figure 8b) overlay are fewer.



(a) Bottom of 5cm-thick overlay (b) Bottom of 20cm-thick overlay

Figure 8 The bottom of overlay after interlayer failure.

Asphaltic interlayer

In comparison with the three factors above, the asphaltic interlayer has much more influence on the shear bond strength as well as the shear bond stiffness. The asphaltic interlayer tends to reduce the shear bond strength and stiffness by 38.8% and 62.9% separately. First, because asphaltic interlayer is impermeable and its surface texture depth is lower than the cement treated base and lean concrete base, the depth of mortar permeating the interlayer would smaller and then the shear bond strength would lower. Second, since the asphaltic interlayer contains plenty of hydrophobic asphalt, the connection between the mortar of overlay and the interlayer would be weaker in comparison with the cement treated base and lean concrete base

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which both consist of hydrophilic aggregate and cement. Third, as viscoelastic material, asphaltic interlayer would perform less brittle. Compared with the cement treated base and lean concrete base, in order to resist the same external force, the asphaltic interlayer would produce more displace and less shear force. Namely, the asphaltic interlayer has smaller shear bond stiffness. The flexibility of asphaltic interlayer could be verified by the curve of shear test. Notably, the specimens with asphaltic interlayer (Figure 9) have a smooth interface after the detachment of overlay and interlayer, which indicate a better construct base for concrete pavement.

Figure 9 Interface of asphaltic interlayer.

Conclusion

In terms of substrate type, compared with the lean concrete base, the shear bond strength of cement treated base decreases by 17.5% because of its lower strength. Meanwhile, the rougher interface after the detachment of overlay and cement treated base would challenge the durability of concrete pavement. In terms of substrate age, compared with the substrate of 7– day curing time, the shear bond strength and stiffness of the 20– day curing substrate decrease by 47.5% and 19.3% separately. These facts can be attributable to the unsynchronized hydration reaction of cement of overlay and substrate. The substrate of long curing time could not be connected well with the mortar of overlay and could also result in the unsynchronized shrinkage. With respect to overlay thickness, the adding pressure at the bottom of thicker overlay would deepen the flowing of mortar into the substrate and decrease the bubbles in the interface. According to the test, compared with the 5cm– thick overlay, the shear bond strength of the 20cm– thick one increases by 34.4%. The asphaltic interlayer has much more influence on the shear bond strength as well as the shear bond stiffness. The asphaltic interlayer tends to reduce the shear bond strength and stiffness by 38.8% and 62.9% separately. For one thing, it is owing to the impermeability, hydrophobicity and small texture depth of asphaltic interlayer. For another, the flexibility of asphaltic interlayer decreases the shear bond stiffness. Thus, asphaltic interlayer could weaken the constraint of substrate on the overlay as well as ensure a smooth interface after detachment, which could address the crack issue of concrete pavement to some degree.

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Conflict of interest

The author declares there is no conflict of interest.

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