Experimental Study on Factors Affecting Interlayer Shear Strength of Fiber Seal

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Abstract: In order to study influence of different factors on interlayer shear strength of fiber seal, an orthogonal experiment about four factors, respectively, test temperature, fiber content, asphalt content and gravel coverage, and three levels are developed with bevel shear test. The influence rules are evaluated by range analysis method. The result demonstrated that fiber content is the most correlative influencing factor. Thus provides a basis for the selection of material and performance of the fiber seal.

Introduction

Fiber seal, which can be used as wearing course and stress absorbing layer [1], composes with hierarchically sprinkling asphalt, fiber and gravel. The structure of fiber seal is shown in Fig.1. Intensive work had been carried out during the past decades worldwide. Ball et al explored the factors affecting multiple chip seal layer instability[2]. Lee and Richard Kim presented a method to determine the optimal protocol for rolling chip seals based on aggregate retention performance and aggregate embedment depth, a third-scale model mobile loading simulator (MMLS3) were employed[3]. Huurman developed a 3D meso-mechanical FE model of a seal and obtained stresses and strains that developed in the various relevant structural components of the seal[4]. Fiber seal has been significantly applied in a series of projects since introduced into China in 2007[5,6] because of its superior performance in waterproof, stress absorbing and bonding properties[7]. Practical application indicated that the capacity of bonding with pavement layer was a key property of fiber seal[8]. However, due to no thorough and systematic studies on the influencing factors, there is a lack of clear guiding ideology for material selection and performance evaluation of fiber seal.

The bonding capacity of fiber seal varies with variable parameters. In this article, shear strength is taken as a evaluation index, four parameters, *A*- fiber content, *B*- asphalt content, *C*- gravel coverage and *D*- test temperature, are selected as influence factors. Meanwhile, three typical levels of each factor are selected according to engineering practice to design orthogonal test, then evaluating the influence rules on the test index with rang analysis and grey correlation analysis (GRA) method. This research could provide theory basis for the material selection of fiber seal.

Interlayer Shear Strength Experiment

Experiment Principle

Bevel shear test is a better way to simulate the stress state of pavement under load compared to direct shear test [9]. The principle of bevel shear test is shown in Fig.1. Two same forces appear on parallel and perpendicular cross sections under the load *T*. T_h is the shearing action on interface what makes specimen failed.
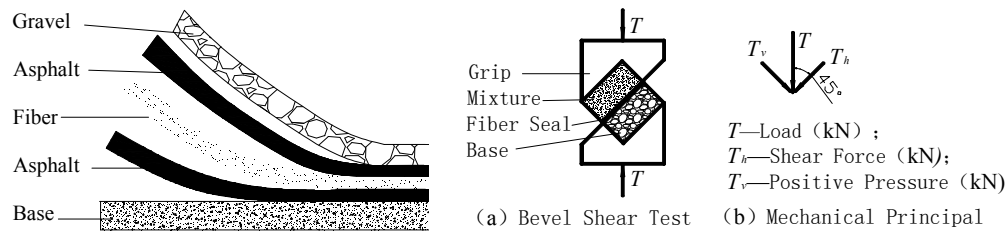
Fig.1. Structure of Fiber Seal and Schematic Diagram of Bevel Shear Test

Material Composition and Performance

Anda 90# road petroleum asphalt is used as binder of fiber seal (SHRP-H-355, 1993), technical specifications are listed in Table 1.

Table 1. Anda 90# Road Petroleum Asphalt Technical Specifications

Test parameters	Penetration (25℃,100g,5s)	Ductility (15℃,5cm/min)	Softing point $T_{R\&B}$	Density (15℃)
Units	[0.1mm]	[cm]	[°C]	[g/cm^3]
Test result	90	＞150	45.0	1.015

Particle size of 3~5mm granite gravel is chosen as aggregates of fiber seal, graduation of gravel is listed in Table 2. Specifications of gravel and polyester fiber are recorded in Table 3 and Table 4, respectively.

Table 2. Graduation of Gravel

sieve size [mm]	16	9.5	4.75	2.36
percent of pass [%]	100	100	7.5	0

Table 3. Technical Specification of Fiber Seal Aggregate

Test projects	Crushing value [%]	Water absorption [%]	Apparent density [g/cm^3]	Adhesion of asphalt
Test result	10.5	0.51	2.81	5 grade
standard	≤14	≤2.0	≥2.60	≥4 grade

Table 4. Technical Indicators of Polyester Fiber

Test projects	Density [g/cm^3]	Oil absorption rate[%]	Moisture content [%]
Result	1.36	350	0.2

Specimen Molding Method

The size of specimen is 150 mm×150mm×150mm , of which the height of semi-rigid base and asphalt mixture is 70mm respectively. Fiber seal is made between the base and upper layer. To match the actual construction process better[2], the technological process of fiber seal in laboratory is described as follows:

(1) Preparing semi-rigid base; (2) Heating the asphalt and gravel to 170℃ ± 5℃ and then spreading a certain quality of asphalt onto base surface; (3) Spreading fiber and compacting; (4) Spreading another layer of asphalt; (5) Spreading gravel and compacting; (6) Shaping asphalt mixture as upper layer on top of fiber seal. The technological process of fiber seal is shown in Fig.2.

a.Prepare base   b.1st layer of asphalt   c. fiber   d. 2nd layer of aspha   e. spread gravel
Fig. 1. Process of Laboratory Production

The experiment was conducted per material test system (MTS 810) after the specimens cured 7d, loading in strain control mode, at a speed of 3.5mm/min [10], collecting the failure loads T and converting into shear strength.

Orthogonal Test

Fiber content (*A*), asphalt content (*B*), gravel coverage (*C*) and test temperature (*D*) are the factors to be observed, there are three levels of every factor, as shown in Table 5.

Table 5. Experiment Factor Levels

Level	Factors			
	A	*B*	*C*	*D*
1	40	1.3	35	5
2	60	1.6	50	20
3	80	1.9	70	35

Table $L_9(3^4)$ was chosen in the orthogonal test and 9 groups of samples were tested based on Table 6, in which homologus shear strength is also listed.

Table 6. L_9 (3^4) Orthogonal Test and Result

No.	*A*	*B*	*C*	*D*	Shear Strength [MPa]
1	1 (40)	1 (1.3)	1 (35)	1 (5)	0.38
2	1	2 (1.6)	2 (50)	2 (20)	0.73
3	1	3 (1.9)	3 (70)	3 (35)	0.48
4	2 (60)	1	2	3	0.82
5	2	2	3	1	1.04
6	2	3	1	2	0.93
7	3 (80)	1	3	2	0.25
8	3	2	1	3	0.44
9	3	3	2	1	0.78

Range Analysis

In range analysis, range *R* typifies the influence degree on experiment index of every factor, the result is shown in Table 7. Fig.3 reflects the change trend of shear strength with influence factors.

Conclusions can be drawn from Table 7 and Fig.3:

(1) Fiber content is the most important factor affecting the shear strength of fiber seal, next are asphalt content and gravel coverage, test temperature is the smallest factor.

(2) According to the range value, to take account of getting higher shear strength, the suggested composition is $A_2B_2C_2D_1$, namely, fiber content is 60g/cm², asphalt content 1. 6g/cm², gravel coverage 50% and test temperature 5℃.

(3) With fiber content increasing, shear strength improves firstly and then reduces. Shear strength meet peak when fiber content reaches 60%. This phenomenon indicates the appropriate amount of fiber can improve the bonding performance of fiber seal, while excessive amounts leads to poor bonding strength. Gravel coverage has similar rule.

(4) Shear strength increases firstly and obtains the maximum value when asphalt content attains 1.6 g/cm^2, then grows down smoothly with increasing in asphalt content, with the increment of temperature, shear strength decreases monotonically.

Table 7. Visual Analysis of Result

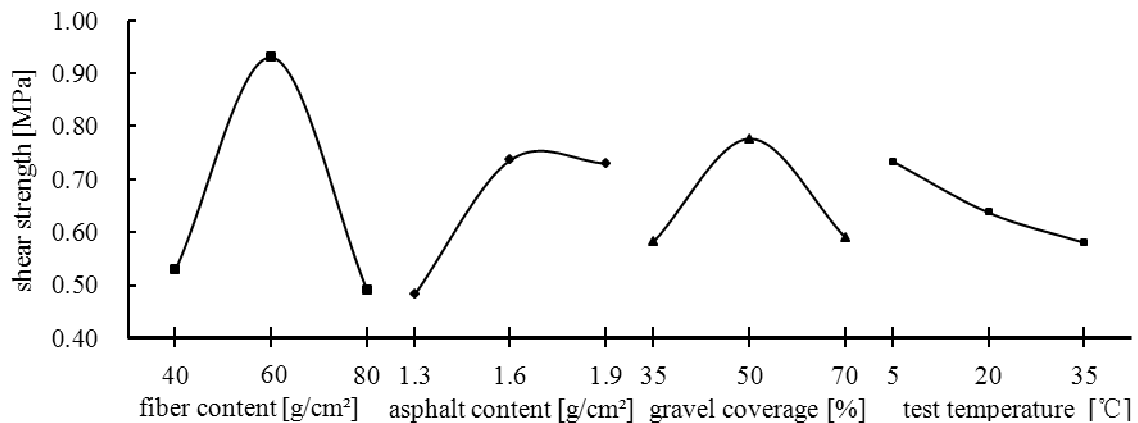| Parameter	Result of visual analysis of shear strength			
	A	B	C	D
k_1	0.53	0.48	0.58	0.73
k_2	0.93	0.74	0.78	0.64
k_3	0.49	0.73	0.59	0.58
Range R	0.44	0.25	0.19	0.15
Order of factors	A>B>C>D			
Optimal level	60	1.6	50	5
Optimal composition	$A_2B_2C_2D_1$			

Fig.3. Relationship of Index with Influencing Factors

Grey Relational Analysis

GRA is used to analyze correlativity of influencing factors taking grey correlation degree (GCD) as estimating indexes [11]. Studies have shown that GRA is an effective means to deal with the orthogonal test result [12,13]. The steps of GRA include: (1) Establishing the comparative sequence and the referenced sequence; (2) Initializing the data because of the different dimensions or units of each factor; (3) Obtaining absolute difference of the comparative sequence and the referenced sequence; (4) Seeking for the extremums among absolute difference; (5) Calculating coefficient in GRA and GCD; (6) Arranging and analyzing grey correlations. GCD is shown in Table 8.

Table 8. Grey Relational Coefficient and GCD

No.	Influencing factors			
	Fiber content	Asphalt content	Gravel coverage	Temperature
1	1.000	1.000	1.000	1.000
2	0.760	0.809	0.833	0.584
3	0.917	0.936	0.879	0.337
4	0.816	0.716	0.780	0.376
5	0.703	0.660	0.732	0.627
6	0.755	0.748	0.669	0.653
7	0.685	0.895	0.743	0.466
8	0.776	0.976	0.949	0.333
9	0.982	0.832	0.802	0.735
GCD	0.822	0.841	0.821	0.568

The influence of each comparative sequence on a reference sequence will be clear from the arrangement of grey correlation degree. The conclusion draw from Table 8 is that the factors can be arranged in the order of effecting scale on shear strength as follows: asphalt content >fiber content > gravel coverage > temperature.

Conclusion

In this paper, an orthogonal test was developed to explore the factors affecting interlayer shear strength of fiber seal, and the conclusions can be drawn as follows:

(1)Visual analysis shows that the shear strength of fiber seal increases firstly, and then decreases with the increment of material content, while decreases monotonically with the increment of temperature.

(2) To get the maximum of shear strength, the suggested composition is that fiber content is $60g/cm^2$, asphalt content $1.6g/cm^2$, gravel coverage 50% and temperature 5℃.

(3) Both the results of range analysis and GRA demonstrate that the fiber content is the most correlative influencing factor, next is asphalt content, which means it's important to control fiber and asphalt content in selection of materials.

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