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Design and evaluation of epoxy asphalt geogrid stress-absorbing layer

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Abstract: In order to delay or eliminate the occurrence and expansion of the reflective cracking in the asphalt concrete overlay on old cement concrete pavement, an epoxy asphalt geogrid stress-absorbing layer (EAGSAL) was designed. The EAGSAL consists of epoxy asphalt and fiberglass geogrid. The pull-out test, skew shearing test, bending beam test and fatigue test were conducted to evaluate the performance of the EAGSAL and a traditional stress-absorbing layer (TSAL). The results show that the adhesive performance, shear performance, bending strength and fatigue performance of the EAGSAL with an optimal spraying volume of epoxy asphalt are better than those of optimally designed TSAL, and the maximum bending strain of the EAGSAL is very close to that of the TSAL. The EAGSAL has superior performance in reflective cracking resistance. Moreover, the EAGSAL with the optimal spraying volume of approximately 2.0 L/m^2 is thinner and lighter than the TSAL, which can decrease the thickness and improve the bearing ability of the whole pavement structure.

Key words: asphalt concrete overlay; stress-absorbing layer; reflective cracking resistance; epoxy asphalt; fiberglass geogrid

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In the present cement concrete pavement projects, paving an asphalt concrete overlay on old cement concrete pavement which has reached or exceeded the service life is a common method. This can significantly improve the operational performance and riding comfort of the old cement concrete pavement, and make sufficient use of the strength of the original pavement to cut cost[1-2]. However, the frequent occurrence of reflective cracking of asphalt concrete overlay on old cement concrete pavement would not only affect surface appearance and riding comfort, but also cause further water damage, greatly degrading the service performance and shortening the service life of the pavement. The reflective cracking of the asphalt concrete overlay is caused by stress concentrations in the vicinity of joints and cracks in the old cement concrete pavement[3]. Much research on the reflective cracking[4-6] indicates that the problem can be handled in many ways, such as utilizing the stress-absorbing layer between the asphalt concrete overlay and old cement pavement, or modifying the asphalt mixture of the asphalt concrete overlay.

Stress-absorbing layers are designed to dissipate energy caused by horizontal or vertical deformation, so that the movement (vertical/horizontal) of the underlying pavement will not bring large tensile stresses to the overlay. Many different stress-absorbing layers, such as the geogrid mesh and the stress-absorbing membrane interlayer (SAMI) etc., have appeared with distinct characteristics. They can all delay the appearance and expansion of the reflective cracking to some extent[7-8]. However, due to the increasing number of heavy vehicles, harsh environments and poor-quality old cement concrete pavement, the existing stress-absorbing layers often cannot completely meet our requirements[9-10].

The epoxy asphalt, as a thermosetting material with the features of superior high temperature stability, low temperature anti-cracking, fatigue resistance and waterproof performance, has been successfully used in deck pavement in recent years[11-13]. Geogrid, a common material adopted in the stress-absorbing layer, has higher resistance to repeated loading cycles and higher stiffness modulus to show better behaviors[14]. It is always used with conventional asphalt mixture like a fine mixture consisting of SBS modified asphalt and fine aggregate. However, no research on the stress-absorbing layer consisting of geogrid and epoxy asphalt has been conducted. To deal with the reflective cracking in the asphalt concrete overlay on old cement pavement, considering the good properties of epoxy asphalt, the epoxy asphalt geogrid stress-absorbing layer (EAGSAL) consisting of epoxy asphalt and geogrid is designed. The performance of the EAGSAL and the traditional stress-absorbing layer are studied and evaluated by the pull-out test, skew shearing test, bending beam test and fatigue test.

1 Materials and Design

1.1 Epoxy asphalt

The 2451-type local epoxy asphalt used for this study is popular in China, consisting of two components marked

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as A and B. Component A is the epoxy resin, while component B is the mixture of petroleum asphalt and curing agent. This epoxy asphalt was prepared by mixing component A and component B at a fixed ratio of 1∶2.45, when component A was heated to 87 ℃ and component B to 133 ℃. Viscosity from 0 to 1 Pa · s, tensile strength and fracture elongation are three main technical indices of the epoxy asphalt that need to be evaluated. The time required for viscosity from 0 to 1 Pa · s was obtained by the rotation viscosity test following ASTM D4402, and the test temperature was 120 ℃. The values of tensile strength and fracture elongation were obtained from the tensile test following ASTM D638. Tensile specimens were prepared and tested after curing at 23 ℃. Each test was repeated three times. The average values of test results of 2451-type local epoxy asphalt and evaluation criteria determined with reference to the requirement of the binder using in the cement concrete bridge pavement[15] are listed in Tab. 1.

Tab. 1 Technical indices of 2451-type local epoxy asphalt

Technical indices	Measured average value	Criteria	Test method
Viscosity from 0 to 1 Pa · s/min	25	≥20	ASTM D4402
Tensile strength/MPa	8.6	≥6.9	ASTM D638
Fracture elongation/%	210	≥190	ASTM D638

1.2 Geogrid

According to the requirements of the research and the feasibility of the experiment, three main geogrids including plastic geogrid, polyester geogrid and fiberglass geogrid are selected in this study. In order to obtain the mechanical properties of these three kinds of geogrids, tensile tests were performed at 23 ℃ on the materials testing machine systems (MTS), following the procedure in the current Chinese national regulation standard, Test Methods of Geosynthetic Material for Highway Engineering (JTG E 50—2006). In this test, the relationship between tensile strength and elongation is regarded as an index to evaluate the mechanical properties of geogrids, and the results are shown in Fig. 1.

It can be found from Fig. 1 that the tensile strength of the three kinds of geogrids all increases with the increasing elongation at the beginning, but plunges after the peak. According to the tensile strength and elongation of epoxy asphalt in Tab. 1, the geogrids can provide higher tensile strength when the elongation of the EAGSAL is smaller, which can improve the cracking resistance of the EAGSAL. Moreover, the elongation of all geogrids is more than 8% when the tensile strength reaches the peak, which is enough for use in the stress-absorbing layer. By comparing the peaks of tensile strength of three kinds of geogrids, the fiberglass geogrid is the greatest, which

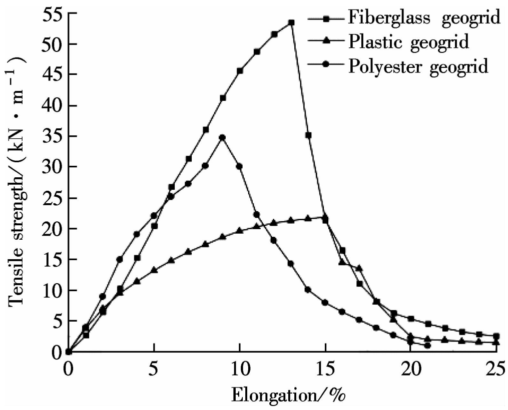

Fig. 1 Typical curves of tensile test

means that the fiberglass geogrid most easily meets the requirement of high tensile strength of the EAGSAL material. Thus, the fiberglass geogrid is chosen as the raw materials of the EAGSAL through a comprehensive consideration of its tensile strength and elongation.

1.3 Specimen preparation

As the EAGSAL is too thin to perform some tests, a pavement structure with three layers including asphalt concrete overlay, EAGSAL and old cement pavement is designed, as shown in Fig. 2. The EAGSAL is composed of epoxy asphalt and fiberglass geogrid.

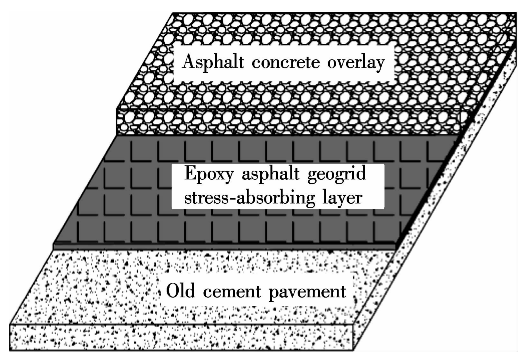

Fig. 2 Stereogram of specimen

Five spraying volumes are designed to study the influence of spraying volume of epoxy asphalt on the performance of the EAGSAL: 0.8, 1.2, 1.6, 2.0 and 2.4 L/m^2. In order to make a comparative analysis between the EAGSAL and the traditional stress-absorbing layer, an optimal design was conducted on a traditional stress-absorbing layer (TSAL) consisting of SBS modified asphalt and fine aggregate. The nominal maximum aggregate size of fine aggregate, the SBS content in the modified asphalt and the asphalt content of the TSAL are 4.75 mm, 5% and 9.5%, respectively. Moreover, the measured thickness and weight of the TSAL are approximately 1 cm and 10 kg/m^2, respectively. The asphalt of AH-90 and basalt are used in the asphalt concrete overlay, and the gradation of asphalt concrete is AC-10 type. The grading limits and gradation of AC-10 type are determined by the current Chinese national regulation, Technical Specification for Construction of Highway Asphalt Pavement (JTG F 40—2004), are listed in Tab. 2.

Tab. 2 Grading limits and gradation of AC-10 type

Sieve size/mm	Percentage passing/%		
	Lower limit	Upper limit	Gradation
13.2	100	100	100
9.5	90	100	95
4.75	45	75	60
2.36	30	58	44
1.18	20	44	32
0.6	13	32	23
0.3	9	23	16
0.15	6	16	11
0.075	4	8	6

The procedures of preparing specimen are as follows: First, a 30 cm × 30 cm × 5 cm cement concrete slab using P · Ⅱ 42.5R-type concrete is prepared, then after 28 d curing in a standard curing room, it is placed in a 30 cm × 30 cm × 10 cm steel mold, on which a 30 cm × 30 cm fiberglass geogrid is put. Then, the epoxy asphalt is sprayed on the slabs with fiberglass geogrid, whose spraying volume is the same as that in the previous design. Finally, after curing for 24 h at 20 ℃, the asphalt concrete of AC-10 is poured into the mold and compacted by a steel wheel, following the procedure in the current Chinese national regulation standard, Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E 20—2011), and then reserved for 24 h at 20 ℃. Thus, the 30 cm × 30 cm × 10 cm specimen is made, and four replicates are prepared for each spraying volume. The specimens of the TSAL are prepared like the above.

2 Test Method

The mechanics mechanism of composite pavement structure layers is very complicated, and many kinds of performance evaluation methods are used on the stress-absorbing layer. Based on the related research[16-17] and the feasibility of the experiment, four kinds of tests were conducted to compare the performance in reflective cracking resistance between the EAGSAL with different spraying volumes and the TSAL: the pull-out test, skew shearing test, bending beam test and fatigue test. The first two tests are used to evaluate the interfacial property, including the adhesive performance and shear performance[18-19], while the next two ones aim to assess the low-temperature cracking resistance and fatigue performance, respectively.

2.1 Pull-out test

5 cm × 5 cm × 6 cm cubic specimens for the pull-out test were cut from the previously prepared 30 cm × 30 cm × 10 cm specimens, as shown in Fig. 3 and Fig. 4. The thickness of both the asphalt concrete overlay and old cement pavement should be the same as far as possible. The test was conducted at 23 ℃ following the procedure in the current Chinese national regulation, Pull-off Test for Adhesion (GB/T 5210—2006). Three replicas were tested for each kind of stress-absorbing layer.

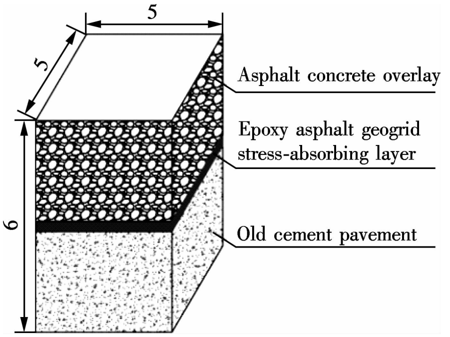

Fig. 3 Cubic specimens(unit: cm)

Fig. 4 Pull-out test equipment

2.2 Skew shearing test

The specimens for the skew shearing test are the same as those for the pull-out test, and the test machine is shown in Fig. 5. The test was conducted at 23 ℃, a 4° shear angle and a 20 mm/min loading rate according to the actual working condition of the road and the current Chinese national regulation, Test Method for Building Sealants (GB/T 13477—2002). Three specimens were tested for each kind of stress-absorbing layer.

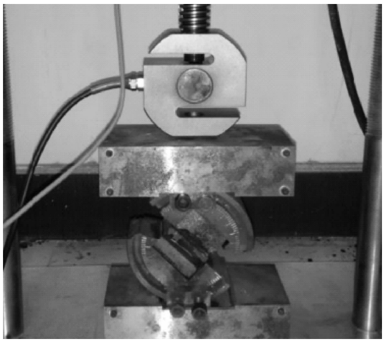

Fig. 5 Skew shearing test equipment

2.3 Bending beam test

3 cm × 7 cm × 25 cm beams for the bending beam test

were cut from the previously prepared 30 cm × 30 cm × 10 cm specimens, and the requirement concerning thickness is the same as that for the pull-out test. The effective span and the loading rate are 20 cm and 50 mm/min, respectively. The test was performed at −10 ℃ on the materials testing machine systems (MTS), following the procedure in the current Chinese national regulation standard, Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E 20—2011). Three replicates were examined for each kind of stress-absorbing layer.

2.4 Fatigue test

In the test, a crack channel was cut at the midpoint of the beams of 6 cm × 7 cm × 30 cm, whose depth was 2 cm, as shown in Fig. 6. The four-point bending fatigue test was conducted with the universal testing machine system (UTM) at 15 ℃. In this test, the controlled-stress loading mode was selected, and the haversine load waveform with 10 Hz frequency was used; the stress ratio of 0.50 was determined according to the relative research[20] and the requirements of the study. The control stress was calculated by multiplying the maximum bending strength of the beams determined by the above bending beam test under the same condition by the stress ratio. Three replicas were produced for each kind of stress-absorbing layer.

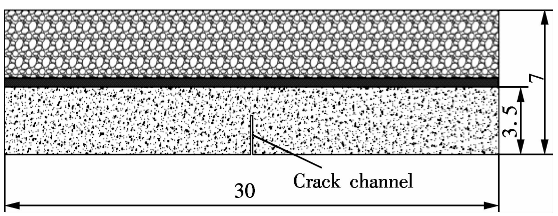

Fig. 6 Structure diagram of beam (unit: cm)

3 Results and Discussion

3.1 Adhesive performance

As the middle layer in a composite pavement structure, the stress-absorbing layer should play an important role in connecting the asphalt concrete overlay and old cement pavement. That is to say, the stress-absorbing layer should have great adhesive performance in maintaining the continuity of each layer under the action from the external load. Fig. 7 shows that the adhesive strength of the EAGSAL is much greater than that of the TSAL, which is because the epoxy asphalt has better adhesive performance than SBS modified asphalt. In addition, the adhesive strength reaches its peak when the spraying volume of epoxy asphalt is 2.0 L/m^2, so it is not correct that a greater spraying volume does better.

3.2 Shear performance

In practical applications, the pavement not only bears

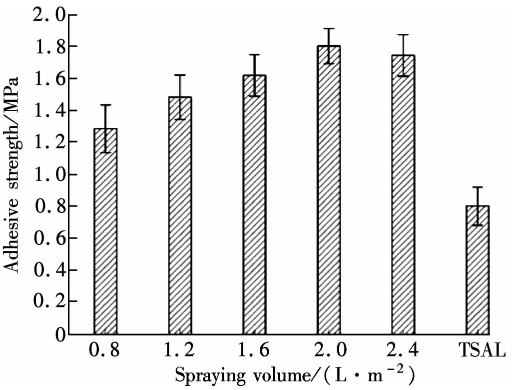

Fig. 7 Results of the pull-out test

the vertical effect from vehicle load, but withstands the horizontal effect from vehicle's braking force, which requires that the stress-absorbing layer should have superior shear performance. The results of the skew shearing test recorded in Fig. 8 clearly show that the EAGSAL, with the most appropriate spraying volume of 2.0 L/m^2, provides higher shear strength compared with the TSAL. This is because too little spraying volume makes the stress-absorbing layer too thin to form the bonding surface, while an excessive one may make the stress-absorbing layer form an oily surface.

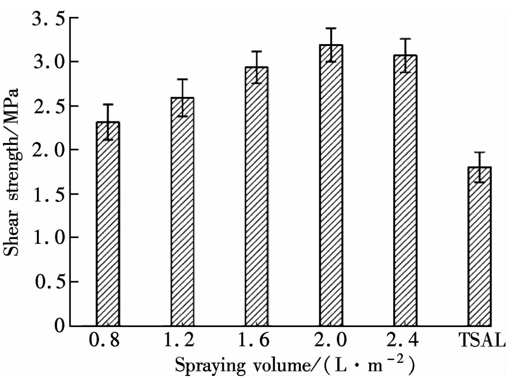

Fig. 8 Results of the skew shearing test

3.3 Low-temperature cracking resistance

The main function of the stress-absorbing layer is to delay the occurrence and expansion of the reflective cracking to some extent, so a large bending strength and maximum bending strain are needed. From Fig. 9, it can be found that the bending strength increases with a growing spraying volume of epoxy asphalt, but the amplitude of variation is small when the volume changes from 2.0 to 2.4 L/m^2. This means that increasing the bending strength through excessive growth of volume is meaningless. On the other hand, the maximum bending strain of the TSAL is greater than that of the EAGSAL, which may be attributed to the larger thickness of the TSAL, but when the EAGSAL is under a spraying volume of 2.0 L/m^2, its maximum bending strain is very close to TSAL's. A comprehensive consideration of the bending strength and the maximum bending strain shows that the appropriate volume of epoxy asphalt is approximately 2.0 L/m^2.

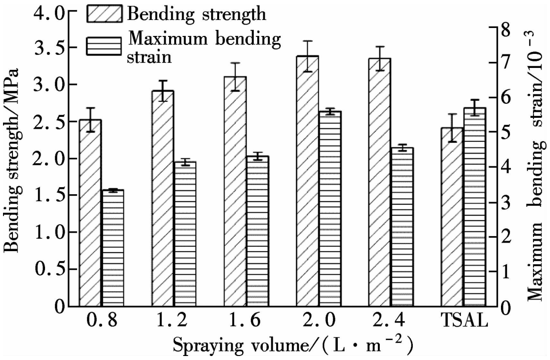

Fig. 9 Results of the bending beam test

3.4 Fatigue performance

The fatigue life of the EAGSAL and the TSAL presented in Fig. 10 shows that its growth trend is similar to the bending strength above. The fatigue life at 2.0 L/m^2 spraying volume is approximately three times as much as that of the TSAL, which means that the EAGSAL, with an appropriate spraying volume of epoxy asphalt, can provide better fatigue performance than the TSAL.

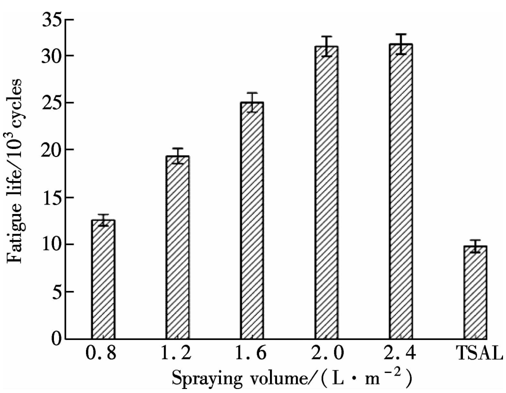

Fig. 10 Results of the fatigue test

3.5 Composite analysis

Due to the complex broken surface and corners of the TSAL, the interlock force of the TSAL is greater than that of the EAGSAL, but on the other hand, more stress concentration points are caused by the rough aggregate, which make the TSAL fragile. Meanwhile, the EAGSAL has greater tensile strength due to the high tensile strength of fiberglass geogrid and epoxy asphalt, which can bear greater concentration stress. Moreover, the EAGSAL has good uniformity and integrity, which can disperse energy caused by horizontal or vertical deformation.

However, due to the larger thickness of the TSAL, the maximum bending strain of the EAGSAL is smaller than that of the TSAL. Therefore, the deformation ability of the EAGSAL is worse than that of the TSAL, but when the EAGSAL is under a spraying volume of 2.0 L/m^2, its maximum bending strain is very close to TSAL's.

Furthermore, by a comprehensive consideration of the performance studied in this paper, the appropriate volume of the EAGSAL is approximately 2.0 L/m^2. The measured thickness and mass of the EAGSAL with a sparing volume of 2.0 L/m^2 are 0.5 cm and 3 kg/m^2, respectively, decreased by 50% and 70% in comparison with the TSAL. EAGSAL can reduce the thickness and improve the bearing ability of the whole pavement structure.

4 Conclusions

1) The peak of tensile strength of fiberglass geogrid is greater than that of two other kinds of geogrids, and fiberglass geogrid can provide greater tensile strength when the elongation of the EAGSAL is less.

2) The adhesive performance, shear performance, bending strength and fatigue performance of the EAGSAL with its optimal spraying volume are better than those of optimally designed TSAL, and the maximum bending strain of the EAGSAL is very close to that of the TSAL. It can be demonstrated that the EAGSAL has superior performance in reflective cracking resistance compared with the TSAL.

3) The optimal spraying volume of epoxy asphalt in the EAGSAL is approximately 2.0 L/m^2, which can make the EAGSAL thinner and lighter than the TSAL, and can decrease the thickness and improve the bearing ability of the whole pavement structure.

Due to the high price and thermosetting properties of epoxy asphalt, the cost of the EAGSAL is much greater than that of the TSAL and the construction of the EAGSAL is more difficult than that of the TSAL, and a more comprehensive and deeper analysis of the EAGSAL will be needed in the future study.

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环氧沥青土工格栅应力吸收层的设计和性能评估

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摘要:为了延缓或者消除水泥混凝土铺装上沥青混凝土加铺层的反射裂缝的出现和扩展,设计出一种由环氧沥青和玻璃纤维土工格栅组成的环氧沥青土工格栅应力吸收层(EAGSAL).通过拉拔试验、斜剪试验、小梁弯曲试验及疲劳试验对 EAGSAL 和一种普通应力吸收层(TSAL)进行性能研究.结果表明:最佳环氧沥青撒布量下的 EAGSAL 的黏结性能、抗剪性能、抗弯强度以及疲劳性能都优于最佳设计的 TSAL;EAGSAL 的最大弯曲应变与 TSAL 非常接近;EAGSAL 具有较好的抗反射裂缝能力.同时,EAGSAL 的最佳环氧沥青撒布量是 2.0 L/m^2,这使得 EAGSAL 比 TSAL 更轻薄,可降低整个铺装结构的厚度,提高铺装结构的承载能力.

关键词:沥青混凝土加铺层;应力吸收层;抗反射裂缝能力;环氧沥青;玻璃纤维土工格栅
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