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Research Article

Design and Performance of Anticracking Asphalt-Treated Base

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To enhance the crack resistance of asphalt-treated base (ATB), a type of gapped and semiopened gradation ATB mixture, GSOG, was designed. Its design method was proposed based on the volume design method and performance tests. Firstly, several gradations were designed preliminarily in which middle particle sizes of coarse aggregates were partially or completely gapped according to the gradation specification. Secondly, their voids in coarse aggregates (VCA) were determined through dry rod compaction test on coarse aggregates, and then their theoretical voids were calculated. Gradations whose theoretical voids met the requirements were selected to fabricate specimens with Superpave Gyratory Compactor, and their voids were determined using vacuum sealing method and submerged weight in water method. Finally, gradations whose voids meet requirements were selected to fabricate different types of specimens for various performance tests, and the optimal gradation can be selected comprehensively considering their performances, especially focusing on their crack resistance. According to this gradation design method, the gradation of GSOG-25 was designed, and its performances, including high-temperature stability, water stability, fatigue, and antireflection crack resistance, were measured and compared to ordinary ATB-25. The results demonstrate that the performance of GSOG-25 is much better than that of ordinary ATB-25, especially in anticracking capacity.

1. Introduction

In China, semirigid inorganic binding material stabilized macadam was used as a base course in 95% of asphalt pavements [1, 2]. The semirigid base course can objectively provide the necessary structural capacity for pavement under heavy traffic condition in our country. However, semirigid base course cracks easily because of its temperature shrinkage and/or dry shrinkage. The cracks in the base course will result in reflection cracks through asphalt pavement surface after being opened to traffic for only 1 or 2 years whether the pavement is in the frozen or unfrozen regions. Then water will penetrate into the pavement structure and will accelerate the destruction process of the pavement [3–5].

A thorough literature review revealed that extensive past research focused on characterizing and assessing ATB through laboratory evaluations [6–11], field investigations and validations [12–14], and empirical and mechanistic modeling [15, 16]. Marjerison studied the mechanistic comparison of cement- and bituminous-stabilized granular base systems [17]. Schwartz and Khosravifar studied the design and evaluation of foamed asphalt base materials [18]. Wang put forward a performance-based mixture design of asphalt-treated base [19]. Li et al. studied the materials and temperature effects on the resilient response of asphalt-treated alaskan base course materials [20]. Hector developed a new mix design method and specification requirements for asphalt-treated bases [21]. Zhang et al. studied the volumetric properties and permeability of asphalt-treated permeable base mixtures [22]. Haider et al. investigate the effects of HMA surface layer thickness, base type, base thickness, and drainage on the performance of new flexible pavements constructed in different site conditions (subgrade type and climate), and the data are from the SPS-1 experiment of the Long-Term Pavement Performance program. Base type was found to be the most critical design factor affecting fatigue cracking, roughness (IRI), and longitudinal cracking (wheel path). The best performance was shown by pavement sections with asphalt-treated bases [23].

In recent years, a layer of ATB was utilized between the semirigid base course and asphalt concrete layer to avoid or delay the reflective cracks. This is according to the structural and material characteristics of abroad long-lasting asphalt pavement [1–4]. But reflection cracks had not been eliminated fundamentally [3, 4]. The test pavement structure section constructed by Dong et al. demonstrated that ATB can effectively decrease the premature failure caused by reflection cracks [24]. Feng and Hao put forward a five-control-points design method for dense gradation ATB, and the designed gradation was close to the gradation designed through CAVF method [25]. Zhesheng and Qian concluded that ATB has good mechanical and fatigue properties according to fatigue tests results conducted to ATB beams under different stress ratios [26]. Research results of Qian and Shu revealed that ATB with high viscosity hard asphalt (AH30) is superior to the ATB with original asphalt (AH70) in high-temperature stability, water stability, and fatigue life [27].

So, the aim of this paper is to enhance the crack resistance of ATB. The gradation objective and design method were put forward on the anticracking ATB, which was called GSOG later. The gradation of this new kind of anticracking ATB, GSOG, is partially or completely gapped in middle particle size of coarse aggregates, and its void is 8% to 12%, namely, semiopened. In order to compensate for the weakening of the bonding force between the coarse aggregates due to the increase of voids, SBS modified asphalt was used as the binder. Its gradation design method is based on the volume design method and performance tests. According to this GSOG design method, GSOG-25 was designed, and various performance tests were conducted and compared with the ordinary ATB-25. The tests results demonstrated that the performance of GSOG-25 is great and its antireflection cracking capacity is much better than the ordinary ATB. So, it can be used to prolong the service life of asphalt pavement structure.

2. Gradation Design Method of the Anticracking ATB

2.1. Basic Principles. In order to enhance the crack resistance of ATB, the solutions were put forward from two aspects of gradation and asphalt binder. They are given as follows.

(1) Regarding air voids, the voids in the mixture can eliminate or attenuate the stress concentration and extend the crack propagation path. So, a certain amount of voids can be used to enhance the crack resistance of the mixture. The mixture gradation can be designed as a semiopened gradation; namely, its void content is 8% to 12%.

(2) As regards gradation, skeleton structure formed by squeezing of coarse aggregate can enhance the bearing capacity. So, coarse aggregates in the GSOG gradation should squeeze each other to form a stable skeleton to withstand the external load and maintain the stability of the material structure and enhance its high-temperature stability and deformation resistance [28, 29]. To avoid the interference caused by the middle particle size to the coarse aggregate skeleton structure and ensure the stability of the coarse aggregate skeleton structure, the intermediate particle sizes (4.75 mm and/or 9.5 mm) coarse aggregates were completely or partially gapped [30].

(3) For asphalt binder, considering that increasing porosity of the mixture will affect the bond between aggregates and will affect the performance and durability of the mixture, polymer modified asphalt can be used as the asphalt binder. The use of polymer modified asphalt can not only enhance the cohesion between aggregates but also increase the thickness of asphalt film and enhance its fatigue and cracking resistance. This will improve its durability.

(4) Concerning performance, the performances of designed GSOG, including high-temperature stability, low-temperature crack resistance, water stability, fatigue resistance, and crack resistance, should meet the requirements or be better than the ordinary ATB.

2.2. Basis Procedures. According to the upper basic design principles, a gradation optimization method was put forward based on the volume design method [31] and performance tests. Its basic steps are given as follows.

(1) Several gradations with the intermediate particle sizes (4.75 mm and/or 9.5 mm) coarse aggregates gapped completely or partially were initially designed according to the gradation limits of ATB.

(2) The void of coarse aggregate, VCA, was determined through the dry-rodded compaction tests of coarse aggregates.

$$\mathrm{VCA} = \left(\frac{1 - \mathrm{GCA}_{\mathrm{DRC}}}{G_{\mathrm{b.ca}}}\right), \tag{1}$$

where VCA is the void of dry-rodded compacted coarse aggregates, %; $\mathrm{GCA}_{\mathrm{DRC}}$ is the dry-rodded compacted density of coarse aggregates, $\mathrm{g{\cdot}cm^{-3}}$; and $G_{\mathrm{b.ca}}$ is the bulk density of coarse aggregates, $\mathrm{g{\cdot}cm^{-3}}$.

(3) Calculate the air voids of each mixture at different asphalt aggregate ratio according to their gradations and densities of each aggregate.

$$V_{\mathrm{a}} = \mathrm{VCA} - \frac{P_{\mathrm{fa}}/G_{\mathrm{b.fa}} + P_{\mathrm{fi}}/G_{\mathrm{a.fi}} + P_{\mathrm{b}}/G_{\mathrm{b}}}{P_{\mathrm{ca}}/\mathrm{GCA}_{\mathrm{DRC}}}, \tag{2}$$

where V_{a} is the air void of asphalt mixture, %; P_{b} is the asphalt aggregate ratio, %; $G_{\mathrm{b.fa}}$ is the bulk density of fine aggregates, $\mathrm{g{\cdot}cm^{-3}}$; $G_{\mathrm{a.fi}}$ is the apparent density of filler, $\mathrm{g{\cdot}cm^{-3}}$; G_{b} is the density of asphalt, $\mathrm{g{\cdot}cm^{-3}}$; P_{ca} is the mass fraction of coarse aggregate to all aggregates, %; P_{fa} is the mass fraction of fine aggregate to all aggregates, %; and P_{fi} is the mass fraction of filler (<0.075 mm) to all aggregates, %.

(4) Fabricate samples with Superpave Gyratory Compactor (SGC) for those gradations whose voids meet the requirements. Vacuum seal the samples with CoreLok, and then measure their bulk densities and air voids using Immersion Weighting method.

(5) Select the gradations whose air voids meet the requirements to fabricate different types of samples for different performance tests, including high-temperature stability, water stability, and fatigue resistance. Finally, the gradation whose performance is the best was selected as the optimal gradation.

3. Raw Materials

3.1. Asphalt Binders. Two kinds of asphalt binder were used in this paper: Shell 70-A original asphalt and SBS modified

Table 1: Technical indexes of asphalt binders.

Technical indexes	Unit	Shell 70-A	SBS modified asphalt
Penetration (25°C, 5 s, 100 g)	0.1 mm	67	46
Softening point, R&B	°C	47.5	73
Kinematic viscosity @177°C	Pa·s	—	2.0
Kinetic viscosity @60°C	Pa·s	223	—
Flash point	°C	327	230
Elastic recovery @25°C	%	—	83
Difference of softening point for 48 h	°C	—	2.0
Mass lost	%	0.10	0.12
Penetration ratio, 25°C	%	65.2	79

Table 2: Technical indexes of coarse aggregates.

Index	Unit	Actual measurement
Crushing value	%	13.5
Apparent relative density	—	—
Water absorption	%	1.2
Strength	%	9.4
Needle and plate particle content	%	8
Content of <0.075 mm material	%	0.43
Adhesion with SBS modified asphalt	Level	5

asphalt binder. Shell 70-A was used in the ordinary ATB-25 as the contrast material, and the SBS modified asphalt binder was used in the new designed GSOG-25. Their technical indexes were presented in Table 1.

3.2. Aggregate. The coarse aggregates, fine aggregates, and filler were produced from limestone. Their technical indexes were shown in Tables 2, 3, and 4.

4. Proportion Design of GSOG-25 Mixtures

4.1. Initially Designed Gradations. Through controlling the passage percent of aggregates of the four key sizes, 26.5 mm, 9.5 mm, 4.75 mm, 0.075 mm sieves, and partially gapping the usage of aggregates passing sieve size of 4.75 mm and/or 9.5 mm, 5 different gradations were designed initially according to Chinese Technical Specification for Construction of Highway Asphalt Pavement [32], as shown in Table 5.

In Table 5, gradations 1, 3, and 4 were partially gapped at the particle size of 4.75 mm, and gradations 2 and 5 were partially gapped at the particle size of 9.5 mm.

4.2. Measuring the Void of Coarse Aggregate, VCA, for Each Gradation. Dry-rodded compaction was conducted on coarse aggregates (≥4.75 mm) for each gradation, and their VCA were calculated, as shown in Table 6.

4.3. Calculating the Theoretical Voids of Each Gradation. The asphalt aggregate ratio of the mixture was estimated at 4.2%, and the corresponding theoretical void of each gradation was calculated, as shown in Table 7.

From Table 7, it can be seen that the air voids of gradations 2, 4, and 5 meet the requirement. So, they were selected for further research.

4.4. The Air Voids of Fabricated Samples. For gradations 2, 4, and 5, cylinder samples were fabricated at the asphalt aggregate ratio of 4.2% using SGC. The compaction parameters of SGC were the following: compaction times, 174 times, vertical pressure, 600 KPa, and compactor angle, 1.16°.

The samples were vacuum sealed with CoreLok, and then their bulk density and voids were measured with Immersion Weighting method, as shown in Table 8.

It can be seen from Table 8 that the air voids of gradation 2 were very smaller than the requirement, and those of gradations 4 and 5 meet the requirements. So, gradations 4 and 5 were selected for further optimization.

4.5. Performance Tests. In order to enhance crack resistance, the asphalt aggregate ratio should be higher than ordinary ATB mixture. So, three asphalt aggregate ratios, 3.9%, 4.2%, and 4.5%, were selected to fabricate GSOG-25 samples for both gradations (gradations 4 and 5).

The SGC cylinder samples' air voids were shown in Table 9.

(1) Moisture Susceptibility and High-Temperature Stability. High-Temperature Immersion Wheel Truck Test of Asphalt Mixtures can be used to measure the water stability and high-temperature stability of the asphalt mixture. So, the Immersion Wheel Truck Test at 60°C with Hamburg rutting tester was selected. The size of plate sample is 300 mm × 300 mm × 80 mm, the samples were immersed into water at 60°C for 2 hours, and then the test was started. The tests were set to end when loading 30000 times or when rut depth arrived at 20 mm. The results were shown in Table 10.

(2) Fatigue Resistance. Four-point bending fatigue test was selected to evaluate the fatigue resistance of GSOG-25 beam sample. The size of the sample is 300 mm $*$ 60 mm $*$ 80 mm. Because the aim of the tests is to compare the fatigue resistance of different gradation with different asphalt aggregate ratio, the fatigue loading parameters were the same: test temperature is 20°C, loading waveform is sinusoidal wave, loading frequency $f = 10$ Hz, and the cyclic Eigen value

Table 3: Densities of aggregates.

Particle size (mm)	Apparent relative density	Bulk volume relative density (g/cm^3)
26.5	2.783	2.770
19	2.731	2.716
16	2.745	2.734
13.2	2.717	2.693
9.5	2.736	2.723
4.75	2.696	2.618
2.36	2.755	2.720
1.18	2.742	2.695
0.6	2.739	2.676
0.3	2.759	2.707
0.15	2.711	2.672
0.075	2.654	2.609

Table 4: Technical indexes of filler.

Project	Unit	Test result	Specification requirements
Apparent density	t/m^3	2.640	≥2.50
Water content	%	0.41	≤1
Particle size range			
<0.6 mm	%	100	100
<0.15 mm	%	94.5	90~100
<0.075 mm	%	83	75~100
Appearance	—	No clustering	No clustering
Hydrophilic index	—	0.6	<1
Plasticity index	—	3	<4

Table 5: Initially designed gradations.

Sieve sizes (mm)	31.5	26.5	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Gradation 1 (%)	100	77	58.8	49.1	39.5	18.5	17.8	15	12	8	5.5	4.8	3.3
Gradation 2 (%)	100	77	55.8	49.1	28.5	27.5	17.8	15	12	8	5.5	4.8	3.3
Gradation 3 (%)	100	100	67.4	51.9	37.3	19.4	17.5	13.6	10.7	8.4	6.5	5.1	4
Gradation 4 (%)	100	75.7	56.2	45.2	34.3	21	19.8	15	12	8	5.5	4.8	3.3
Gradation 5 (%)	100	75.2	55.2	43.7	32.3	30.5	17.8	15	12	8	5.5	4.8	3.3

$\rho = P_{\min}/P_{\max} = 0.3\,\mathrm{KN}/3\,\mathrm{KN} = 0.1$. The fatigue results were shown in Table 11.

(3) Seepage. Seepage performance was measured on plate sample according to Chinese standard test methods of bitumen and bituminous mixtures for highway engineering [33]. The results were shown in Table 12.

4.6. Selection of Optimal Gradation. It can be seen from Table 6 that gradation 5 with 4.2% asphalt aggregate ratio has the best high-temperature stability and water stability, and gradation 4 with 4.5% asphalt aggregate ratio has the best fatigue resistance. Considering that the project is located in south China, the climate is characterized by high temperature and is rainy, so gradation 5 with 4.2% asphalt aggregate ratio was selected as the optimal gradation.

5. Comparison of the Performances

The performance, especially the antireflection cracking resistance of the optimized GSOG-25, was measured and compared with those of the ordinary ATB-25.

5.1. Design of the Ordinary ATB-25. The gradation of ATB-25 was designed according to Chinese Technical Specification for Construction of Highway Asphalt Pavement (JTG F40-2004) [13], the asphalt binder is Shell 70-A, and optimal asphalt content is 3.7%. Its gradation was shown in Table 13.

Table 6: The VCA of each gradation.

Gradation	Density at dry-rodded compaction ($g{\cdot}cm^{-3}$)	Bulk density of coarse aggregates ($g{\cdot}cm^{-3}$)	VCA (%)
Gradation 1	1.942	2.747	29.32
Gradation 2	1.916	2.739	30.05
Gradation 3	1.863	2.721	31.5
Gradation 4	1.829	2.735	33.1
Gradation 5	1.864	2.729	31.7

Table 7: Theoretical void of each gradation.

Gradation	Estimated asphalt aggregate ratio (%)	Theoretical void (%)
Gradation 1	4.2	5.7
Gradation 2	4.2	9.5
Gradation 3	4.2	6.7
Gradation 4	4.2	12.4
Gradation 5	4.2	12.1

The Marshall technological indexes of the ordinary ATB-25 were shown in Table 14.

5.2. Comparison of the Performances. The performance properties of asphalt mixture include resistance to high-temperature deformation, to low-temperature cracking, to water damage, and to fatigue cracking. Considering that the ATB course usually lies 16 cm to 20 cm below the pavement surface, the low-temperature performance was not concerned in the paper. The compared performances include resistance to high-temperature deformation, to water damage, to fatigue cracking, and to antireflection crack.

(1) Resistance to High-Temperature Deformation. The rutting tests at 60°C were conducted to evaluate their high-temperature stability. The sample size is 300 mm ∗ 300 mm ∗ 80 mm, compacted with kneading compactor. According to Chinese standard test methods of bitumen and bituminous mixtures (JTG E20-2011) [15], the dynamic stability index, DS, was used as the evaluation index.

$$\mathrm{DS} = \frac{d_2 - d_1}{t_2 - t_1}, \tag{3}$$

where DS is dynamic stability, times/mm; d_2 is deformation at the moment of t_2, mm; and d_1 is deformation at the moment of t_1, mm.

The results were shown in Table 15.

It can be seen from Table 15 that the dynamic stability of GSOG-25 is obviously higher than that of ATB-25, and the rut depth of GSOG-25 is only about half of that of ATB-25. So the resistance to high-temperature deformation of GSOG-25 is obviously better than that of ATB-25.

(2) Water Stability. The residual Marshall stability, S, is used as the index to evaluate the water stability according to the Chinese Technical Specification for Construction of Highway Asphalt Pavement.

Standard Marshall test and immersion Marshall test were conducted according to Chinese standard test methods of bitumen and bituminous mixtures for highway engineering, T0709-2011 [13], and then the residual stability, S, can be determined from the Marshall stability S_0 and the immersion Marshall stability S_1 according to formula (4).

$$S = \frac{S_1}{S_0} \times 100\%, \tag{4}$$

where S is the residual stability, %; S_1 is the immersion Marshall stability, kN; and S_0 is the Marshall stability, kN.

The results of water stability tests were shown in Table 16.

It can be seen from Table 16 that the water stability of these two designed mixtures meets the specification requirement. And the residual stability of GSOG-25 is greater than that of ATB-25, which means that the water stability of GSOG-25 is better than that of ATB-25.

(3) Fatigue Resistance. Four-point bending fatigue tests were conducted with servo material tester, UTM-100, to compare the fatigue performance of the two designed mixtures.

The size of the beam samples is 380 mm ∗ 60 mm ∗ 50 mm. The samples were formed by using a vibration roller, HYLN-5, through a pneumatic loading, and it is a good simulation to the site situation of asphalt pavement. The test temperature is 15 ± 0.5°C and loading frequency is 10 ± 0.1 Hz according to Chinese standard test methods of bitumen and bituminous mixtures for highway engineering [13]. The maximum strain was controlled during the repeated loading, and the $\mathrm{N_{f50}}$ method was used to determine the fatigue life, which means that when the modulus of the sample is decreased to 50% of its initial modulus, the cyclic loading times are its fatigue life. The results were given in Table 17 and were contrasted in Figure 1.

It can be seen from Table 17 and Figure 1 that the fatigue performance of GSOG-25 is much better than that of ATB-25 obviously. When the maximum strain is controlled at 400 $\mu\varepsilon$, the fatigue life of GSOG-25 is about 220 times greater than that of the ordinary ATB-25. And when the strain level is controlled at 600 $\mu\varepsilon$, the fatigue life of GSOG-25 is also much greater than that of the ordinary ATB-25.

(4) Antireflection Cracking Resistance. Loading mode of reflection crack resistance test shown in Figure 2 was used to measure the resistance to reflection cracking.

Table 8: Measured air voids of each gradation at asphalt aggregate ratio of 4.2%.

Gradation	Bulk density ($g \cdot cm^{-3}$)	Theoretical maximum relative density ($g \cdot cm^{-3}$)	Void (%)	Average void (%)
Gradation 2	2.379	2.561	7.1	6.8
	3.386	2.561	6.8	
Gradation 4	2.344	2.558	8.4	8.1
	2.358	2.558	7.8	
Gradation 5	2.353	2.554	7.9	8.0
	2.348	2.554	8.1	

Table 9: Measured voids of ATB mixtures.

Gradation	Asphalt aggregate ratio (%)	Voids (%)		
		Sample 1	Sample 2	Average
Gradation 4	3.9	9.7	9.1	9.4
	4.2	8.4	7.8	8.1
	4.5	7.0	7.6	7.3
Gradation 5	3.9	9.5	9.0	9.2
	4.2	7.9	8.1	8.0
	4.5	7.4	6.7	7.1

Table 10: Hamburg immersion rutting test results.

Gradation	Asphalt aggregate ratio (%)	Times	Depth of rut (mm)
Gradation 4	3.9	20900	20
	4.2	30000	14.33
	4.5	30000	12.78
Gradation 5	3.9	30000	12.06
	4.2	30000	7.96
	4.5	30000	11.22

Table 11: Fatigue results.

Gradation	Asphalt aggregate ratio (%)	Fatigue life (cycles)			
		Sample 1	Sample 2	Sample 3	Average
Gradation 4	3.9	527	655	763	648
	4.2	2289	1739	788	1605
	4.5	3707	4344	1867	3306
Gradation 5	3.9	807	1012	711	843
	4.2	1703	1309	1072	1361
	4.5	1925	2090	1884	1966

Table 12: Permeability coefficient and voids of specimens.

Gradation	Asphalt aggregate ratio (%)	Permeability coefficient (ml/min)	Void (%)
Gradation 4	3.9	420	9.8
	4.2	145	9.0
	4.5	No seepage	8.3
Gradation 5	3.9	380	9.6
	4.2	135	8.7
	4.5	No seepage	8.0

Table 13: Gradation of ATB-25.

Size of sieve (mm)	31.5	26.5	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Upper limit	100	100	90	76	62	52	40	29	25	18	14	10	6
Lower limit	100	90	70	55	42	32	20	14	10	8	5	3	2
Gradation	100	93.5	80.5	65.8	52.0	40.1	29.3	20.5	15.6	11.8	8.3	6.3	3.8

Table 14: Marshall technological index of ATB-25.

Technological index						
Bulk density (g·cm^{-3})	Theoretical max. density (g·cm^{-3})	void (%)	VCA (%)	Asphalt saturation (%)	Stability (KN)	Flow value (mm)
2.447	2.571	3.6	12.0	69.6	3.10	3.1

Table 15: Rutting test results.

Index	d_1 (mm)	d_2 (mm)	DS (cycles/mm)	Average (cycles/mm)
GSOG-25				
1	2.189	2.363	3620	3320
2	2.283	2.499	3020	
ATB-25				
1	4.710	5.263	1139	1097
2	4.825	5.423	1054	

Table 16: Residual stability of different mixtures.

Mixture	Marshall stability (kN)	Immersion stability (kN)	Residual stability (%)
ATB-25	3.10	2.74	88.4
GSOG-25	8.13	8.05	99.0

Table 17: Fatigue lives of different mixtures.

Index	Strain level ($\mu\varepsilon$)	Initial modulus (MPa)	Fatigue life (cycles)	Average value (cycles)
GSOG-25	400	4676	467090	441465
		4568	415840	
	600	5032	154920	162015
		4088	169110	
ATB-25	400	6577	21010	23385
		3952	25760	
	600	7453	3030	3305

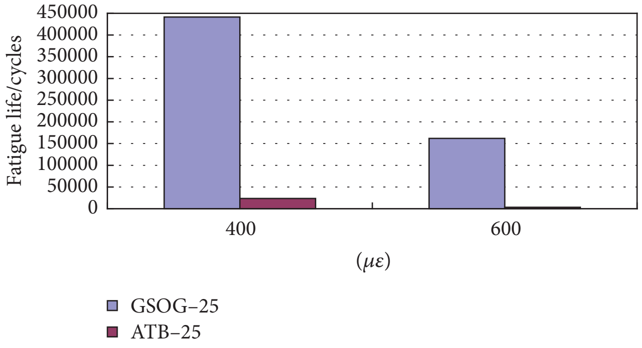
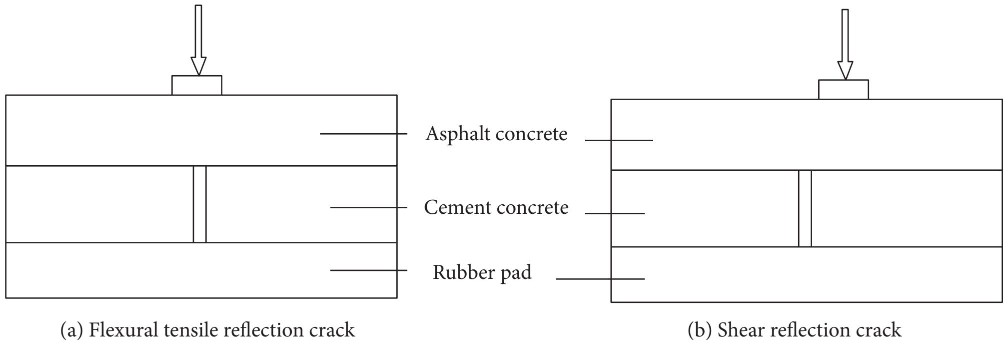


Figure 1: Comparison of fatigue lives of the two mixtures.



(a) Flexural tensile reflection crack (b) Shear reflection crack

Figure 2: Reflection crack resistance test loading mode.

Table 18: Flexural tensile type reflection crack.

Mixture	Sample	Initial crack (*10^4 cycles)	Total life (*10^4 cycles)	Average (*10^4 cycles) Initial crack	Average (*10^4 cycles) Total life
ATB-25	1	0.56	14.6	0.63	16.05
	2	0.74	18.6		
	3	0.68	15.9		
	4	0.54	15.1		
GSOG-25	1	0.68	26.3	0.7	28.3
	2	0.90	31.1		
	3	0.45	10.6		
	4	0.78	27.5		

Table 19: Shearing type reflection crack.

Mixture	Sample	Initial crack (*10^4 cycles)	Total life (*10^4 cycles)	Average (*10^4 cycles) Initial crack	Average (*10^4 cycles) Total life
ATB-25	1	0.62	15.8	0.55	12.45
	2	0.45	9.4		
	3	0.56	11.5		
	4	0.58	13.1		
GSOG-25	1	0.9	21.1	0.77	20.7
	2	0.78	24.2		
	3	0.72	19.4		
	4	0.66	17.9		

The sample is a compound sample, which is compounded with ATB layer, cement concrete layer (with a prefabricated crack), and rubber pad. The dimensions of compound sample are as follows: 30 cm (length) * 6 cm (width) * 20 cm (thickness). The thickness of the compound sample is consisting of 8 cm ATB layer, 10 cm cement concrete, and 2 cm rubber pad. The width of the prefabricated crack is 1 cm. The rubber pad is used to simulate the subgrade, and the cement concrete bricks were used to simulate cracked semirigid base course. The loading pad is 2 cm * 6 cm, and the vertical pressure is 0.7 MPa.

The loading mode has two different modes, symmetrical loading for simulate flexural tensile reflection cracking and loading at the edge of one side of prefabricated crack for simulate shear reflection cracking.

The cracking test results of ATB-25 and GSOG-25 at different loading modes were shown in Tables 18 and 19.

It can be seen from Tables 18 and 19 that the optimized GSOG-25 has better reflection crack resistance than ordinary ATB-25. Their initial crack loading cycles are almost the same, but the total life of GSOG-25 is much greater than that of ATB-25.

6. Conclusion

In order to improve the reflection crack resistance of ATB, the requirements of the mixture and gradation characteristics were put forward, and the gradation design procedures were put forward based on the volume design method and performances tests. And a type of GSOG-25 mixture was optimized according to the design procedures. Comprehensive performance tests, including rutting test, water stability test, fatigue test, and reflection crack test, were conducted on the ordinary ATB-25 and the optimized GSOG-25. The results indicated that the performance of GSOG-25 is superior to ATB-25; its reflection crack resistance has been enhanced much, which meets the purpose of the paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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