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Mix design method of asphalt rubber open-graded friction course and its application in overlay

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Abstract: The mix design method of asphalt rubber open-graded friction course (AR-OGFC) by the Marshall test and key technologies of AR-OGFC overlay are studied. Based on the draindown test, the stripping test and the Marshall test by different beating times, the asphalt content estimating method and Marshall beat criterion are studied. It is found that the asphalt content of AR-OGFC can be estimated by the formula of Arizona, and the proper Marshall test criterion for AR-OGFC is 50 beats on both sides. By analyzing the influence of gradation on OGFC performance, the gradation of AR-OGFC is recommended, and the amount of aggregate passing 4.75 mm should be minimized for AR-OGFC. Through investigation of AR-OGFC overlay projects, key technologies such as the treatment of underlying pavement and the selection of tack coat are advanced, and modified emulsified asphalt should be used in AR-OGFC overlay tack coat.

Key words: asphalt rubber; open-graded friction course; beat time of Marshall test; tack coat

In recent years, AR-OGFC has been paid much attention to due to its low traffic noise, high skid resistance, and high crack resistance characteristics. In China, open-graded mix has not been widely used, and researches or practices about AR-OGFC are even rare. The gradation and the mix design method about AR-OGFC have not been reported in China. In this paper, the mix design method and the main points of the structure design in AR-OGFC overlay are studied and the performance of its foremost two trail projects in China is introduced.

1 Mix Design Method of AR-OGFC

1.1 Review of mix design method

1.1.1 Gradation

According to the review of AR-OGFC gradations of several states in America, the main difference in AR-OGFC gradations is the amount of fine aggregate[1-3]. In Texas, Florida and Arizona, very little fine aggregate is used in OGFC; the percentage passing limit of 2.36 mm is below 10%. However, in California, more fine aggregate is used, and the requirement of the percentage passing 2.36 mm sieve is from 7% to 18%. Sieve 0.075 mm is also a key sieve for OGFC13. In California, Texas and Arizona, the percentage passing 0.075 mm sieve is permitted to be close to zero, but in Florida, at least 2% of filler material (passing 0.075 mm sieve) is required to be used.

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1.1.2 Mix design criteria

In Arizona, AR-OGFC is designed using a static compaction apparatus which loads at a rate of 5 mm/min until a load of 1.5 kg/m^2 is reached. The AR-OGFC binder content is determined by

$$A = \frac{(0.38W + 8.6) \times 2.6}{C} \tag{1}$$

where A is the asphalt content, %; W is the water absorption of aggregate, %; C is the combined oven dry specific gravity of aggregate, %.

When AR-OGFC is used in concrete pavement overlay, binder content should be increased by 1% to achieve better crack resistance performance. In Arizona, asphalt rubber open-graded mix should be tested for draindown in accordance with AASHTO T305 of ASTM 6390. The draindown should not exceed 0.3%.

In California, asphalt rubber content is designed by air void and draindown, where air void is required to be no less than 18%, and draindown is required to be less than 0.3%.

In Texas, asphalt rubber permeable friction course (PFC) is designed using a Texas gyratory compactor with 50 beats, and design parameters include draindown, laboratory-mold density, CRM content, and Cantabro loss.

In China, OGFC is not used so widely as in America and Japan, and in these applications, usually high viscosity asphalt or SBS modified asphalt is used as binder. OGFC is designed by the Marshall test. OGFC by asphalt rubber is seldom used in China, and research about its mix design method is also scarce. According to the aforementioned reviews, the OGFC mix design method in China is different from those of other countries. So, it is necessary to study a proper mix design method suitable for our country's AR-OGFC.

1.2 Mix design method of AR-OGFC

1.2.1 Gradation

It can be concluded from literature review that although gradation requirements have significant differences, the principles of gradation design are consistent[4-6]. Open-graded mixture is obtained by reducing the amount of fine aggregate, while the main difference is the mix of coarse aggregate[7]. As open-graded mixture has a big air void, no matter how the coarse aggregate is mixed, it obtains a good interlock state. Therefore, the grade range of coarse aggregate can be relaxed appropriately. It can be found from engineering applications that the drainage performance of OGFC usually declines due to the decrease in air void. To avoid this situation, it is considered that we should minimize the amount of fine aggregate. The gradation requirements of AR-OGFC are recommended in Tab. 1.

Tab. 1 Mix design grading limits for mineral aggregate of AR-OGFC in Jiangsu province

Sieve size/mm	Percent passing/%
16	100
13. 2	85 to 100
9. 5	45 to 80
4. 75	3 to 15
2. 36	0 to 10
0. 075	0 to 2

1. 2. 2 Specimen molding method

The mix specimen molding method is the basis of the OGFC mix design. The specimen molding laboratory should simulate construction and traffic conditions. In Arizona, AR-OGFC is designed using a static compaction apparatus; however in Jiangsu, OGFC is usually designed by 50-time Marshall blows. To find an AR-OGFC specimen forming method suitable for Jiangsu province, different methods are compared in laboratory tests. In these tests, basalt aggregate from Luhe, Jiangsu province is used, and the asphalt content is 8. 4% . Test results are listed in Tabs. 2 and 3.

Tab. 2 Influence of Marshall beat number on mixture gradation %

Sieve size/mm	13. 2	9. 5	4. 75	2. 36	1. 18	0. 6	0. 3	0. 15	0. 075
Original gradation	96. 0	72. 2	16. 1	8. 0	6. 1	3. 9	2. 5	1. 5	0. 9
Gradation after 50 beats	96. 1	73. 2	16. 5	9. 0	6. 5	4. 2	3. 1	2. 1	0. 9
Gradation after 75 beats	96. 2	78. 9	20. 5	10. 2	7. 3	4. 3	3. 2	2. 1	1

Tab. 3 Density and air void of specimens by forming methods

Static compaction		50 beats		75 beats	
Density/(g·cm $^{-3}$)	Air void/%	Density/(g·cm $^{-3}$)	Air void/%	Density/(g·cm $^{-3}$)	Air void/%
1. 907	24. 3	2. 049	18. 7	2. 201	12. 3

It can be seen from Tab. 2 that because OGFC has comparatively more coarse aggregate, its gradation may deviate from the original gradation when it is beaten excessively. Due to gradation deviation, the air void of the specimen by 75 beats is only half of the specimen by static compaction; however, the specimen by 50 beats has a similar air void to the specimen by static compaction.

In "Technical Specifications for Construction of Highway Asphalt Pavements" (JTG F40-2004) promulgated using the Ministry of Transportation and Communications of China, OGFC is designed using the Marshall test of 50 beats[8], and the same beat number is adopted in several OGFC trail roads in Jiangsu province. It is found from the construction and performance of these roads that the Marshall test of 50 beats is suitable for the construction and traffic conditions. Therefore, based on the feasibility of specimen forming, technical characteristics of AR-OGFC and experiences in Jiangsu province, it is recommended that AR-OGFC be designed by the Marshall test of 50 beats.

1. 2. 3 Design of asphalt content

As for the design of asphalt content, the empirical formula of Arizona shown in Eq. (1) has a reference value. At the same time, in the OGFC mix design of different countries, the draindown test and the stripping test are usually used to determine proper asphalt content. In Japan, the asphalt content range of the OGFC is designed by the inflexion points of draindown-asphalt content curves and stripping-asphalt content curves.

In this paper, asphalt contents designed by laboratory test and Eq. (1) are compared. Tab. 4 lists the estimated asphalt content by Eq. (1), where the AR-OGFC mix adopts gradation as listed in Tab. 2.

Tab. 4 Estimated asphalt content of AR-OGFC

Combined water absorption of composite aggregate/%	Combined specific gravity of aggregate/ (g·cm $^{-3}$)	Estimated asphalt content by aggregate/%
1. 389	2. 854	9. 2

Results of the draindown test and the stripping test of AR-OGFC are shown in Figs. 1 and 2. It can be seen from the draindown-asphalt curve that the upper limit of the asphalt content is 9. 4% . In the same way, the lower limit of the asphalt content is 8. 9% from the strip-asphalt content curve. Therefore, the proper asphalt content should be between 8. 9% and 9. 4% , and the estimated asphalt content by Eq. (1) approaches its middle value. It can be concluded that the empirical formula of Arizona has similar results to those of the experimental method. Therefore, the empirical formula can be used as an easy way for asphalt content determination.

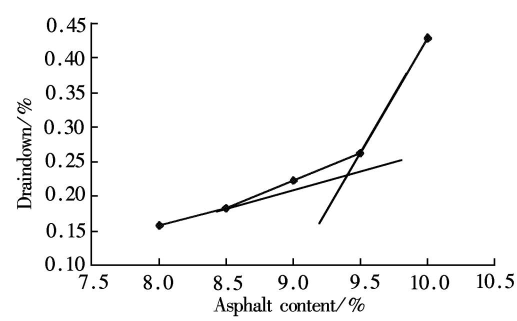

Fig. 1 Asphalt content vs. draindown

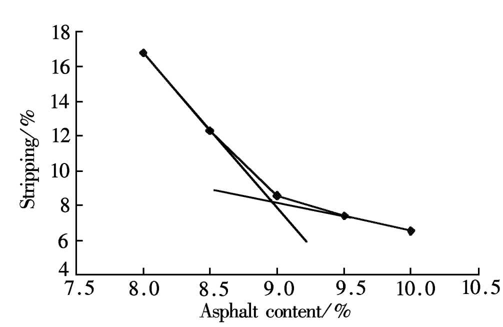

Fig. 2 Asphalt content vs. stripping

1.3 Examples of AR-OGFC mix design

1.3.1 AR-OGFC mix design of Ninggao Expressway

The mix design results of AR-OGFC are listed in Tabs. 5 and 6. The design air void is 22%, and optimal asphalt content is 8.9%.

Tab. 5 Aggregate gradation design results of AR-OGFC13 for Ninggao Expressway

Sieve size/mm	Percent passing/%
16	100
13.2	91.2
9.5	52.5
4.75	4.2
2.36	1.5
1.18	0.7
0.6	0.7
0.3	0.7
0.15	0.7
0.075	0.7

Tab. 6 Marshall test results of AR-OGFC13

Asphalt content/%	Stability/kN	Flow value/(0.1 mm)	VV/%	VMA/%	VFA/%
8.9	3.78	36	22.4	36.2	38.1

Note: VV denotes volume of air voids; VMA denotes voids in mineral aggregates; VFA denotes voids filled with asphalt.

1.3.2 AR-OGFC mix design of Nanjing Belt Expressway

The AR-OGFC mix design results of Nanjing Belt Expressway are listed in Tabs. 7 and 8. The design air void is 23.9%, and the optimal asphalt content is 8.0%.

Tab. 7 Aggregate gradation design results of AR-OGFC13 for Nanjing Belt Expressway

Sieve size/mm	Percent passing/%
16	100.0
13.2	92.3
9.5	58.9
4.75	0.9
2.36	0.4
1.18	0.4
0.6	0.4
0.3	0.4
0.15	0.4
0.075	0.4

Tab. 8 Marshall test results of AR-OGFC13

Asphalt content/%	Stability/kN	Flow value/(0.1 mm)	VV/%	VMA/%	VFA/%
8.0	2.77	30.4	23.9	36.4	34.1

2 Key Technologies for AR-OGFC Overlay Design

In Jiangsu province, AR-OGFC is mainly used as overlay on concrete pavement or asphalt pavement, whose thickness is usually 2.5 to 3.0 cm. Excepting overlay structures and mix designs, the treatment of old pavements and the selection of tack coat materials are also key factors influencing overlay performances.

2.1 Treatment of original pavement

As for OGFC overlay, original pavements should have sufficient carrying capacity, smoothness, and waterproof abilities.

Therefore, the treatment of old pavements is important. OGFC overlay is permeable; therefore, if the defects of the old pavement are not properly treated, these defects may deteriorate gradually, followed by overlay failure (see Fig. 3).

Fig. 3 Overlay failure due to improper treatment of old pavement

In the following conditions, pavements should be milled and paved before overlaying.

1) Pavement has experienced too much repair and repairing areas exceed 15% of that of a lane;

2) Pavement distress has developed severely, where net-shaped cracks, water damage and rutting are continuous;

3) Reflective cracking space is less than 15 m, and it is accompanied by pumping.

Local distress should be repaired by usual methods. The local distress of a lower course should be similarly repaired after the upper course has been milled, and the repaired area should include at least one lane in transverseness and exceed 1 m of the distress area in longitude.

In some projects, accurate milling is adopted to improve the smoothness of the surface course. It is found that this method may disturb the pavement and accelerate the deterioration of distress; therefore, the milling method of the surface should be avoided as far as possible.

2.2 Design of tack coat

The tack coat is important for the OGFC overlay. Asphalt rubber stress absorbing membrane interlayer (SAMI) and modified emulsified asphalt are usually used as tack coats. In the application of SAMI, the quantity of asphalt rubber is 1.5 to 2.5 kg/m^2. The advantages of SAMI are high waterproofing ability and good anti-cracking performance. However, in construction, the asphalt may exceed the allowable quantity in overlapping areas which may cause bleeding problems (see Fig. 4). At the same time, the asphalt in SAMI may uplift and then reduce the air void of the OGFC overlay, which may cause the permeability of the overlay to decline, even lose. According to engineering experiences, tack coat using modified emulsified asphalt may avoid these aforementioned disadvantages. Therefore, modified emulsified asphalt is recommended to be used as the tack coat of AR-OGFC overlay. Moreover, to ensure the bonding and waterproofing effects, more emulsified asphalt should be used than usual pavement tack coat. The quality of the emulsified asphalt used for AR-OGFC overlay tack coat is recommended to be 0. 3 to 0. 5 kg/m^2 (converted into asphalt deposit) .

Fig. 4 Bleeding in overlapping area of SAMI

3 Application Effects of AR-OGFC Overlay

3. 1 Ninggao Expressway AR-OGFC Trail Project

The trail project of AR-OGFC on Ninggao Expressway is 1 km long, and opened to traffic in October, 2006, the pavement structure of which is shown in Fig. 5.

2. 5 cm AR-OGFC13
Asphalt rubber SAMI
Original pavement

Fig. 5 AR-OGFC overlay structure of trail project on Ninggao Expressway

3. 1. 1 Performance in noise reduction

One year after opening to traffic, traffic noise of the trail section and the control section were tested. The results are listed in Tab. 9. Compared with the dense graded asphalt mix of the original pavement, the AR-OGFC overlay can reduce traffic noise by 4. 9 dB, which is similar to that formed in other projects[5,9], and shows very good noise elimination performance.

Tab. 9 Noise test results of AR-OGFC overlay trail road and control road

Section	Test results/dB
Original pavement(AC16)	78. 0
AR-OGFC overlay	73. 1

3. 1. 2 Permeability performance

After construction, the permeable coefficient of the trail pavement is over 1 000 mL/min. Two years after opening to traffic, the trail pavement permeability performance is shown in Fig. 6. The AR-OGFC overlay shows good permeability performance.

3. 1. 3 Other performances

There are about 40 reflective cracks with spaces from 20 to 30 m on the original pavement. Two years after opening to traffic, no cracks appeared; even the thickness of the overlay was only 2. 5 cm. At the same time, other distresses such as net-shaped cracks and bleeding were not found on this trail pavement.

3. 2 Nanjing Belt Expressway AR-OGFC Trail Project

The structure of the Nanjing Belt Expressway AR-OGFC

Fig. 6 Pavement permeability performance of AR-OGFC overlay after raining

Trail Project is shown in Fig. 7. Different from the Ninggao Expressway AR-OGFC Trail Road, a modified emulsified asphalt tack coat is used in this project. The trail road was opened to traffic in September, 2008.

2. 5 cm AR-OGFC13
SBS modified emulsified asphalt tack coat
Original pavement

Fig. 7 AR-OGFC overlay structure of trail project on Nanjing Belt Expressway

3. 2. 1 Performance in noise reduction

Traffic noise of the trail section and the control section were tested. Results are listed in Tab. 10. Compared with the dense graded asphalt mix of the original pavement, the AR-OGFC overlay can reduce traffic noise by 3. 1 dB.

Tab. 10 Noise test results of AR-OGFC overlay trail road and control road

Section	Test results/dB
Original pavement(AC13)	85. 1
AR-OGFC overlay	82. 0

3. 2. 2 Permeability performance

After construction, the permeable coefficient of the trail pavement is over 1 000 mL/min.

4 Conclusions

The mix design method of AR-OGFC are recommended and validated. The key technologies of the AR-OGFC overlay design are studied. Finally, the performances of the AR-OGFC overlay are observed and summarized.

1) It is found that the amount of aggregate passing 4. 75 mm should be minimized for AR-OGFC. In AR-OGFC mix design, the proper method of specimen molding is the Marshall compaction test of 50 beats.

2) It is found that the empirical formula of Arizona has similar results to those of the experimental method in the draindown test and the stripping test. The empirical formula is recommended as an easy way for asphalt content determination.

3) Key technologies of AR-OGFC overlay design, such as the treatment of old pavements and proper tack coat materials, are introduced.

4) Performance observation shows that AR-OGFC overlay has good permeability and noise reduction capability.

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橡胶沥青开级配混合料设计方法及其在罩面工程中的应用

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摘要:为研究橡胶沥青开级配混合料的马歇尔设计方法以及开级配混合料罩面应用的关键技术,通过析漏试验、飞散试验和不同次数的马歇尔击实试验提出了橡胶沥青开级配混合料油石比预估方法和马歇尔击实标准,表明油石比预估可采用亚利桑那州的预估公式,马歇尔击实标准采用双面 50 次. 通过对开级配混合料级配对性能影响的分析,提出了橡胶沥青开级配混合料的级配范围,发现橡胶沥青开级配混合料应尽量减少 4.75 mm 以下集料用量. 通过总结橡胶沥青开级配罩面的工程经验,提出了老路处治、粘层设计等方面的关键技术,其中,粘层材料宜采用改性乳化沥青.

关键词:橡胶沥青;开级配;马谢尔击实次数;粘层

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