Evaluation of Water Damage Resistance Performance of OGFC-13 Asphalt Mixture

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Abstract: Problems like poor durability and blocking of pores which may lead to severe early damages of the pavement are major concerns when OGFC mixtures are put to use. On the basis of robust design, 9 types of OGFC mixtures that meet the requirements are identified herein, and in light of the porous structure of OGFC-13 asphalt mixtures, this research studies the influence of the porosity and the rate of semi-connected pores on the mixture’s durability, proposes the idea of using the attenuation momentum as the indicator for assessment of the anti-water damage performance of OGFC mixtures and tests the mixtures’ anti-blocking ability. The experiment result shows that combination of the indicators of attenuation momentum and anti-blocking capability well reflects the OGFC mixtures’ durability. According to the attenuation momentum and anti-blocking capability, gradation G9 is identified as the optimal gradation. This research can facilitate improvement and assessment of OGFC mixtures’ durability.

1. Introduction
Open-graded friction course (OGFC) features strong skid resistance and quick drainage of water. Design of drainage asphalt mixtures in China now mainly adopts the Japanese PA design method, but whether this method applies to different regions in China needs further research. Based on the robust design principle \cite{2}, the passing rates of the three key sieves are taken herein as the contributing factors to decide the gradation of the drainage asphalt mixtures. Also, in light of OGFC’s porous structure, the influence of the mixture’s porosity and its rate of semi-connected pores on OGFC’s durability is analyzed, and through the general equilibrium method, an integrated assessment system for properties of OGFC-13 is established to figure out the optimal gradation of OGFC.

2. Robust Theory-Based Design of OGFC Gradation
The robust theory is applied herein for design of OGFC gradation. The nominal maximum aggregate size is 13.2mm, and according to the gradation range of drainage asphalt mixtures recommended in Technical Specifications for Construction of Highway Asphalt Pavement of China, the $L_{3}^{(3^{'})}$ orthogonal table is selected for the orthogonal test, and factors and levels are shown in Table 1.
Table 1 Selected Orthogonal Test (passing rate %)

| S/N | A(0.075mm) | Empty column | B(2.36mm) | C(9.5mm) |
|-----|------------|--------------|-----------|----------|
| 1   | 1(3)       | 1            | 1(7)      | 1(70)    |
| 2   | 1(3)       | 2            | 2(14)     | 2(76)    |
| 3   | 1(3)       | 3            | 3(20)     | 3(81)    |
| 4   | 2(5)       | 1            | 2(14)     | 3(81)    |
| 5   | 2(5)       | 2            | 3(20)     | 1(70)    |
| 6   | 2(5)       | 3            | 1(7)      | 2(76)    |
| 7   | 3(7)       | 1            | 3(20)     | 2(76)    |
| 8   | 3(7)       | 2            | 1(14)     | 3(81)    |
| 9   | 3(7)       | 3            | 2(7)      | 1(70)    |

In Table 1.1, Factor A is the passing rate of the mineral aggregate through the 0.075mm sieve, Factor B its passing rate through the 2.36mm sieve, Factor C its passing rate through the 9.5mm sieve. Three levels are set for each factor, representing the upper limit, the lower limit and the median of the recommended gradation. The recommended gradation range of OGFC-13 is displayed in Table 2. The passing rates of different gradations through the sieves are presented in Table 3.

Table 2 Gradation Range of OGFC-13

| Dimension of sieve /mm | 16.0 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|------------------------|------|------|-----|------|------|------|-----|-----|------|-------|
| Passing rate/%         | 100  | 90-100 | 70-81 | 60-100 | 40-100 | 20-100 | 10-100 | 5-100 | 2.5-100 | 1.5-100 |

Table 3 Amount of Materials for Composite Gradation (%)

| Sieve /mm | G1 | G2 | G3 | G4 | G5 | G6 | G7 | G8 | G9 |
|-----------|----|----|----|----|----|----|----|----|----|
| <0.075    | 3  | 3  | 3  | 5  | 5  | 5  | 7  | 7  | 7  |
| 0.075~2.36| 4  | 11 | 17 | 9  | 15 | 2  | 13 | 0  | 7  |
| 2.36~9.5  | 63 | 62 | 61 | 67 | 50 | 69 | 56 | 74 | 56 |
| >9.5      | 30 | 24 | 19 | 19 | 30 | 22 | 23 | 19 | 30 |

3. Property Testing of Mixtures of Different Gradations

3.1 Attenuation Momentum-based Analysis and Assessment of Durability

There are three types of pores in drainage asphalt mixtures: connected pores, semi-connected pores and closed pores. When water pours onto the drainage asphalt pavement, water in the connected pores is drained out of the pavement directly; water in the semi-connected pores remains in the pavement where hydrodynamic pressure is produced under the load of vehicles on the road, diminishing the adhesion between the aggregate and the asphalt membrane. As time goes on, the asphalt on the surface of the aggregate will be replaced by water, stripping the asphalt from the aggregate, and constant load from vehicles will lead to water damages such as cracks, stripping and potholes.

According to the porous structure of OGFC mixtures, this experiment analyzes the flowing routes of water inside the asphalt mixtures and works out that the total mass of water in the asphalt mixture equals the mass of water that flows out of the mixtures plus the mass of water that remains inside the mixture, i.e.:

$$\Delta m_{\text{remaining}} = m_{\text{flow-in}} - m_{\text{flow-out}} \quad (1)$$
When the water enters the asphalt mixture at a certain speed, the speed will be reduced due to the semi-connected pores and connected pores in the mixture. Analyzed from the perspective of energy conversion, such reduction will accelerate structural damages inside the mixture. Thus, based on the losses of speed of water after passing the specimens, damages of water that enters the mixtures at a certain speed can be assessed. In light of the reduction of mass of water mentioned above, the applied attenuation momentum $\Delta P$ is used to judge the water stability property of the mixture, that is, the smaller the value of $\Delta P$ is, the stronger the specimen’s resistance against water damage is; otherwise, the weaker the resistance is. The formula for $\Delta P$ is shown in (2):

$$\Delta P = (M_{\text{flow-in}} - M_{\text{flow-out}}) \times \Delta V$$  \hspace{1cm} (2)

The mass of water that remains inside the mixture can reflect the size of semi-connected pores in the mixture. Test specimens can adopt the processed standard Marshall specimens, and a 1.5cm-long and 1cm-diameter columnar wedge is placed inside the mold before molding the specimen and its surface is oiled to facilitate specimen withdrawal. When the test specimen takes shape, the wedge is taken out and there will be water-injection pores in the specimen. To avoid experiment errors that might be caused by direct injection of water that flows through the whole specimen and ensure that the water only flows through the pores instead of over-brimming onto the specimen’s surface. Due to the short distance between the bottom of the injection hole and the supporting stand, the influence of gravity on the flowing speed of water can be neglected. The testing device is shown in Fig. 1 and Fig. 2, and experiments are done on specimens with 9 groups of different gradations. The formula for attenuation of water flow speed is shown in (3):

$$\Delta V = V_i - \frac{Q}{S \times \Delta t}$$  \hspace{1cm} (3)

where $Q$ refers to the volume of water that flows out in unit time ($m^3$) and $S$ refers to the area of the drainage hole ($m^2$).

Results of experiments on specimens with 9 gradations are shown in Table 4:
Table 4 Experiment Results of Specimens with Different Gradations

| Gradation | G1  | G2  | G3  | G4  | G5  | G6  | G7  | G8  | G9  |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \(\Delta M_{\text{str}}\) (g) | 62.6 | 56.7 | 53.1 | 54.5 | 52.8 | 64.3 | 49.2 | 68.3 | 47.3 |
| \(\Delta V\) (m/s) | 0.567 | 0.368 | 0.603 | 0.572 | 0.506 | 0.567 | 0.424 | 0.613 | 0.475 |
| \(\Delta P\) (g.m/s) | 35.494 | 20.866 | 32.019 | 31.174 | 26.717 | 36.458 | 20.861 | 41.868 | 22.468 |
| porosity (%) | 20.68 | 20.56 | 21.27 | 21.55 | 20.72 | 20.28 | 19.54 | 22.39 | 21.34 |

As shown in Fig. 3, specimens with G8 gradation has the largest porosity, highest attenuation momentum and the poorest water stability. In terms of attenuation momentum, the best three groups G7, G2 and G9, among which G7 shows the smallest porosity, lowest attenuation momentum and best water stability. Specimen mixtures with G1 and G2 gradations share similar porosity, but differ much from each other in terms of attenuation momentum. The rate of semi-connected pores in these two groups of mixtures shows great distinction and the rate in the G2 group is higher than that in the G9 group. G9 mixtures which have relatively lower attenuation momentum and more connected pores are well-structured.

3.2 Analysis of Pore Blocking Test

A major problem in engineering of drainage asphalt pavement is how to maintain good drainage performance when the pavement is in service. Experience at home and abroad confirms that the porosity declines gradually after the pavement is put to use. When the pavement is put to use, the inflow of dust, foliage humus and sand will decrease the porosity and, after several years’ accumulation, disable the water drainage function of the asphalt pavement.

Kurihara and et al. [3] studied the blocking property of porous asphalt mixture and cement concrete with porosity at 20% and analyzed the influence of the volume of blocking materials on water permeability. Balades and et al. [4-6] conducted experiments on four kinds of methods for alleviation of pore blocking: wet cleaning, suction cleaning, suction-sweeping cleaning and wash-suction combined cleaning. Yet, all these four methods are measures taken after blocking and there is no analysis as to how to improve the anti-blocking performance of the asphalt mixtures during design. Sha Aimin and Jiang Wei [7] from Chang’an University have made much research in this regard, and their research results are referred to herein to analyze the pore blocking experiments of mixtures with different gradations.
According to Jiang Wei’s research results, particles with grain sizes at 1.18~2.36mm and 0.15~0.3mm are most likely to cause blocking of PAC-13 mixtures. Thus, particles with grain sizes at 1.18~2.36mm and 0.15~0.3mm are selected to conduct the anti-blocking experiments on specimens with 9 different gradations. The particles, all weighted at 10g, are sprinkled evenly onto the specimens that are still in the mold, and after oscillation for 30 seconds, 1000g water is sprayed onto the surface evenly; then the mass of water that passes through the fines of specimens is measured, and the mass of the fines after being dried is also measured and labelled as b before the fines are sieved; when the specimen is dried, fines remaining on the surface of the specimens are collected carefully with a brush, and the mass of the fines are weighted and labelled as c before they are sieved. Deduct the mass of b and c from the total mass of fines in different groups of gradations, and we will get the mass of particles that block the pores of the specimens, and this mass is labelled as a \(^8\). The experiment result is shown in Fig. 5.

| Type of Gradation | Blocking rate (%) |
|-------------------|-------------------|
|                   | 0.15~0.3 | 1.18~2.36 | Total blocking rate |
| G1                | 14.2      | 13.8      | 28.0               |
| G2                | 13.4      | 16.8      | 30.2               |
| G3                | 11.7      | 16.2      | 27.9               |
| G4                | 14.1      | 17.3      | 31.4               |
| G5                | 16.3      | 17.8      | 34.1               |
| G6                | 12.4      | 16.6      | 29.0               |
| G7                | 14.8      | 18.8      | 33.6               |
| G8                | 10.2      | 11.9      | 22.1               |
| G9                | 11.3      | 15.2      | 26.5               |

From table 5 above, it can be seen that the smallest rate of blocking by particles with diameter at 0.15~0.3mm and 1.18~2.36mm shows in the G8 group, but it is its large porosity that results in the small blocking rate, and this group has lots of semi-connected pores, so the G8 gradation cannot be regarded as the best gradation. G7 and G2 groups which have strong water resistance show poor anti-blocking performance, while Group G9 of which the blocking rate is 26.5% presents good anti-blocking performance. Thus, the G9 gradation is the best gradation.

4. Conclusion
(1) Based on robust design, this research identifies 9 groups of gradations for the OGFC-13 mixture, and through property tests on each group of specimens, it proposes using the attenuation momentum as the evaluation indicator for resistance against water damage of the mixture;
(2) Blocking rate experiments are conducted to test the anti-blocking performance of mixtures with the 9 different groups of gradation, providing reference for assessment of the mixture’s durability;
(3) Through comparative analysis, it is found that mixtures with the G9 gradation shows the strongest resistance against water damage and best anti-blocking performance.

The research result will provide guidance for assessment of water damage resistance performance and anti-blocking ability of OGFC materials.

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