Study on SBS/rubber composite modified asphalt ultra-thin wear layer

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Abstract. In this paper, the mix ratio of SBS/waste rubber powder composite modified asphalt was designed. The dosage of rubber powder (60 mesh) was determined to be 15%, and SBS modifier (linear) was 2%. Based on the optimum mix ratio of asphalt mixture, the road performance of composite modified asphalt was tested and the composite modified ultra-thin wear layer was designed. The noise reduction characteristics of the overlay structure were studied by using the impedance tube instrument, it is found that the composite modified rubber asphalt ultra-thin overlay structure has advantages in reducing the intermediate-frequency and high-frequency noise.

1. Introduction
SBS modified asphalt mixture is widely used in highway engineering due to its favorable high-temperature performance and shear resistance ability, and has become the main material of high-grade highways. Applying rubber powder to asphalt mixture is beneficial to solving issues like environmental pollution and waste recycling of rubber tires, and can improve the road performance of the mixture [1, 2]. Combined with the characteristics of SBS and rubber powder, the rubber powder is added into the SBS modified asphalt to form the composite modified rubber asphalt. It has been found that the high- and low-temperature performance and water stability of composite modified asphalt mixture are improved compared with traditional hot mix asphalt mixture [3-5].

The key technology of high durability, low noise and ultra-thin overlay was studied in this paper. The mix ratio of overlay wear layer of composite modified rubber asphalt concrete was optimized, focusing on grading design and related road performance of ARAC-5 (asphalt-rubberized asphalt concrete with nominal maximum size of 5mm) mixture. Based on this research, a high-durability, low-noise and ultra-thin overlay technology based on composite modified rubber asphalt concrete is formed to achieve the overall goal of preventive maintenance, including improving road serviceability performance, extending pavement service life and saving maintenance costs.

2. Raw material test

2.1. Raw material test
The gradation of mineral material used in the project is ARAC-5, with 2.36 mm as the key control sieve size. Coarse aggregate refers to the aggregate with sieve size greater than 2.36 mm and fine aggregate has sieve size smaller than 2.36 mm. The mineral materials used in this project are limestone aggregates.
The aggregates of all grades are tested according to the test method of *Test Methods of Aggregate for Highway Engineering* (JTG E42-2005) [6]. The results of aggregates volume parameters are shown in the following table.

**Table 1. Test results of aggregate technical index**

| Technical index                      | Unit | Test result | Code value | Test method |
|--------------------------------------|------|-------------|------------|-------------|
| Bulk volume relative density         | 3-5mm| 2.676       | -          | T0304       |
|                                      | 3-5mm| 2.718       | ≮2.6       | T0304       |
| Apparent relative density            | 0-3mm| 2.752       | ≮2.5       | T0304       |
| Absorption rate of course aggregate  | 3-5mm| 0.58        | ≥2.0       | T0304       |

2.2. *Mineral powder*

The mineral powder used here is limestone ore, the density is 2.712 g/cm³ and the Hydrophilic coefficient is 0.65. The grain gradation test results are shown as follows.

**Table 2. Grain gradation test results of mineral powder**

| Sieve size (mm) | 0.60 | 0.30 | 0.15 | 0.075 |
|-----------------|------|------|------|-------|
| Passing percentage (%) | 100  | ---  | 94   | 86    |
| Technical requirement  | 100  | ---  | 90~100 | 75~100 |

2.3. *Asphalt*

The matrix asphalt accounts for the majority of SBS/rubber composite modified asphalt, and its properties have a significant influence on the performance of SBS/rubber composite modified asphalt. The matrix asphalt used in the test is 70# road petroleum asphalt and the main technical indicators are shown in the following table.

**Table 3. Technical indicators test results of 70# asphalt**

| Indicators                      | Unit | Code requirement | Measured value | Test method |
|---------------------------------|------|------------------|----------------|-------------|
| Penetration ratio (25°C, 100g, 5s) | 0.1 mm | 60~80            | 72              | T0604       |
| Ductility (15°C, 5cm/min)       | cm   | ≮100             | >100           | T0606       |
| Softening point (5°C/min)       | °C   | ≮46              | 48.5           | T0606       |

2.4. *Rubber powder*

The rubber powder employed in the asphalt pavement generally refers to the rubber powder having a certain fineness obtained by crushing automobile waste tires [7]. Studies have shown that rubber asphalt prepared from truck tire rubber powder of high natural rubber content is better. The mesh size of the rubber powder also affects the performance of the rubber asphalt. The larger the mesh number, the finer the particles [8]. Under the premise of ensuring that the mixture can be easily rolled and formed, considering the processing cost of rubber powder, the storage stability of modified asphalt, the high-temperature performance and the elastic property, the coarse rubber powder is highly preferred. Finally, desulfurized rubber powder with the mesh size of 60 is selected as the raw material for preparing composite modified asphalt, and the dosage was 15% of the asphalt mass.

2.5. *SBS modifier*

SBS (styrene-butadiene-styrene) modifier is a thermoplastic elastomer with both rubber and plastic properties. It has elastic properties of rubber at normal temperature and can flow like hot plastic at high temperatures [9, 10]. The SBS modifier used in the project is linear SBS. The modification effect of SBS modified asphalt owes to the formation of network stiffening structure. The node position is thermoplastic styrene (S), the glass transition temperature is 80 °C, and it has no plasticity at normal temperature, which is beneficial to the stability of pavement structure. As a three-dimensional network structure, butadiene (B) has a glass transition temperature of -80 °C, and thus has
good elasticity and flexibility. The two-phase separation structure and two glass transition temperatures lead to a favorable high- and low-temperature properties of SBS modified asphalt [11]. The amount of SBS modifier is 2% of that of asphalt.

3. Mix design of SBS/rubber composite modified asphalt mixture
ARAC-5 gradation is adopted in this project, and the asphalt mixture mix design method is Marshall method. The Marshall design method has clear requirements for the density, void ratio, voids in mineral aggregate, asphalt saturation and other indicators of the mixture, and is a volume design method. The specific gradation determination process is shown as follows.

3.1. SBS modifier
According to the requirements of Technical Code for Asphalt Rubber Pavement (DGTJ08-2012) [12], the design gradation of mineral powder in ARAC-5 asphalt mixture is determined, as shown in and Figure 1.

![Figure 1. Design gradation passing rate graph of ARAC-5](image)

3.2. Optimal asphalt-aggregate ratio determination of ARAC-5
By consulting relevant literature and previous engineering experience, Marshall test pieces were formed by using 5.9%, 8.2%, 8.5%, 8.8%, and 9.1% asphalt-aggregate ratios respectively, and the volume parameters and mechanical indexes of Marshall specimens were tested. The relationship between bulk volume density, void ratio, VMA, VFA, stability, flow value and asphalt-aggregate ratio is plotted as shown in Figure 2.

It can be seen from the figure that when the design void ratio is set to be 4.0%, the asphalt-aggregate ratio is 8.5%. Under this condition, all the indexes of the specimen meet the specification requirements, hence the optimum asphalt-aggregate ratio is determined to be 8.5%.

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4. Road performance study of asphalt mixture
The high-temperature performance and water stability of the ARAC-5 ultra-thin wear layer asphalt mixture were verified under the condition of 8.5% asphalt-aggregate ratio.

4.1. High-temperature stability
According to the requirements of Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011) [13], 300 mm × 300 mm × 50 mm asphalt concrete slab specimen was made and cured at room temperature for 48h and heated at 60 °C for 5 h. The rubber wheel with a wheel pressure of 0.7 MPa is repeatedly rolled on the specimen for a certain period of time. During the test, the relationship between the deformation of the specimen and the time or the number of passes of the wheel is determined, to calculate the deformation rate (RD) or dynamic stability (number of rolling cycles required to produce a 1 mm groove, DS) of the asphalt mixture, which serves as an evaluation
index of the anti-rutting ability of the asphalt mixture. Dynamic stability is used as an evaluation index here.

The test results are shown in Table 4. The dynamic stability of the mixture is higher than the code requirement, indicating that the ARAC-5 type mixture has good high-temperature performance.

Table 4. Dynamic stability test results of asphalt mixture

| Test number | Mixing temperature (°C) | Compaction temperature (°C) | Dynamic stability (times/mm) | Mean of dynamic stability (times/mm) |
|-------------|-------------------------|-----------------------------|-----------------------------|-------------------------------------|
| ARAC-5 (1)  | 175                     | 170                         | 3621                        |                                     |
| ARAC-5 (2)  | 175                     | 170                         | 3734                        | 3678                                |
| Code requirement | -                       | -                           | > 3500                      |                                     |

4.2. Water stability

The Marshall specimen was formed according to the the mix design. The water stability of the mixture was evaluated by the water immersion Marshall test and the freeze-thaw split test. The voids ratio of the specimen subjected to the water immersion Marshall test was controlled to be the design void ratio of 4%, and that at the freeze-thaw split test was 7%. The residual stability and freeze-thaw splitting strength ratio of each specimen were measured and then the water stability was evaluated.

A hot-mixed and hot-pressed Marshall specimen was formed at an optimum asphalt-aggregate ratio based on the preferred gradation. The stability values of the specimen for 30 min and 48 h of water immersion were measured respectively, and the residual stability was calculated as 96.9%, which is greater than the required value of 80%.

The splitting strength of the Marshall specimen with and without the freeze-thaw cycle was measured and calculated, which is 0.92 MPa and 1.14 MPa, respectively. The freeze-thaw splitting strength ratio is 81%, which is greater than 80%, as required.

According to the test data analysis of water stability performance, the residual stability and freeze-thaw splitting strength ratio of the mixture are higher than the specification requirements, indicating that the ARAC-5 asphalt mixture has good water stability.

4.3. Research on noise reduction characteristics of composite modified rubber asphalt wear layer

4.3.1. Test principle of impedance tube. This paper focuses on the noise reduction characteristics of the composite modified rubber asphalt wear layer. The impedance tube test is the indoor test and the sound absorption coefficient of the cover structure is tested based on the transfer function method.

The test sample of the transfer function method is mounted on one end of a straight, rigid, airtight impedance tube. The plane acoustic waves in the tube are generated by the sound source. The sound pressure is measured at two locations, and the acoustic transfer function of the two microphone signals is obtained, which is used to calculate the normal incident sound absorption coefficient of the test sample. The computation formula of the sound absorption coefficient of the test material is shown:

\[
\alpha = \frac{E_a}{E_i} \times 100\%
\]

where: \(\alpha\) — Material sound absorption coefficient, %;
\(E_i\) — Total incident sound energy, J;
\(E_a\) — Sound energy absorbed by the material, J.

Sound absorption coefficient is an important index to evaluate the sound absorption performance of materials. The larger the sound absorption coefficient, the better the sound absorption performance of the material. Composite modified rubber asphalt concrete specimens with a height of 10 cm, 3 cm, 4 cm and 6.35 cm were formed by gyratory method, and SMA-10 specimen (SBS modified asphalt, asphalt-aggregate ratio of 5.9%, partial coarse gradation) is molded simultaneously. The sound absorption
coefficient is tested by Acoustics—Determination of sound absorption coefficient and impedance in impedance tubes—Part 2: Transfer function method (GB/T 18696.2-2002) [14].

4.3.2. Test results and analysis. The sound absorption coefficient of composite modified rubber asphalt concrete ARAC-5 with different thicknesses is shown in Figure 3. The sound absorption peak, peak frequency, and sound absorption coefficient are summarized as shown in Table 5.

![Figure 3. Sound absorption coefficient of composite modified rubber asphalt concrete ARAC-5.](image)

**Table 5. Sound absorption coefficient summary**

| Test type | First sound absorption peak (%) | First sound absorption peak frequency (Hz) | Second sound absorption peak (%) | Second sound absorption peak frequency (Hz) | Mean of sound absorption coefficient (%) |
|-----------|---------------------------------|------------------------------------------|---------------------------------|------------------------------------------|------------------------------------------|
| 6.35 cm   | 15                              | 400                                      | 65                              | 1700                                     | 13.57                                    |
| 4 cm      | 20                              | 650                                      | 62                              | 1770                                     | 13.69                                    |
| 3 cm      | 24                              | 800                                      | 60                              | 1760                                     | 15.94                                    |

Based on the test results of Figure 3 and Table 5, we can conclude that: The specimen thickness has a great influence on the low-frequency sound absorption coefficient of the asphalt mixture, and has no significant influence on the high-frequency sound absorption coefficient. The low-frequency sound absorption coefficient of the ARAC-5 ultra-thin overlay structure developed in this paper increases with the thickness, and the first sound absorption peak gradually decreases. The corresponding sound absorption peak frequency is reduced from 800Hz to 400Hz. When the thickness of the ARAC-5 structure is relatively large, the first sound absorption peak does not appear, so from the perspective of reducing low-frequency noise, the reasonable thickness of the ultra-thin cover should be 3–4cm.

5. Conclusion

In this paper, the reasonable formula of SBS/waste rubber powder composite modified asphalt is studied. From the perspective of cost-effectiveness, the rubber powder (60 mesh) dosage is determined to be 15%, and the SBS modifier (linear type) is 2%. Based on the preferred composite modified asphalt formulation, the low-noise composite modified ultra-thin wear layer is designed. The impedance tube instrument is used to study the noise reduction characteristics of the overlay structure. The sound absorption coefficient of SBS/waste rubber powder composite modified asphalt ultra-thin wear layer and that of SBS modified asphalt ARAC-5 were tested. The composite modified rubber asphalt ultra-thin cover structure has advantages in reducing intermediate-frequency and high-frequency noise.
References

[1] F. Xiao, S.N. Amirkhanian, B.J. Putman and H. Huang, Feasibility of superpave gyratory compaction of rubberized asphalt concrete mixtures containing reclaimed asphalt pavement. Construction and Building Materials, 2012, 27 (1), 432-438.

[2] T. Wang, F. Xiao, S.N. Amirkhanian, W. Huang and M. Zheng, A review on low temperature performances of rubberized asphalt materials. Construction and Building Materials, 2017, 145, 483-505.

[3] J.R.M. Oliveira, H.M.R.D. Silva, L.P.F. Abreu and S.R.M. Fernandes, Use of a warm mix asphalt additive to reduce the production temperatures and to improve the performance of asphalt rubber mixtures. Journal of Cleaner Production, 2013, 41, 15-22.

[4] R.T. Rasool, P. Song and S. Wang, Thermal analysis on the interactions among asphalt modified with SBS and different degraded tire rubber. Construction and Building Materials, 2018, 182, 134-143.

[5] H. Zhang and M. Gong, Study on durability of composite-modified asphalt mixture based on inherent and improved performance. Construction and Building Materials, 2018, 179, 539-552.

[6] Ministry of Transport of the People’s Republic of China. Test Methods of Aggregate for Highway Engineering (JTG E42-2005). Beijing, China Communications Press, 2005.

[7] T. Wang, F. Xiao, X. Zhu, B. Huang, J. Wang and S. Amirkhanian, Energy consumption and environmental impact of rubberized asphalt pavement. Journal of Cleaner Production, 2018, 180, 139-158.

[8] Y. Wang, B. Zhan and J. Cheng, Study on preparation process of SBS/ crumb rubber composite modified asphalt, Hangzhou, China: Trans Tech Publications, 2012, 417-422.

[9] G.D. Airey, Rheological properties of styrene butadiene styrene polymer modified road bitumens, Fuel, 2003, 82 (14), 1709-1719.

[10] F.J. Navarro, P. Partal, F. Martinez-Boza and C. Gallegos, Thermo-rheological behaviour and storage stability of ground tire rubber-modified bitumens, Elsevier Ltd, 2004, 83, 2041-2049.

[11] F.Q. Dong, W.Y. Fan, G.M. Yang, J.M. Wei, H. Luo, M.M. Wu and Y. Z. Zhang, Dispersion of SBS and its influence on the performance of SBS modified asphalt. Journal of Testing and Evaluation, 2014, 42 (5), JTE20130213 (8 pp.).

[12] Urban and Rural Construction and Transportation Committee of Shanghai. Technical Code for Asphalt Rubber Pavement (DG/TJ08-2109-2012). Shanghai, 2012.

[13] Ministry of Transport of the People’s Republic of China. Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011). Beijing, China Communications Press, 2011.

[14] General Administration of Quality Supervision, Inspection and Quarantine of the People’s Republic of China. Acoustics—Determination of sound absorption coefficient and impedance in impedance tubes—Part 2: Transfer function method (GB/T 18696.2-2002). Beijing, 2002.