Investigation on the performance of colored asphalt and pavement

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Abstract. Colored asphalt pavement is essential to beautify the city and manage the traffic. Colored asphalt was prepared by mixing aromatic oil, petroleum resin and styrene-butadiene-styrene block copolymer (SBS). The effect of aromatic oil, petroleum resin and SBS on the performance of colored asphalt was investigated. The results showed that aromatic oil help improve the low-temperature properties, resin can enhance the high-temperature properties, and SBS strengthen both high and low temperature performances. Qualified 70# colored asphalt was prepared by optimizing the formulation. The properties of colored asphalt mixtures indicated that the mixtures had superior rutting resistance and water stability, while low-temperature cracking resistance is inferior.

1. Introduction

With the rapid development of urban road construction and the enhancement of people's aesthetic sense of the environment, monotonous black and white colors have become more tedious for drivers. Colored asphalt pavement has become popular for the purpose of people's requirement for the coordination, safety and comfort between roads and the environment. Compared with the traditional black and white pavement, colored asphalt pavement can not only beautify the environment, reduce the drivers' fatigue but also can be alert to driving safety due to its rich colors. Different colors can distinguish various functions of the road, including guide the traffic flow and reduce mutual interference between other vehicles. Colored asphalt pavement is beneficial to reduce the urban heat island effect by reflecting the ultraviolet light back into space [1].

As a new pavement technology, colored asphalt pavement began in Europe and the United States in the 1950s, and has gradually expanded its application areas. Numerous studies have concluded that colored asphalt pavement is superior to conventional traffic signs in reminding drivers to drive safely. Colored pavement is composed of colorless asphalt binder, aggregates and various pigments. Its construction method is similar to conventional asphalt pavement. Colorless asphalt binder can be prepared by mixing the aromatic oil, petroleum resin and polymer. The properties of colorless asphalt binder are determined by the compatibility between each component. Many researchers have developed colored asphalt with good properties. Lee et al. prepared a yellowish synthetic resin binder and carried on the Marshall stability test, wheel tracking test, raveling test and accelerated weathering test. Testing results proved that the pavement performance satisfied the requirements of the technical standards [2].
Chang'an university developed colored asphalt micro-surfaces by using SBS modified emulsified asphalt as binder and adding a certain amount of colored aggregates as well as additives. Tang et al. prepared colored binder modified by nano-montmorillonite and tested the performance of its mixtures. The results indicated that nano-montmorillonite could strengthen the high temperature and anti-oxidation properties. The colored asphalt mixture exhibited enhanced stability, improved flow value and moisture susceptibility [3, 4].

In this paper, colored asphalt which meets the requirements of GB/T 32984-2016 was prepared by using aromatic oil, petroleum resin and polymer as raw materials. The influence of each component and dosage on the performance of colored asphalt was considered. Furthermore, the high-temperature stability, low-temperature cracking resistance and water stability of mixture were evaluated by rutting test, bending test and freeze-thaw splitting test, respectively.

2. Experiment and methods

2.1. Materials
Aromatic oil was served as the compatibilizer, which kinematic viscosity at 100 °C was 27 mm²/s. The mass fraction of group composition was tested, of which the saturated fraction was 25.7%, aromatic constituent was 67.0%, and polar compound was 7.3%. The petroleum resin was translucent brown particles with a softening point of 120 °C. Polymer modifier used in this study was SBS with a linear type. The block ratio between styrene and butadiene was 30:70 and the molecular weight was 120000. Pigment was red ferric oxide.

2.2. Preparation of colored asphalt and mixtures
Colored asphalt samples were prepared by mixing aromatic oil, polymer and petroleum resin under high shear. The aromatic oil was first heated to 180 °C in a batch reactor and then SBS was added into the reactor slowly and sheared at the constant temperature of 180 °C with shear speed of 4000 rpm. After a developing procedure for 50 min, the SBS was swollen and dispersed well, petroleum resin was finally added and stirred at a speed of 1000 rpm for 30 min. Finally, pigment was mixed to color the blends. A series of colored asphalts were obtained.

AC-13 type gradation was chosen to prepare the colored asphalt mixture, and asphalt-aggregate ratio was 5% determined by test. The specimens were prepared for further testing.

2.3. Test methods
Physical properties of colored asphalt include penetration, softening point, ductility and viscosity were tested according to Highway Engineering (JTG E20-2011). The performance of mixtures such as high-temperature stability, low-temperature cracking resistance and water stability were also evaluated following the same specification.

3. Results and discussion
At present, the main analysis methods and product classification of colored asphalt still follow the paving asphalt standard. In this investigation, variations of the properties of colored asphalt with the proportion changes of each component were studied, and the performance of mixture was evaluated.

3.1. Performance evaluation of colored asphalt

3.1.1. Effect of aromatic oil content on physical properties of colored asphalt. The aromatic oil is a viscous liquid with a high content of aromatic fractions. Aromatics contribute to the compatibility between resin and polymer, which also help to adjust the penetration and viscosity of colored asphalt. The addition of aromatic oil can improve the ductility and decrease the viscosity in order to enhance the construction workability. The effect of aromatic oil content on physical properties of colored asphalt was shown in table 1. It can be observed that the penetration and ductility strengthened while softening
point and viscosity declined as the increasing content of aromatic oil. In general, the softening point evaluates the high-temperature properties while the ductility represents the low-temperature properties. Increased ductility indicate that aromatic oil help improve the low-temperature properties.

### Table 1. The effect of aromatic oil content on physical properties of colored asphalt.

| Content of aromatic oil (%) | Penetration (25 °C, 0.1mm) | Softening point (°C) | Ductility (10 °C, cm) | Viscosity (135°C, Pa·s) | Residue penetration ratio (%) | Residue ductility (10 °C, cm) |
|----------------------------|-----------------------------|----------------------|-----------------------|-------------------------|-------------------------------|-------------------------------|
| Sample 1                   | 67                          | 65.8                 | 87                    | 0.31                    | 69                            | 62                            |
| Sample 2                   | 77                          | 64.4                 | 93                    | 0.28                    | 75                            | 68                            |
| Sample 3                   | 79                          | 62.8                 | 95                    | 0.24                    | 77                            | 74                            |
| Sample 4                   | 86                          | 61.2                 | 96                    | 0.19                    | 73                            | 79                            |
| Sample 5                   | 100                         | 59.0                 | 98                    | 0.11                    | 74                            | 83                            |

3.1.2. **Effect of petroleum resin content on physical properties of colored asphalt.** Petroleum resin was solid particle which contribute to the stiffness of colored asphalt. The influence of petroleum resin on the properties of colored asphalt was evaluated. As shown in Table 2, the addition of petroleum resin decreases the penetration and ductility, and increase the softening point and viscosity. The viscosity increment is slight due to the fact that resin can be melted at testing temperature of viscosity. The resin helps to improve the high-temperature properties.

### Table 2. The effect of petroleum resin content on physical properties of colored asphalt.

| Content of petroleum resin (%) | Penetration (25 °C, 0.1mm) | Softening point (°C) | Ductility (10 °C, cm) | Viscosity (135°C, Pa·s) | Residue penetration ratio (%) | Residue ductility (10 °C, cm) |
|-------------------------------|-----------------------------|----------------------|-----------------------|-------------------------|-------------------------------|-------------------------------|
| Sample 1                      | 102                         | 53.6                 | 101                   | 0.18                    | 63                            | 72                            |
| Sample 2                      | 82                          | 55.8                 | 82                    | 0.19                    | 61                            | 64                            |
| Sample 3                      | 75                          | 56.2                 | 72                    | 0.19                    | 61                            | 59                            |
| Sample 4                      | 53                          | 58.2                 | 62                    | 0.20                    | 66                            | -                             |
| Sample 5                      | 48                          | 59.0                 | 46                    | 0.20                    | 56                            | -                             |

3.1.3. **Effect of SBS content on physical properties of colored asphalt.** SBS was widely used to modify the base asphalt in order to enhance the comprehensive properties of modified asphalt. It can take both high-temperature and low-temperature properties into consideration at the same time. Table 3 presents the effects of SBS on the physical properties of colored asphalt. As can be seen, SBS both enhance the softening point and ductility, meanwhile, it also increase the viscosity dramatically. High viscosity will cause the inferior construction workability, therefore, SBS content should be constricted to be within a certain range.

### Table 3. The effect of SBS content on physical properties of colored asphalt.

| Content of SBS (%) | Penetration (25 °C, 0.1mm) | Softening point (°C) | Ductility (10 °C, cm) | Viscosity (135°C, Pa·s) | Residue penetration ratio (%) | Residue ductility (10 °C, cm) |
|--------------------|-----------------------------|----------------------|-----------------------|-------------------------|-------------------------------|-------------------------------|
| Sample 1           | 75                          | 56.2                 | 72                    | 0.19                    | 61                            | 59                            |
| Sample 2           | 75                          | 59.8                 | 89                    | 0.21                    | 67                            | 60                            |
| Sample 3           | 78                          | 62.8                 | 93                    | 0.29                    | 77                            | 74                            |
| Sample 4           | 80                          | 66.0                 | 90                    | 0.38                    | 79                            | 78                            |
| Sample 5           | 79                          | 67.8                 | 89                    | 0.45                    | 82                            | 83                            |
3.1.4. Preparation and Physical properties of 70# colored asphalt. By way of optimizing the formulation of colored asphalt, qualified 70# colored asphalt was prepared. Its physical properties are listed in table 4. As can be seen, all the key parameters can meet the requirements of GB/T 32984-2016.

| Test                                              | 70#          | Specification |
|---------------------------------------------------|--------------|---------------|
| Penetration (25 °C, 0.1mm)                        | 75           | 60-80         |
| Softening point (°C)                              | 56.2         | ≥55           |
| Ductility (10 °C, cm)                             | 72           | ≥30           |
| Kinematic viscosity (135°C, Pa·s)                 | 0.19         | ≤3            |
| Dynamic viscosity (60 °C, Pa·s)                   | 560          | ≥180          |
| TFOT Mass loss (%)                                | 1.1          | ≤±1.5         |
| Residue penetration ratio (%)                     | 61           | ≥55           |
| Residue ductility (10 °C, cm)                     | 59           | ≥6            |

3.2. Performance evaluation of colored asphalt mixture

For purpose of assessing the performance of colored asphalt mixtures, 70# colored asphalt was taken as the binder and AC-13 skeleton dense gradation was chosen to prepare the mixture [5, 6]. Furthermore, target mixture proportion design was carried on to determine the aggregate gradation scope, optimum asphalt content of mixture and the temperature and time of curing was confirmed. The high-temperature stability, low-temperature cracking resistance and water stability were tested by rutting test, bending test and freeze-thaw splitting test, respectively.

3.2.1. High-temperature stability. Generally, the ability of asphalt pavements to resist deformation under high temperature conditions is often referred to as the high temperature stability of asphalt mixture. Colored asphalt is a viscoelastic material, its physical and mechanical properties are related to temperature and vehicle load. As the temperature increases, the strength and stiffness of the asphalt pavement decreases significantly. In order to prevent the deformation diseases such as shifting and rutting at high temperature season, the asphalt pavement must ensure good high temperature stability.

Currently, there are many methods for evaluating the high-temperature stability of asphalt mixtures including rutting test, simple shearing test, uniaxial loading test, large-scale looping test and so on. Among these methods, rutting test is the most widely used and direct evaluation method which can better simulate the actual driving situation. It takes the dynamic stability as the index to evaluate the high-temperature performance. Table 5 shows the testing values of rutting test. It can be observed that the dynamic stability of colored asphalt mixture exceeds the requirement of the specification. This demonstrates that the colored asphalt mixture has excellent rutting resistance and suit for the pavement construction.

| Test | Rut depth at t₁ (mm) | Rut depth at t₂ (mm) | Dynamic stability (times/mm) | Average values (times/mm) | Specification (times/mm) |
|------|-----------------------|----------------------|-------------------------------|---------------------------|--------------------------|
| 1    | 3.505                 | 3.984                | 1315                          |                           | ≥1000                    |
| 2    | 3.695                 | 4.185                | 1286                          | 1264                      | ≥1000                    |
| 3    | 3.826                 | 4.355                | 1190                          |                           |                          |

3.2.2. Low-temperature cracking resistance. The performance of colored asphalt is mainly affected by temperature. It becomes brittle at low temperature and is prone to crack, leading to the thermal contraction cracks of the pavement. The existence of the cracks not only affects the integrity and continuity of the pavement, but also causes the destruction of the subgrade because of the permeation of the rainwater [7]. The cracks further shorten the effective life span of the expressway and bring the
hidden danger to traffic safety. Therefore, it is vital to evaluate the cracking resistance of the colored asphalt mixtures at low temperatures.

Numerous methods to evaluate the low-temperature cracking resistance of the mixtures, including direct tensile test, indirect tensile test, creep test, stress relaxation test, bending test and temperature stress test of restricted specimen. In this study, bending test was conducted for evaluating the performance of colored asphalt mixture under low temperature. As shown in table 6, the maximum bending strain was obtained. It can be seen from the table, the bending strain fails to comply with the specified requirements. This is due to the fact that the addition of petroleum resin raises the glass transition temperature of the colored asphalt. The glass transition temperature of petroleum resin is nearly 80 °C. The resin becomes fragile at the testing temperature of -10 °C, resulting in poor flexibility of the colored asphalt and worse low-temperature performance of the mixture. For the purpose of promoting the low-temperature cracking resistance, more SBS and low pour point aromatic oil should be selected.

Table 6. The results of the freeze-thaw splitting test.

| Bending strain (με) | Specification (%) |
|--------------------|-------------------|
| 1680               | ≥2000             |

3.2.3. **Water stability.** The water damage is one of the key indexes of pavement performances. The adhesion between colored asphalt binder and aggregates become worse under the condition of water flushing and freeze-thaw cycles. The asphalt film peels off from the aggregate surface and further form the pit holes due to the weakening adhesion. In the study, freeze-thaw splitting test was conducted to evaluate the water stability of the mixtures. According to the specifications, the tensile strength ratio (TSR) of colored asphalt mixtures in non-motor vehicle lanes is not less than 75%. The testing results of the TSR are listed in table 7. As shown in the table, the color asphalt mixture possesses fine water stability due to the resin and SBS which strengthen the adhesion and cross-linking interaction between asphalt and aggregates.

Table 7. The results of the freeze-thaw splitting test.

| Freeze-thaw splitting strength (MPa) | Splitting strength (MPa) | TSR (%) | Specification (%) |
|-------------------------------------|--------------------------|---------|-------------------|
| 1.73                                | 2.25                     | 77      | 75                |

4. **Conclusion**

In this research, the influence of aromatic oil, petroleum resin and SBS on the performance of colored asphalt was investigated. The results showed that aromatic oil help improve the low-temperature properties, resin help enhance the high-temperature properties, and SBS strengthen both high and low temperature performances. Qualified 70# colored asphalt was prepared by optimizing the formulation of each component. The colored asphalt mixtures exhibit superior rutting resistance and water stability, while low-temperature cracking resistance is inferior.

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**References**

[1] Deng-Fong Lin, Huan-Lin Luo, Fading and color changes in colored asphalt quantified by the image analysis method, Constr. Build. Mater. 18(2004)255-261.

[2] Rang W. Lee, Ju Won Kim, Dae Woong Kim, Development of color pavement in Korea, J. Transp. Eng. 1985, 111-292.

[3] Xinde Tang, Chao Kong, Jiang Tian, eatl, Preparation and pavement performance of colored asphalt, Applied mechanics and materials, 727-728(2015)362-365.
[4] Ping Tang, Liantong Mo, Changluan Pan, et al., Investigation of rheological properties of light colored synthetic asphalt binders containing different polymer modifiers, Constr. Build. Mater. 161 (2018) 175-185.

[5] Chou Fu. Liang, Hung Yu. Wang, Jun Kai. Lu, et al., The investigation of colored normal temperature asphalt concrete, Advanced materials research, 723 (2013) 686-693.

[6] Zhigang Xin, Research application of colored asphalt mixture pavement, Advanced materials research, 900 (2014) 459-462.

[7] Xinde Tang, Yueqing Yang, Xuxiang Tan, et al., Research on pavement performance of silane coupler-modified colored asphalt, 2017 2nd International conference on architectural engineering and new materials, (2017) 601-605.