High-temperature properties of composite modified light-colored synthetic asphalt binders

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Abstract

To analyze the impact of polymer modifiers on the high-temperature viscosity and rheological properties of light-colored synthetic asphalt binders. Aromatic oils, petroleum resins, and polymer modifiers were selected to prepare a light-colored synthetic modified asphalt binder by physical mixing. In this study, SBS plus EVA was used to modify the light-colored synthetic asphalt binders, and seven sets of samples were prepared. The modified light-colored synthetic asphalt binder's basic engineering properties were measured through the three major index tests; the rotational viscosity test and DSR test measure its high-temperature viscosity and rheological properties, and the content of different polymer modifiers was analyzed on the viscosity and influence of rheological properties. The results show that the compound modification method can increase the viscosity of light-colored synthetic asphalt binders, and SBS is better than EVA in improving the viscosity and rheological properties. EVA's low content has little effect on the high-temperature viscosity and rheological properties of light-colored synthetic asphalt binders. Too much SBS will increase the impact of EVA to improve high-temperature viscosity. Modification of compounds may also improve the high-temperature rutting resistance of light-colored synthetic asphalt binders. SBS will degrade in the RTFOT aging process of light-colored synthetic asphalt binders, and its improving effect will be impaired. The content of SBS should not exceed 6%.

1. Introduction

Over the last decade, China's economy has been highly developed, and economic development has naturally improved people's living standards. People have progressively increased their demands on life and the travel environment, and the black and white road colors are likely to make drivers visually tired. Asphalt pavement color was cultivated and could improve the quality of people's living environment [1]. The colored asphalt pavement had good recognizability and could be used to divide traffic sections into urban intersections. Contribute to organizing and managing urban traffic. Simultaneously, it could also be applied to driveways for non-motorized vehicles, thereby improving the commuting environment for urban residents. The colorful asphalt paving of the roads in parks and scenic sites could increase people's enjoyment and enhance life quality [2]. The colorful asphalt paving of residential areas' streets can improve the living environment and create a warm atmosphere [3]. Paving colored asphalt pavements at road turn, long, steep slopes of expressways, tunnel entrances and exits, and other accident-prone areas can be a warning [4]. During the hot summer, the regular asphalt pavement will absorb much heat and create a heat island effect in the city [5]. The color of the paved pavement uses the characteristic of self-reflection to reduce the heat of the pavement [6]. In recent years, Chinese road researchers have focused on the road performance of colored asphalt pavements and improving discoloration capacity [7]. There was little research on the high- and low-temperature performance of colored asphalt [8]. Light-colored synthetic asphalt was an essential element in colored asphalt [9]. How to improve the
In this paper, aromatic oil and C9 petroleum resin were used as raw materials, SBS and EVA were used as polymer modifiers. Because SBS can improve the high- and low-temperature performance of light-colored synthetic asphalt binders, and its lighter color allows the light-colored synthetic asphalt binders to maintain the original appearance color, and considering the cost and application area of light-colored synthetic asphalt, aromatic oil was selected as basic raw materials, and SBS and EVA were selected as polymer modifiers to improve the viscosity and high-temperature rheological properties of light-colored asphalt binders. Petroleum resin and aromatic oil were selected as basic raw materials, and SBS and EVA were selected as polymer modifiers to improve the viscosity and high-temperature rheological properties of light-colored synthetic asphalt binders. Prepare seven groups of light-colored synthetic asphalt binders, choose Brookfield Viscometer and DSR to determine the viscosity and high-temperature rheological properties of modified light-colored asphalt binders.

### 2. Materials and methods

#### 2.1. Materials

In this paper, aromatic oil and C9 petroleum resin were used as raw materials, SBS and EVA were used as polymer modifiers. Because SBS can improve the high- and low-temperature performance of light-colored synthetic asphalt binders, its lighter color allows the light-colored synthetic asphalt binders to maintain the original appearance color, and considering the cost and application area of light-colored synthetic asphalt binders, light-colored polymer (EVA) was selected to improve its high-temperature performance based on the above modification. And LCAB was prepared under high temperature and high-speed shear. The aromatic oil used in this article is dark green, with an aromatic content of 78%, a kinematic viscosity of 35.8 mm$^2$ s$^{-1}$ at 100 °C and a density of 104 $\sim$ 108 at 20 °C; C9 petroleum resin is light yellow with a relative density of 0.97 $\sim$ 1.04, average. The molecular weight is 2000–5000, and the softening point is 95 °C. In this paper, a star-shaped SBS modifier was used. The elongation at break measured by ASTM D-638 test method was 720%, the styrene content was 31%, and the molecular weight was 250,000 g/Mol measured by GPC (MW) test method. The VA content of the ethylene-vinyl acetate polymer used in this document was 6 g/10 min, and elongation at break was 900%. According to the four-component principle of petroleum asphalt, aromatic oil replaces aromatic components and partially saturated components, as a viscous liquid, imparts fluidity and plasticity to synthetic light-colored synthetic asphalt; petroleum resin replaces partially saturated parts and gums to increase the stability of synthetic light-colored synthetic asphalt. To improve adhesion and plasticity, polymer modifier replaces asphalting to improve thermal stability and viscosity.

#### Table 1. Light-colored synthetic asphalt binders material composition.

| Sample | Aromatic oil% | Petroleum resin% | SBS% | EVA% |
|--------|---------------|------------------|------|------|
| A0     | 55            | 45               | —    | —    |
| A1     | 55            | 45               | 4    | 1    |
| A2     | 55            | 45               | 4    | 2    |
| A3     | 55            | 45               | 4    | 3    |
| A4     | 55            | 45               | 6    | 1    |
| A5     | 55            | 45               | 6    | 2    |
| A6     | 55            | 45               | 6    | 3    |

The high and low-temperature performance of light-colored synthetic asphalt binders is an urgent problem to resolve. There are two main methods for preparing light-colored synthetic asphalt binders [10]. One is to remove the black asphaltenes in the asphalt to obtain a light-colored synthetic asphalt with a transparent color [11]; the other is to select light-colored synthetic petrochemical products through the physical blending method to get a light-colored synthetic asphalt binder with performance equivalent to petroleum asphalt [12]. At present, industrial oils, resins, and polymer modifiers are primarily used to synthesize light-colored synthetic asphalt. This method of preparation simple and was widely used to produce clear-colored asphalt binders [13]. Wang’s research shows that petroleum resins with high softening points will reduce the high and low-temperature performance of light-colored synthetic asphalt binders, and rubber oils with high aromatic content can improve low-temperature performance [14]. Li investigated the effect of the ratio of resin to rubber oil on the light-colored synthetic asphaltic binder’s performance, and the percentage of resin should be less than 50% [15]. Wang pointed out that the polymer-modified macromolecular chain in light-colored synthetic asphalt binder improves mechanical properties and alters the phase transition process [16]. Based on the high- and low-temperature performance of light-colored synthetic asphalt, the resin ratio should typically not exceed 50% [17]. Moreover, industrial oil’s different aromatic contents will also modify its performance at low and high temperatures. The type of resin will also affect the performance of light-colored synthetic asphalt. Petroleum resin has better toughness and cohesiveness [18].

Currently, researchers are focusing primarily on the road performance of colored asphalt pavements. The light-colored synthetic asphalt binder is applied to the top layer of the pavement, and it is urgent to improve its viscosity and stability at high temperatures. The purpose of this article is to study the effect of polymer modifiers on the high-temperature rheological properties of light-colored synthetic asphalt binders. Petroleum resin and aromatic oil were selected as basic raw materials, and SBS and EVA were selected as polymer modifiers to improve the viscosity and high-temperature rheological properties of light-colored synthetic asphalt binders. Prepare seven groups of light-colored synthetic asphalt binders, choose Brookfield Viscometer and DSR to determine the viscosity and high-temperature rheological properties of modified light-colored asphalt binders.
2.2. Sample preparation and experimental testing
According to reports, the ratio of petroleum resin to industrial oil should not exceed 1:1, and the content of petroleum resin over 50% will cause the high and low-temperature performance of light-colored synthetic asphalt to decrease significantly. In this paper, 55% of aromatic oil and 45% of petroleum resin make light asphalt. By adding SBS and EVA, high and low-temperature performance and viscosity of light-colored synthetic asphalt were improved. A total of six groups of modified light-colored synthetic bituminous binders were prepared. The addition amount of polymer modifier is shown in table 1. The aromatic oil is placed in a constant temperature bath at 150 °C for 10 min, and then petroleum resin is added and stirred for 15 min until it was completely dispersed. Finally, the polymer modifier was added, and the mixture was mixed with a high-speed cutting machine for 25–40 min [19, 20].

The prepared modified asphaltic binder prevents the oven from being maintained at 165°C for 15 h. This article selects 70# of petroleum asphalt for comparison (According to China’s road petroleum asphalt technical requirements, the penetration value at 25 °C is 60 mm ∼ 80 mm, 01 mm). Following T0604 JTG E20-2011, T0605 JTG E20-2011, and T0606 JTG E20-2011 [21], the penetration, ductility, and softening point of light-colored synthetic asphalt binders were measured respectively. The viscosity of asphalt was used to determine the paving temperature and compaction temperature of asphalt mixtures and, to some extent, characterize the adhesion of asphalt. According to T0625 JTG E20-2011 [21], a Brookfield Viscometer with a temperature controller was selected to measure light-colored asphalt binders’ viscosity. The measured temperature is 120 °C to 175 °C with a speed of 20 r min⁻¹ and a shear rate 6.8 s⁻¹. According to ASTM D 4402 uses a rotational film heating test to simulate the light-colored synthetic asphalt binder’s RTFOT aging [22]. In this paper, according to AASHTO T 315-09, DSR was selected to conduct a temperature scanning test on the light-colored synthetic asphalt binder, and a plate with a diameter of 25 mm and a gap of 1 mm was chosen [23]. The speed was 10 rad s⁻¹, which means 88 km h⁻¹ for vehicles on the road. The test can obtain the complex viscosity, complex shear modulus, phase angle, and rutting factor of various asphalt binders.

Figure 1. Conventional test results.
light-colored synthetic asphalts. These data characterize the high-temperature viscosity and rheological properties of light-colored synthetic asphalt.

3. Results and discussion

3.1. Conventional performance test results

Figure 1 shows the test results of the three primary indicators. The indicators used to assess the primary performance of petroleum asphalt are also used to evaluate the basic technical properties of light-colored synthetic asphalt binders. The softening point is used to characterize the high-temperature stability of the bituminous binder and measure its viscosity [24, 25]. Penetration reflects the viscosity of asphalt binder to a certain extent. Ductility is an index to evaluate the plasticity of asphalt materials. The test results figure 1 indicate that the high and low-temperature performance of light-colored synthetic asphalt binders is significantly improved after the addition of SBS EVA. It can be seen from A1, A2, and A3 of figure 1(a) that the softening point increases as the EVA content increases. Due to the low amount of EVA added, a smaller increase in softening point. The same finding can be derived from A4, A5, and A6. It can be calculated from A1, A3, and A4 that adding 2% EVA based on A1 increased the softening point by 7.37%, and adding 2% SBS increases the softening point by 7.55%. This shows that SBS and EVA modification methods have similar effects for improving high-temperature performance. It can be seen from figure 1(b) that the addition of polymer modifiers can improve the low-temperature performance of light-colored synthetic asphalt binders. Compared with A1, A3, and A4, we can see that the ductility of A4 is higher than that of A3. This shows that SBS is better than EVA in the performance improvement at low temperatures. At the same time, six groups of light-colored synthetic asphalt can be seen that, with the increase of EVA content, the low-temperature performance of asphalt has not been significantly improved. In addition, figure 1(c) shows that penetration increases with the addition of SBS EVA. The increase in penetration is primarily due to the addition of SBS show in figure 1(c). We can see from A1, A2, and A3 that with the rise in EVA addition, the value of penetration gradually decreases. Observe that A4, A5, and A6 get the same conclusion. This demonstrates that adding EVA can reduce the penetration of light-colored synthetic asphalt binders. Primarily because, as a resin modifier, EVA increases the consistency of light-colored synthetic asphalt binders and reduces penetration. In summary, it can be seen from the test results of basic engineering properties that it is feasible to choose SBS plus EVA to improve the high-temperature performance of light-colored synthetic asphalt binders. Among them, SBS has a better effect on improving high temperature and low-temperature performance. EVA is effective in improving high-temperature performance.

3.2. Performance grade (PG) test results

This paper primarily studies the high-temperature rheological properties of light-colored synthetic asphalt binders, and it is inevitable to analyze changes in road performance grades of light-colored synthetic asphalt binders after modification. A dynamic shear rheometer measures the complex modulus and phase angle of different light-colored synthetic asphalts binders, and the rutting factor is calculated [26]. According to the SHARP specification, the rutting factor’s temperature satisfies 1 Kpa is the failure temperature, which is used as a measure of the PG grades. Figure 2(a) shows that the light-colored synthetic unmodified asphalt binder failure...
temperature is $64\,^\circ C$, and the road efficiency performance grades (PG64) can be determined. The light-colored synthetic asphalt binder’s failure temperature increases to various degrees through adding SBS and EVA, and whose road performance grades are also improved. The difference is that the addition of the polymer modifiers increases the light-colored synthetic asphalt binder’s failure temperature, which indicates that the road performance grades of the light-colored synthetic asphalt binder are also different. The road performance grades determined from figure 2 are shown in table 2. The road performance grade of the three groups with 4% SBS is PG76, which is lower than the three groups of light-colored synthetic asphalt binders with 6% SBS shown in figure 2(b). In terms of improving the light-colored synthetic asphaltic binder’s road performance, the improvement effect of SBS is better than that of EVA. The same conclusion can be drawn from the three groups A1, A3, and A4. With 2% SBS and 2% EVA based on A1, the road performance grades in A4 is considerably higher than in A3. The choice of compound modification method can improve the road performance level of light-colored synthetic asphalt binder and determine the additional amount of polymer modification according to the regional temperature conditions to achieve the best economic benefits.

### 3.3. Test the effect of temperature on viscosity

Figure 3 shows the rotation viscosity tests of various light-colored synthetic asphalt binders. The rotation viscosity test measures the light-colored synthetic asphalt binders’ apparent viscosity at different temperatures as a viscoelastic material. Viscosity at different temperatures is driven into a viscosity-temperature curve, and the curve is used to determine the mixing and compaction temperature of the asphalt mixture [27]. According to the Chinese Asphalt Test Regulations, the temperature when the viscosity is $0.17\, \text{Pa}\cdot\text{s} \pm 0.02\, \text{Pa}\cdot\text{s}$ is used as the mixing temperature range; the temperature when the viscosity is $0.28\, \text{Pa}\cdot\text{s} \pm 0.03\, \text{Pa}\cdot\text{s}$ is used as the compaction temperature range. As shown in figure 3, the mixing light-colored synthetic asphalt binder’s mixing and compacting temperature is significantly higher than $175\, ^\circ C$. Explain if this method is appropriate to determine if the changed asphalt is still determined. The reasonable mixing and compaction temperature should be determined under the project. This paper chooses to refer to the Chinese standard that the viscosity at $135\, ^\circ C$ should not be greater than $3\, \text{Pa}\cdot\text{s}$, aiming to ensure the asphalt’s workability and engineering properties. Except for A6, other modified light-colored synthetic asphalts binders may meet the requirements of the specifications. The viscosity curve shows that the viscosity of light-colored synthetic asphalt binders is strongly influenced by temperature. As the temperature rises, the viscosity gradually declines.

To further analyze the influence of temperature on viscosity, Arrhenius’ formula equation (1) is selected to describe the relationship between viscosity and temperature [28].

\[ \ln(\eta) = \ln(A) - \frac{E_a}{RT} \]

where

- $\eta$ is the viscosity of the asphalt binder at a specific temperature
- $A$ is the viscosity constant
- $E_a$ is the activation energy
- $R$ is the gas constant
- $T$ is the temperature in Kelvin

Figure 3. The relationship between viscosity and temperature.

Table 2. Performance grade of binders.

| Samples | A0   | A1   | A2   | A3   | A4   | A5   | A6   |
|---------|------|------|------|------|------|------|------|
| Grade   | PG64 | PG76 | PG76 | PG76 | PG82 | PG82 | PG82 |

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\( \eta \) is the viscosity Pa·s, \( E_\eta \) is the viscous Flow activation energy, J·mol\(^{-1}\), the minimum energy required to characterize asphalt molecules’ flow. \( R \) is Molar gas constant, 8.314 J·(mol·K\(^{-1}\)). \( T \) is the absolute temperature, K. LnA is called Arrhenius constant, J·mol\(^{-1}\). The results obtained by fitting are shown in figure 4 and table 3.

\[
\ln \eta = \frac{E_\eta}{RT} + \text{LnA}
\]  

(1)
The square $R^2$ of the fit results is near 1, and the accuracy of the linear fit is high. The intercept of the line, $\ln A$, can be obtained by line fitting. $E_\eta / K$ is the slope of the fitting line, and the flow activation energy $E_\eta$ can be computed [29]. Specifically, as shown in figure 5, the addition of SBS and EVA significantly increased the light-colored asphalt binder’s flow activation energy, and the molecular flow resistance in the asphalt also increased correspondingly. The main reason is that SBS forms a three-dimensional network structure in light-colored synthetic asphalt binders, and EVA macromolecules react with molecules in light-colored synthetic asphalt binders, making it more difficult for asphalt molecules to flow. Looking at A1, A2, and A3, we can see that as the EVA content increases by 2% and 3%, and the flow activation energy increases by 2.23% and 4.95%, respectively. It can be found from A4, A5, and A6 that the EVA content increases, flow activation energy increases by 4.34% and 10.08%, respectively. It can be concluded that EVA’s effect on improving viscosity increases with SBS. The primary reason is that the content of SBS increases, and the degree of cross-linking and rigidity of the three-dimensional network in light-colored synthetic asphalt molecules gradually increases. The movement of the macromolecular structure in EVA is even more difficult. The ability to circulate molecules through the pitch will naturally increase. Besides, we can be seen from the Flow activation energy of A1, A3, and A4, adding 2% SBS and 2% EVA to the basis of A1, respectively. The flow activation energy of A3 is slightly smaller than that of A4. This shows that the effect of SBS to improve viscosity is significantly better than that of EVA, which is the reason for the nature of the polymer modifier itself. In summary, SBS may enhance the viscosity enhancement effect of EVA. Given the cost, the content of the SBS should not be too substantial. The quantity of EVA added should be increased as required.

3.4. Analysis of rutting factor

Figure 6 depicts the rutting factor of various light-colored synthetic asphalt binders. The rutting factor characterizes the asphalt’s ability to withstand permanent deformation in high-temperature conditions [30, 31]. The addition of polymer modifiers significantly enhances the rutting resistance of light-colored synthetic asphalt binders. The compound modification method can improve the high-temperature rutting strength of asphalt binders by significantly increasing the flow activation energy.
light-colored synthetic asphalt binders. Of course, the rutting factor depends heavily on the temperature and gradually decreases as the temperature rises. When the added amount of SBS is 6%, its rutting factor is significantly higher than that of the three groups of light-colored synthetic asphalt binders with 4% SBS. SBS is effective for improving the ability to withstand rutting. By observing A1, A2, and A3, we can see that as EVA's content increases, its rutting factor does not increase significantly. Perhaps that is the reason for the decline in EVA content. A similar conclusion can be derived from A4, A5, and A6. An appropriate increase in EVA content may lead to further discoveries. Comparing A1, A3, and A4, it can be seen that adding 2% SBS based on A1 gives A4, and its rutting factor is significantly higher than that of A3 with 2% EVA. This suggests that the SBS plays a significant role in improving rutting resistance at high temperatures, while the EVA plays a secondary role. The reason is that the macromolecular structure of the polymer modifier itself is different, and the macromolecular form in EVA can increase the degree of crosslinking and rigidity of the three-dimensional network. However, its improvement is more diminutive than SBS. As a result, SBS is better than EVA in improving high-temperature performance. The rutting factor increased considerably after RTFOT aging, mainly because RTFOT aging changed viscoelastic components’ relationship. Figure 6(b) shows that the difference between A1, A2, and A3 and A4, A5, and A6 is gradually reduced after RTFOT aging. It indicates that SBS has deteriorated in the RTFOT aging process and that the modifying effect of SBS will be reduced. In short, depending on the cost and the impact of the modification, the additional amount of SBS should not exceed 6%.

### 3.5. Temperature sensitivity of light-colored synthetic asphalt binders

The nature of the light-colored synthetic asphalt binder is also a thermoplastics material. As the temperature rises, the rutting factor progressively decreases. To further analyze its temperature sensitivity, scattered points of $\ln\left(\frac{G^*}{\sin\delta}\right)$ - $\ln T$ is selected for linear adjustment\textsuperscript{[32]}. Figure 7 shows the temperature sensitivity of the light-colored synthetic asphalt binders before and after RTFOT aging. The linear fitting results are shown in Table 4. $R^2$ approach 1, indicating that the linear fitting result is accurate. The smallest absolute slope value indicates that the temperature sensitivity of the light-colored synthetic asphalt binders is low. Table 4 shows that the temperature sensitivity of light-colored synthetic asphalt binders is also a thermoplastics material. As the temperature rises, the rutting factor progressively decreases. To further analyze its temperature sensitivity, scattered points of $\ln\left(\frac{G^*}{\sin\delta}\right)$ - $\ln T$ is selected for linear adjustment\textsuperscript{[32]}. Figure 7 shows the temperature sensitivity of the light-colored synthetic asphalt binders before and after RTFOT aging. The linear fitting results are shown in Table 4. $R^2$ approach 1, indicating that the linear fitting result is accurate. The smallest absolute slope value indicates that the temperature sensitivity of the light-colored synthetic asphalt binders is low. Table 4 shows that the temperature sensitivity of light-colored synthetic asphalt binders is low.
sensitivity of the three groups of light-colored synthetic asphalt binders mixed with 6% SBS is lower than that of the three groups combined with 4% SBS. It can be concluded that SBS is superior to EVA to improve the temperature sensitivity of light-colored synthetic asphalt binders. Looking at A1, A2, and A3, we can see that as the EVA content increases, the temperature sensitivity of the light-colored asphalt binders gradually decreases. However, the degree of reduced temperature sensitivity is not very clear. The same results can be obtained from A4, A5, and A6, demonstrating that the modifier effect is not evident when the EVA content is low. The temperature sensitivity of the light-colored synthetic asphalt binders increases after RTFOT, which can be due to polymer degradation during the short-term aging process. In short, reducing SBS content can produce more interesting results, and increasing EVA is also a new direction.

4. Conclusions

In this study, seven light-colored synthetic asphalt binder groups were prepared by changing the addition of polymer modifiers. The viscosity and high-temperature rheological properties of light-colored synthetic asphalt binders were studied using three performance indicators, RV and DSR. The following conclusions can be drawn from the experimental data and analysis:

1. The results of conventional performance tests show that a modification of compounds can significantly improve the high and low-temperature performance and viscosity of the light-colored synthetic asphalt binders. The compound modification method can enhance the road performance of the light-colored asphalt binders, and the content of the SBS can have a significant impact on road performance grade (PG). Low EVA content has little influence on road performance. The road performance grade of the three light-colored synthetic asphalt binder groups of 6% SBS is PG82, while the remaining three groups are PG76.

2. The SBS modifier effect is evident due to the EVA, and the increase in EVA content has little effect on viscosity. This is the reason for the nature of the polymer modifier itself. SBS can form a three-dimensional network structure within the light-colored synthetic asphalt binders, increasing the flow activation energy during the molecular flow. The effect of improving the viscosity of EVA increases with the rise in SBS. The degree of cross-linking of the network structure formed by EVA as a resin modifier is inferior to SBS. The modification of the compound makes it more challenging to move the macromolecular chain in the modifier, and the viscosity and high-temperature performance are improved. However, as the temperature rises, the viscosity dependency on the polymer modifier gradually decreases. Based on the cost and modifying effect, the content of the polymer should not be too high.

3. The rheological properties of the light-colored synthetic asphalt binders show that the polymer modifier significantly increases the proportion of elastic components and improves the viscosity and high-temperature rheological properties; we also can obtain the same results from its temperature sensitivity. Of these, SBS plays a significant role, while the EVA plays a secondary role. SBS deteriorates following RTFOT aging, and the higher the SBS content, the higher the degree of reduction. Also, after RTFOT aging, EVA’s effect on improving the viscosity of the light-colored synthetic binder and the anti-rutting effect is enhanced. SBS content must not exceed 6%, and an appropriate increase in EVA may better explore changes in high-temperature performance.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Declaration of competing interest

The authors declare that they have no conflicts of interest to report regarding the present study.
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References

[1] Zhang L 2019 Study on the performance of modified colored asphalt at high and low temperature Urban Road Bridge and Flood Control 01 181–4
[2] Xu M, Pan X and Deng Q 2012 Setting method of thin-layer antiskid colored pavement tunnel based on increasing lumiance of pavement Tenth COTA Int. Conf. Transp. Prof. 3073–83
[3] Ando R, Inagaki T and Mitamura Y 2011 Does colored pavement make non-signalized intersections safer? A case study in Japan Procedia - Social and Behavioral Sciences. 20 741–51
[4] Zhao X, Tang L L, Wang J Z, Yang L Q and Liu J W 2019 Visual induction evaluation of tunnel in color pavement environment Journal of Fuzhou University (Natural Science Edition) 47 417–23
[5] Yuan J Y, Liu X J, Yao S, Gao Y, Wang Z D and Zhang Z T 2020 Safety of color pavement of expressway based on eye movement characteristics Science Technology and Engineering 20 14278–82
[6] Santamouris M, Xirafi F, Gaitani N and Spanou A 2012 Improving the microclimate in a dense urban area using experimental and theoretical techniques—the case of maroussi Athens International Journal of Ventilation. 11 1–16
[7] Gaitani N, Spanou A, Saliari M, Synnea A and Lagoudaki K P 2011 Improving the microclimate in urban areas: a case study in the centre of Athens Build. Serv. Eng. Res. Technol. 32 53–71
[8] Synnea A, Karlessi T, Gaitani N, Santamouris M, Assimakopoulos D N and Papakatsikas C 2011 Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate Build. Environ. 46 38–44
[9] Sengoz B, Bagayogo L, Oner J and Topal A 2017 Investigation of rheological properties of transparent bitumen Constr. Build. Mater. 154 1105–11
[10] Cai X F, Zhang J, Li M, Zhao P, Chen D and Liu J H 2018 Study on preparation and road performance of colored asphalt Hunan Communications Science and Technology 44 50–3
[11] Ping T, Fan C L, Bin F, Mo L T and Lin Z H 2018 Preparation and rheological properties analysis of colored asphalt Transportation Science and Technology 01 83–6
[12] Tang P, Mo L, Pan C, Fang H, Javilla B and Riara M 2018 Investigation of rheological properties of light-colored synthetic asphalt binders containing different polymer modifiers Constr. Build. Mater. 161 175–85
[13] Zhao L, Zha R, Chen Q, Zhang X, Shen B and Ling H 2018 Rheological properties of SBS modified light-colored synthetic asphalt binder Journal of East China University of Science and Technology (Natural Science Edition) 44 21–7
[14] Yong Q W, Peng X and Hai C M 2020 Analysis of the relationship between chemical composition and thermal behavior of colored asphalt binder Chinese Journal of Ceramics 39 332–6
[15] Li L I and Li W M 1999 Study on cementing materials for color pavement Journal of Building Materials 03 235–40
[16] Wang T 2018 Experimental study on high and low temperature performance of color cement urban roads Bridges and Flood Control 55 160–2
[17] Chen S, Yang G, Pei X and Liu R 2020 Study on the properties of colored asphalt binder Contemporary Chemical Industry 23 129–30
[18] Ding R J, Jian H X, Xiang B J, Yu G L and Jian F D 2020 Study on the road performance of tunnel bright colored asphalt with high performance New Building Materials 47 85–8
[19] Wang X P, Ou Y and Chan F 2011 Preparation and modification of hot paving colored asphalt binder Neijiang Science and Technology 32 100–33
[20] Huang Z Z 2008 Color asphalt binder and its preparation method Technology and Marketing 1 16
[21] T&G E20-2011 2011 Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering China Communications Press
[22] AASHTO 2013 Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Binder (Rolling Thin-Film Oven Test) AASHTO T240 Washington, DC
[23] AASHTO 2013 Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR) (T 315–12) American Association of State Highway and Transportation Officials
[24] Liu B, Li J J, Han M, Zhang Z and Jiang X 2020 Properties of poly styrene grafted activated waste rubber powder (PS-ARP) composite SBS modified asphalt Constr. Build. Mater. 238 117737
[25] Chen T, Ma T, Huang X, Guan Y, Zhang Z and Tang F 2019 The performance of hot-recycling asphalt binder containing crumb rubber modified asphalt based on physiochemical and rheological measurements Constr. Build. Mater. 226 83–93
[26] Yan K, Tian S, Chen J and Liu J 2020 High temperature rheological properties of APAO and EVA compound modified asphalt Constr. Build. Mater. 233 117246
[27] Saboo N and Kumar P 2015 Study of flow behavior for predicting mixing temperature of bitumen Constr. Build. Mater. 87 38–44
[28] Liu H, Zeidada W, Al-Khateeb G G, Shamableh A and Samarnaa M 2020 Characterization of the shear-thinning behavior of asphalt binders with consideration of yield stress Mater. Struct. 53 105
[29] Jiang X, Li P, Ding Z, Yang L and Zhao J 2019 Investigations on viscosity and flow behavior of polyphosphoric acid (PPA) modified asphalt at high temperatures Constr. Build. Mater. 228 116610
[30] Wang Y and Zhang H 2021 Influence of asphalt microstructure to its high and low temperature performance based on atomic force microscope (AFM) Constr. Build. Mater. 267 120998
[31] Lei Y, Wang H, You E H, Yang X, Gao J and Dong S G 2018 Evaluation of the effect of bio-oil on the high-temperature performance of rubber modified asphalt Constr. Build. Mater. 191 692–701
[32] Zhang K, Wang H, Gao J, You Z and Yang X 2017 High temperature performance of SBS modified bio-asphalt Constr. Build. Mater. 144 99–105