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PREPARATION OF THE COMPOSITE ASPHALT MATERIAL AND ITS PERFORMANCE IN ROAD REHABILITATION

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ABSTRACT

Asphalt materials have a very wide range of applications in roads, but with the increase of traffic pressure and the intensification of cracking and rutting in traditional asphalt pavements, there is an urgent need to further improve the performance of asphalt materials. In this paper, composite asphalt materials containing 10%, 20%, and 30% trinidad lake asphalt (TLA) and 0%, 2%, 3%, and 4% styrene-butadiene rubber (SBR) were prepared. Their basic properties and the properties of the mixes used for road rehabilitation were analyzed. It was found that the addition of TLA and SBR caused a decrease in the penetration degree of the material, but significantly increased the softening point of the material, TLA was detrimental to the ductility of the material, and SBR could improve the ductility. From the analysis of the performance of road rehabilitation mixes, the comprehensive performance of 20% TLA+3% SBR was good, its dynamic stability reached 3,712.66 times/mm, its water stability was also good, and its stiffness modulus was 3,332.64 MPa. The results prove the improvement of TLA and SBR for asphalt performance, and this method can be applied in practical projects.

KEYWORDS

Composite asphalt, Road rehabilitation, Styrene-butadiene rubber, Trinidad lake asphalt

INTRODUCTION

With the development of society, the scale of road networks has been expanded [1]. Asphalt is a very widely used material in road construction [2], with the advantages of friction resistance and levelling [3], but this material is easily softened at high temperature and rutting [4], and easily cracked at low temperature. Under the influence of increasing traffic [5], the phenomenon of cracking and depression of asphalt roads is becoming more and more serious [6], which has a great impact on the quality of roads [7]. In order to improve the performance of pavements using asphalt materials in road rehabilitation, composite asphalt materials obtained by adding modifiers to the base asphalt have received considerable attention from researchers [8]. Sembiring et al. [9] mixed asphalt with silica in a ratio of 1:2 and obtained a composite material after calcination at 200-450 °C. Their study showed that with increasing calcination temperature, the density and strength of the material were improved, and the material could be used as a roofing material. Choudhary et al. [10] added waste glass powder (GP) and glass-hydrated lime (GL) in different proportions to asphalt concrete and found that the GL and GP mixes had better rutting and fatigue resistance, the GP mix had poor adhesion, the GL mix had good moisture resistance, and the use of GL and GP could effectively reduce the material cost. Kashfi et al. [11] studied nanomaterials and styrene-butadiene rubber (SBR). They found that nanomaterials could improve the resistance of the mix, reduce the amount of wear, and improve rutting resistance, loosening, etc. One et al. [12] found that the use of portland composite cement (PCC) and Buton granular asphalt (BGA) could improve the indirect tensile strength of the mix through indoor tests and P1.5B8 and P2B8 had the best performance. This paper studied both trinidad lake asphalt (TLA) and SBR. Composite asphalt materials mixed with different

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content of TLA and SBR were designed, and their performance in road rehabilitation was analyzed to find the best preparation of the material to improve the effect of asphalt materials in engineering applications.

MATERIALS AND METHODS

Test materials

The matrix asphalt used in the study was 70# asphalt (Qingzhou Xintong Asphalt Technology Co., Ltd., China), and its basic properties are shown in Table 1.

Tab. 1 - Basic properties of matrix asphalt

Technical specifications	JTGF40-2004 specification requirements	Actual measurement results
Penetration degree (25 °C, 5 s, 100 g)/0.1 mm	60-80	68.41
Penetration index (PI)	-1.5-1.0	-1.46
Softening point/°C	≥ 46	48.12
Rotational viscosity (135 °C)/(mPa·s)	< 3000	421
Density (15 °C)/(g/cm^3)	Actual measurement	1.037
Ductility (10 °C, 5 cm/min)/cm	≥ 15	36.37
Ductility (15 °C, 5 cm/min)/cm	≥ 100	> 100
Penetration ratio/%	≥ 61	63.4

TLA is a natural asphalt with a long history [13], which has excellent resistance to oxidation, acid, and alkali compared with conventional asphalt [14]. The mixture of TLA and asphalt can effectively improve the performance [15]. The TLA used in the study was from Gangfeng Global Group Limited, and its basic properties are shown in Table 2.

Tab. 2 - Basic properties of TLA

Technical specifications	JT/T860.5-2014 specification requirements	Actual measurement results
Penetration degree (25 °C, 5 s, 100 g)/0.1 mm	0-5	2.5
Softening point/°C	≥ 90	97.3
Ash content/%	33-38	36.1
Density (25 °C)/(g/cm^3)	1.3-1.5	1.43
Residual penetration ratio/%	≥ 50	96

The current study shows that TLA has slightly poor performance at low temperatures. In order to improve the performance of composite asphalt materials at low temperatures, SBR is added to it for modification. SBR has excellent anti-aging and anti-friction properties [16], which has good effect on improving the crack resistance at low temperatures. The SBR used in the study was from Jinan Yuanbolai Chemical Technology Co., Ltd. and its basic properties are shown in Table 3.

Tab. 3 - Basic properties of SBR

Technical specifications	Actual measurement results
Ash content/%	≤ 0.5
Organic acid/%	4.50-6.75
Bound styrene/%	22.5-24.5
Raw rubber Menny viscosity ML(1+4)100 °C	44-56
300% tensile stress at a given elongation (MPa) 145 °C, 35 min	20.6 ± 2.5
Tensile strength (145 °C × 35 min), MPa	≥ 24.5

The coarse and fine aggregates used in the study were basalt (Shijiazhuang Deze Mineral Products Co., Ltd., China), and the filler was mineral powder (Foshan Sanshui District Jiachangyuan Building Materials Business Department, China). Their basic properties are shown in Table 4.

Tab. 4 - Basic properties of aggregates and fillers

Technical specifications		JTGE42-2005 specification requirements	Actual measurement results
Coarse aggregate	Crushing value/%	≤ 26	13.3
	Apparent relative density/(g/cm^3)	≥ 2.6	2.73
	Water absorption/%	≤ 2	0.78
	The content of elongated and flaky particles/%	≤ 15	7.68
	< 0.075 mm particle content/%	≤ 1	0.4
	Los Angeles wear value/%	≤ 28	11.7
Fine aggregate	Apparent relative density/(g/cm^3)	≥ 2.5	2.87
	Silt content/%	≤ 3	1.32
	Methylene blue value/(g/kg)	≤ 25	23
Filler	Apparent density/(t/m^3)	≥ 2.5	2.58
	Water content/%	≤ 1	0.42
	Hydrophilic coefficient	< 1	0.65
	Plasticity index	< 4	2.2

Composite asphalt material preparation

Since TLA is easier to melt with the matrix asphalt and SBR is more difficult to melt, the following steps are used to prepare the composite asphalt material.

(1) The matrix asphalt was preheated to 160 °C in an oven, and the TLA was preheated to 180 °C to make them in a flowing state.
(2) SBR was added to the matrix asphalt and stirred in a stirrer at a speed of 1,000 r/min for ten minutes.
(3) The temperature was maintained for ten minutes to allow the SBR to develop and swell.
(4) After raising the temperature to 155 °C, TLA was added to the mixture and sheared using a high-speed shear apparatus at a speed of 5000 r/min for one hour.
(5) The temperature was maintained, and the mixture was stirred under 155 °C at a speed of 1000 r/min for ten minutes.
(6) The preparation was completed.

Referring to the existing research results [17], the mixing proportion of TLA was set as 10%-30%, and the mixing proportion of SBR should not be too high because it is not easy to melt with the matrix asphalt, so the mixing proportion was set as 0%, 2%, 3% and 4%. The preparation scheme of the composite asphalt material is shown in Table 5.

Tab. 5 - Composite asphalt material preparation schemes

Preparation scheme	TLA mixing proportion/%	SBR mixing proportion/%
1	0%	0%
2	10%	0%
3	10%	2%
4	10%	3%
5	10%	4%
6	20%	0%
7	20%	2%
8	20%	3%
9	20%	4%
10	30%	0%
11	30%	2%
12	30%	3%
13	30%	4%

Basic property analysis of composite asphalt materials

According to JTGE20-2011, the following basic properties of composite asphalt materials were analyzed.

(1) Penetration degree/0.1 mm: it reflects the consistency of the material, measured at 25 °C in this paper.

(2) Softening point/°C: it reflects the viscosity of the material as well as its high temperature stability.

(3) Ductility/cm: it reflects the plasticity of the material, measured at 10 °C in this paper.

Composite asphalt mix preparation

According to the existing engineering experience, the test used continuous gradation AC-13, and the best oil to stone ratio was set at 5%. The mixture preparation process is as follows.

The aggregates were well mixed, placed in an oven, and heated for 4-6 hours.

The composite asphalt material was melted and set aside.

The mixing sequence was: aggregate + asphalt → mineral powder, and the mixing was performed in a mixing pot.

Road rehabilitation performance analysis

(1) High temperature stability

Asphalt pavements are prone to deformation in high temperature environments. High-temperature stability refers to the ability of the mixture to resist plastic deformation under the combined effect of wheel load and temperature. The rutting test [18] was conducted to analyze the high-temperature stability of the composite asphalt mixture in road rehabilitation. The size of the test specimen was 30 × 30 × 5 cm, and the temperature was set as 60 °C. The specific steps are shown below.

① The rutting plate was kept at a constant temperature of 60 °C for five hours.
② The specimen was fixed in the center of the rutting meter, and the device door was closed.
③ The rutting meter was turned on to start the test.

The dynamic stability of the specimen (times/mm) is:

$$DS = \frac{N\times(t_2-t_1)}{d_2-d_1}\times C_1\times C_2, \tag{1}$$

where:

N: the walking speed of the wheel, 42 times/min,
t_1: 45 min,
t_2: 60 min,
d_1: rutting depth at time t_1,
d_2: rutting depth at time t_2,
C_1: the correction factor for tester type, whose value was 1 when the crank connecting rod drives the loading wheel to do round-trip operations,
C_2: the coefficient of the test specimen, whose value was 1 when the specimen with a width of 30 cm is prepared in the laboratory.

(2) Water stability

When water enters the mix, it affects the bond between the asphalt and the mineral aggregate, resulting in structural damage to the mix. Water stability refers to the bond between the asphalt and the mineral aggregate. The analysis of water stability consisted of two tests.

The first test was the water immersion Marshall test [19].

① Two groups of standard Marshall specimens were prepared. The specimen had a diameter of 101.6 mm ± 0.2 mm and a height of 63.5 mm ± 1.3 mm. There were eight specimens, and they were divided into two groups, four each group.

② The first group was placed in a constant temperature water bath at 60 °C for 30-40 min. The upper and lower squeeze heads of the Marshall tester were also put into the bath and dried after being taken out. The specimen was put above the lower squeeze head and covered by the upper squeeze head. The Marshall stability was measured.

③ The second group adopted the same method, but the constant temperature water bath was extended to 48 h. Then, the Marshall stability was measured.

④ The residual stability was calculated:

$$MS_0 = \frac{MS_2}{MS_1} \times 100\%, \tag{2}$$

where:
MS_1: 30-40 min stability,
MS_2: 48 hours stability.

The second test was the freeze-thaw splitting test [20].

① Two groups of Marshall specimens were prepared by 50 times of double-sided compaction.

② The first group was placed in a water bath for two hours at 20 °C, and maximum damage load P_{T1} was measured.

③ The second group was placed in a water bath for 30 min under vacuum conditions, and after a freeze-thaw cycle, maximum damage load P_{T2} was measured.

④ The splitting tensile strength of the two groups of specimens was calculated:

$$R_{T1} = \frac{0.006287 P_{T1}}{h_1}, \tag{3}$$

$$R_{T2} = \frac{0.006287 P_{T2}}{h_2}, \tag{4}$$

where:
h_1: the height of the specimen in the first group,
h_2: the height of the specimen in the second group.

⑤ The residual intensity was calculated:

$$TSR = \frac{R_{T2}}{R_{T1}}. \tag{5}$$

(3) Low-temperature crack resistance

In low-temperature environments, asphalt pavements tend to harden and crack easily under load. Low temperature crack resistance refers to the crack resistance of the mixture in low temperature environment. The low-temperature crack resistance of composite asphalt mixtures in road rehabilitation was analyzed by means of a small beam bending test [21] using specimens with a size of 250 × 30 × 35 mm, as follows.

① The specimen was placed at a constant temperature of -10 °C for more than three hours.
② The specimen was fixed by a bending fixture.
③ Open the testing machine and keep applying the load until the specimen is destroyed.

The flexural-tensile strength when the specimen is damaged is:

$$R_B = \frac{3\times L\times P}{2\times b\times h^2}. \tag{6}$$

The maximum flexural-tensile strain is:

$$\varepsilon_B = \frac{6\times h\times d}{L^2}. \tag{7}$$

The flexural-tensile stiffness modulus is:

$$S_B = \frac{R_B}{\varepsilon_B}. \tag{8}$$

In the above equations, L is the span of the specimen, P is the maximum load when the specimen is damaged, b is the width of the midspan cross-sectional specimen, h is the height of the midspan cross-sectional specimen, and d is the midspan deflection of the specimen at the time of damage.

ANALYSIS OF RESULTS

The penetration degree (25°C) of the composite asphalt materials prepared by different schemes is shown in Figure 1.

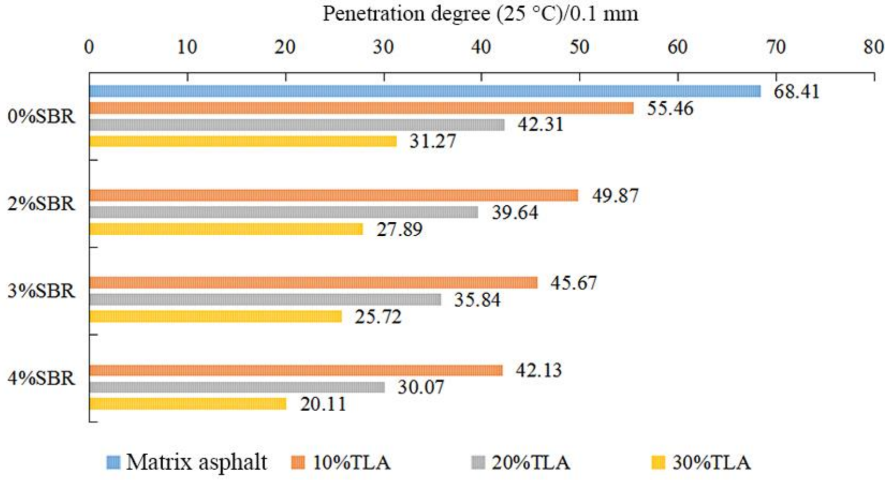

Fig. 1 – Penetration degree analysis

From Figure 1, the degree of penetration of the matrix asphalt was 68.41/0.1 mm at 25 °C. Without the addition of SBR (0% SBR), the penetration degree decreased continuously with the increase of TLA mixing proportion, and the penetration degree of 10% TLA, 20% TLA, and 30% TLA decreased by 12.95/0.1 mm, 26.1/0.1 mm, and 37.14/0.1 mm, respectively, compared to the matrix asphalt.

When the mixing proportion of TLA was fixed, the addition of SBR also decreased the penetration degree, but the decrease was small. For example, in the case of 10% TLA, the penetration degree was 49.87/0.1 mm after the addition of 2% SBR, which was 5.59/0.1 mm lower than that of 0% SBR; after the addition of 3% SBR, the penetration degree was 9.79/0.1 mm lower than that of 0% SBR; after the addition of 4%, the penetration degree was 13.36/0.1 mm lower than that of 0% SBR. The comparison between TLA and SBR showed that the effect of TLA on the penetration degree of the material was greater.

A comparison of the softening points of the composite asphalt materials prepared by different schemes is shown in Figure 2.

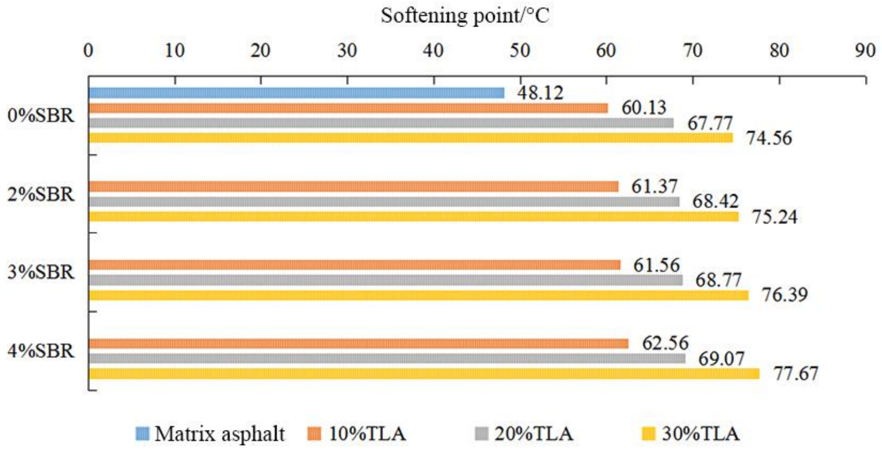

Fig. 2 – Softening point analysis

From Figure 2, the softening point of the matrix asphalt was the lowest, 48.12 °C, indicating that the quality of the matrix asphalt was easily affected under high temperature conditions. After the addition of TLA and SBR, the softening point of the material showed a significant increase. First, in the absence of SBR addition (0% SBR), the softening point of the material added with 10% TLA was 60.13 °C, which was 12.01 °C higher than the matrix asphalt, and the softening points of the materials added with 20% TLA and 30% TLA were 19.65 °C and 26.44 °C higher than the matrix asphalt, respectively, proving the effectiveness of TLA in improving the high temperature performance of the material.

When the mixing proportion of TLA was fixed, the addition of SBR further improved the softening point of the material. For example, when the mixing proportion of TLA was fixed at 10%, the addition of 2%, 3%, and 4% SBR resulted in an increase in softening point of 1.24 °C, 1.43 °C, and 2.43 °C, respectively, compared to 0% SBR, demonstrating the improved high temperature stability of the material with the combined effect of TLA and SBR.

The ductility (10 °C) of the composite asphalt material prepared by different schemes is shown in Figure 3.

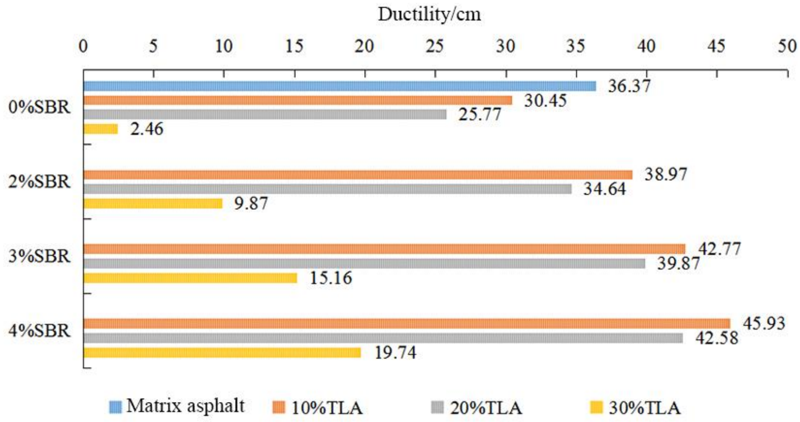

Fig. 3 – Ductility analysis

From Figure 3, the ductility of the matrix asphalt was 36.37 cm, and there was a significant decrease in the ductility of the material from 10% TLA, 20% TLA to 30% TLA. Without the addition of SBR (0% SBR), the ductility of the material added with 10% TLA, 20% TLA, and 30% TLA were 30.45 cm, 25.77 cm, and 2.46 cm, respectively, which was 16.28%, 29.14%, and 93.24% lower than that of the matrix asphalt, indicating that the addition of TLA resulted in a decrease in the ductility of the material under low temperature conditions, i.e., the material was more easily broken, which was detrimental to its use in road rehabilitation.

When the mixing proportion of TLA was fixed, SBR had an improving effect on the material ductility. Taking 10% TLA as an example, the ductility of the material increased by 27.98%, 40.46%, and 50.84% after adding 2% SBR, 3% SBR, and 4% SBR. Therefore, in actual use, if the content of TLA was high, the content of SBR should also be high to improve the ductility of the material.

Based on the above analysis of the performance of composite asphalt materials prepared by different schemes, only the following schemes were compared in the mix performance analysis.

① 10% TLA+2% SBR

② 10% TLA+3% SBR

③ 20% TLA+2% SBR

④ 20% TLA+3% SBR

The analysis of the dynamic stability of the different mixes when applied to road rehabilitation is shown in Figure 4.

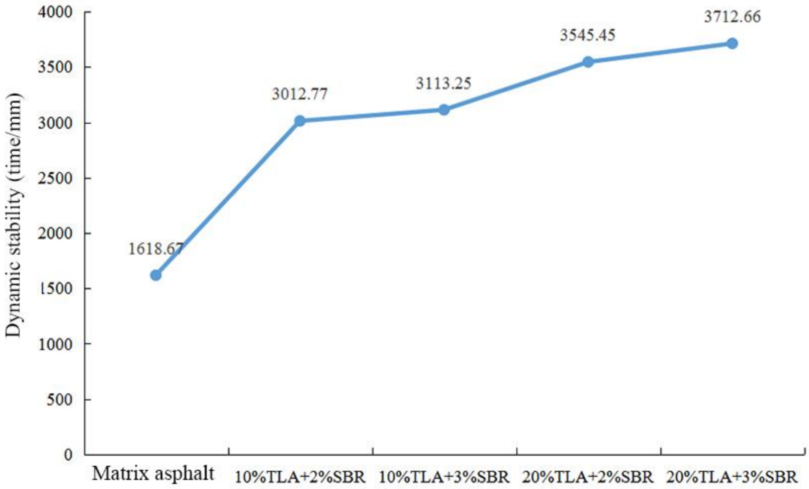

Fig. 4 – Dynamic stability analysis

From Figure 4, the dynamic stability of the matrix asphalt was the worst, 1,611.25 times/mm, while the dynamic stability of the mixes was sufficiently improved after the addition of TLA and SBR. Compared to the matrix asphalt, the dynamic stability of the 10% TLA+2% SBR mix was improved by 86.13%, and the 10% TLA+2% SBR mix was improved by 92.33%. The comparison between 10%TLA+2%SBR and 10%TLA+2%SBR showed that the amplitude of increase in dynamic stability was small. The dynamic stability was further improved in the material added with 20%TLA+2%SBR, which was doubled compared to the matrix asphalt. Similarly, the increase amplitude of the dynamic stability of 20%TLA+3%SBR was also not large. The results showed that the addition of TLA could significantly improve the dynamic stability of the mix and the effect of SBR was relatively small.

When applied to road rehabilitation, the water stability analysis of different mixes is shown in Figure 5.

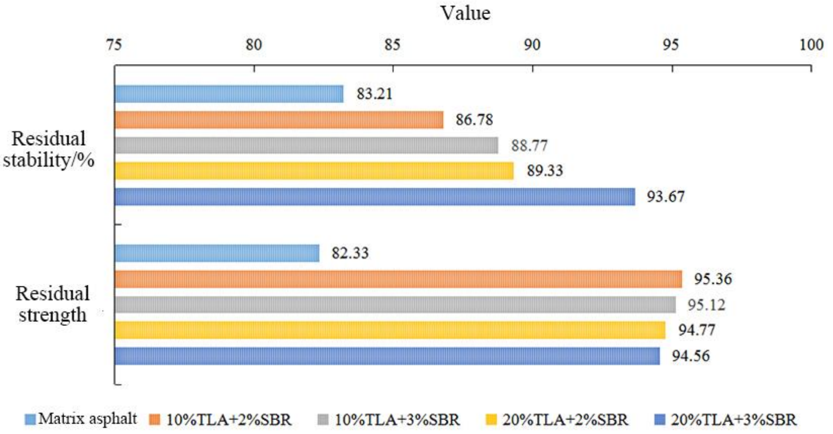

Fig. 5 – Water stability analysis

According to Figure 5, first, in terms of residual stability, the matrix asphalt was the lowest, 83.21%, and the addition of both TLA and SBR improved the residual stability of the mixes. Compared to the matrix asphalt, the four mixes improved by 3.57%, 5.56%, 6.12%, and 10.46%, respectively. In the mixes after the addition of TLA and SBR, the adhesion between asphalt and aggregate was improved, which strengthened the water stability of the mixes.

Then, in terms of residual strength, the value of the matrix asphalt was 82.33, and after the addition of TLA and SBR, the residual strength of the mixes all reached above 90. In comparison, the residual strength of 10% TLA + 2% SBR had the highest value, 95.36, while the residual strength of the remaining three mixes decreased slightly, but were still significantly better than the matrix asphalt, indicating that the composite asphalt material could effectively improve the splitting strength of the mixes in road rehabilitation.

Finally, a comparison of the low-temperature crack resistance of different mixes when applied to road rehabilitation is shown in Figure 6.

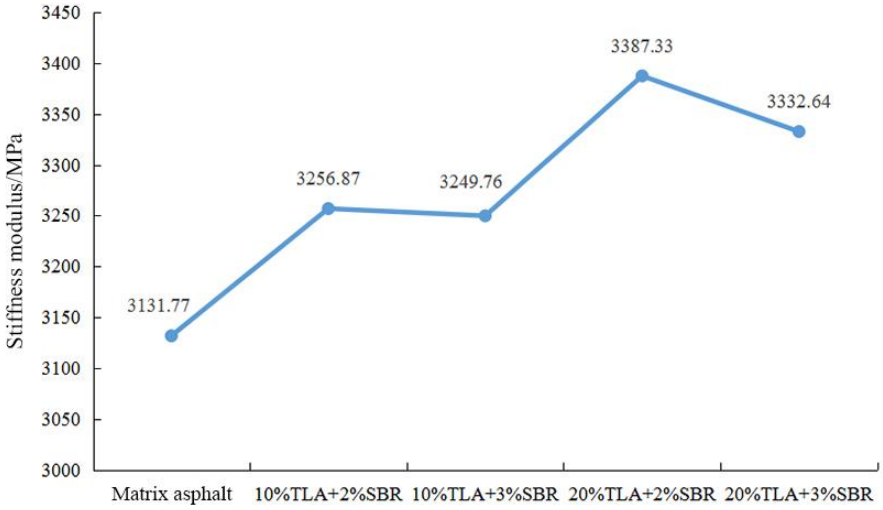

Fig. 6 – Low-temperature crack resistance analysis

From Figure 6, the stiffness modulus of the matrix asphalt was 3,131.77 MPa, and the stiffness modulus of the mix was greatly increased after the addition of TLA and SBR. In comparison, the stiffness modulus of the mix containing 20% TLA was higher than that of the mix containing 10% TLA, while the stiffness modulus of the mix containing 3% SBR was slightly lower than that of the mix containing 2% SBR. Under low-temperature conditions, the addition of TLA made the mix stiffer and brittle, while the addition of SBR improved the deformation capacity of the mix to some extent, which is consistent with the performance analysis of composite asphalt materials.

The comprehensive results showed that the asphalt prepared with 20% TLA and 3% SBR had good performance in all properties, so the mix prepared by this scheme can be used in the actual road rehabilitation.

CONCLUSION

In this paper, TLA and SBR were used to optimize the performance of asphalt materials. The composite asphalt materials were prepared by different schemes, and their basic properties and performance in road rehabilitation were analyzed. The results showed that increasing the mixing proportion of TLA and SBR could reduce the penetration degree, and the effect of TLA on the penetration degree was greater. After the addition of TLA and SBR, the softening point and ductility of the materials were improved. From the perspective of the performance in road rehabilitation, the dynamic stability of 20% TLA+3% SBR was 3,712.66 times/mm, the residual stability was 93.67%, the residual strength reached 95.56, and the stiffness modulus was 3,332.64 MPa, all of which were significantly improved compared with the matrix asphalt, so it can be applied in practical engineering.

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