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The Law of Performance in BRA Modified Asphalt

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Abstract: Budun Rock Asphalt (BRA) is used to modify the neat asphalt binder in this study. To investigate the effectiveness of the underlying modifier, comprehensive experiments are conducted with a variety of blending ratios between the modifier and neat binder. These laboratory tests mainly include fundamental properties of binders, such as physical characteristics and workability. Furthermore, performance-based tests of asphalt mixture are highlighted in the study and show that the overall performance of an asphalt mixture containing BRA modifier increases with the increase of the modifier percentage/dosage to certain level. When the dosage of natural BRA reaches approximately 45%, the optimal performance, in terms of rutting and water resistance capability and low-temperature properties, can be achieved. In addition, by comparison, a cost study is conducted, which indicates that the BRA modified asphalt is significantly more economic than its counterparts, such as Styrene-Butadiene-Styrene (SBS) modified asphalt.

***Key words**: Asphalt mixture performance; Blending ratio; Budun rock asphalt, Modified asphalt.*

Introduction

In China, asphalt is commonly used on nearly 90% of highway pavements. The asphalt pavement industry is actively looking for bituminous materials that are cost effective and perform well. One of the new materials, Budun Rock Asphalt (BRA), is in the early stages of application in asphalt pavement in China. However, demand for BRA has increased in recent years. [1-2]

The natural BRA originates from natural asphalt rock on Budun Island in Indonesia. It is a bacteria-generated bituminous substance, which came from oil deposited in the rocks over many years and experienced physical and chemical changes under heat, pressure, oxidation catalysts, and bacterium. BRA is supplied in a mixture of asphalt and rock in the form of aggregates of varying sizes. The BRA modifier contains approximately 20% asphalt by weight. It has been found that, as a petroleum asphalt modifier, the BRA modifier shows some desirable characteristics that can improve pavement performance. Overall, it has been preliminarily reported that the major characteristics of the BRA include the following: [3-4]

(1) It contains high nitrogen content, which can greatly improve the adhesion between asphalt and aggregate and its anti-stripping capacity.
(2) It can improve the durability of asphalt pavement by slowing down the asphalt aging process.
(3) It does not contain wax and can improve the capacity of low-temperature cracking of asphalt pavement.
(4) The modification process with BRA modifier is simple and does not require additional equipment.
(5) It has good compatibility with petroleum asphalt.
(6) The production temperature of asphalt mixture with BRA modifier can be 10°C lower than that with SBS modifier, which reduces energy consumption.

In 2003, for the first time, a 2-km BRA test road was built on Xuan-da highway in Hebei of China [2]. In recent years, research projects have studied the BRA asphalt modification mechanism and how BRA influences asphalt concrete’s physical and chemical properties, its mixture design, and its performance related to rutting, low temperature, and moisture [2-4]. The results showed that the BRA modified asphalt mixture exhibited higher anti-rutting capacity at high temperatures, better crack resistance at low temperatures, and improved resistance to water damage.

Currently, the use of BRA as a modifier for pavement application in China is still in the research and evaluation phase. Although improved asphalt mixture properties have been observed, more research is needed to study the BRA material and evaluate its effects on pavement performance in the laboratory and in the field.

The objectives of this research were to (1) study the properties of BRA modified asphalt and how they influence asphalt mixture performance, focusing on the high-temperature stability and resistance to moisture damage; and (2) evaluate the cost effectiveness of using BRA for highway application, as compared to the costs of conventional modifiers [5-16].

To accomplish at these two objectives, this paper is organized as follows. The second section describes the study of the performance of asphalt binder modified by BRA with different dosages. The third section investigates asphalt mixture performance containing BRA as the modifier. The fourth section conducts a cost analysis to compare economic efficiency between using BRA and other conventional modifiers. Major conclusions are presented in the last section of the paper.

Testing and Performance of BRA Modified Asphalt Binder

Asphalt Materials Used in the Study

To establish a reference, a neat or unmodified binder is first selected, referred to as Class A, Grade No.7, or AH-70, according to Chinese Highway Specification. The AH-70 binder is commonly used for

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Table 1. Test Results of AH-70 Binder and Specification Limits.

Item		Specification Requirements	Test Results
Penetration (25°C, 5s ,100g)(0.1mm)		60-80	65
Ductility (15°C, 5cm/min)(cm)		≥ 100	> 100
Softening Point (°C) (Ring and Ball Apparatus)		≥ 46	52
Open Flash Point (°C)		≥ 260	356
Wax Content (Distillation Method) (%)		≤ 2.2	1.74
Density (25°C)(g/cm^3)		Test Record	1.022
Solubility (Trichloroethylene)%		≥ 99.5	99.6
RTFOT-Residue	Mass loss	≤ ±0.8%	0.02
	Penetration Ratio	≥ 61%	71.2
	Ductility(15°C) (cm)	≥ 15	> 100

Table 2. Test Results for BRA Modifier and Specifications Limits.

Items	Asphalt Content	Mineral Content	Maximum Particle Size of Minerals	Water Content
Requirements	≥ 25%	≤ 75%	≤ 1.18mm	＜1%
Test Results	27%	73%	0.6	0.3%

pavements subjected to heavy traffic in China. Standard tests are performed to obtain the basic properties of this reference binder (Table 1). In addition, properties of the BRA are tested according to the Special Specification for BRA (Table 2). Test results show that both the neat binder and modifier meet the requirements of the specification. No other property specifications are required for BRA in China at this time.

Specimen Preparation

The specimen preparation process for BRA modified asphalt is described in the following steps: [17]

1. Heat the neat binder, AH-70, to 150°C.
2. Add BRA to the heated neat binder (BRA content is the ratio of BRA modifier to neat binder by weight).
3. Mix the mixtures for 25 to 30 minutes at 145°C-155°C with the highest temperature lower than 160°C (instantaneous temperature), until BRA modifier is evenly dispersed in asphalt.
4. Store the BRA modified asphalt in an oven for 15 to 30 minutes at a temperature of 150°C for testing.

In order to obtain the optimal content of the BRA modifier, a series of BRA modifier dosages are used in the study, which ranges from 0 to 50% of the neat binder, as shown in the first column in Tables 3a and 3b. In addition, according to the experimental results in Table 2, BRA modifier contains 27% of asphalt binder. The actual binder contents extracted from the BRA modifier (not including the sands in BRA mixture), expressed as percentages of the neat asphalt by weight, are shown in the second column in Table 3a and 3b. To simplify the tables, the testing results are shown in Table 3a for penetration test, and 3b for softening point, ductility, and rolling thin film oven test **(**RTFOT) residue penetration tests. These properties are also depicted in Fig. 1 showing the trends of property changes with increasing BRA contents.

For comparison purpose, the Chinese technical requirements for No. 30 asphalt binder and SBS modified asphalt binder are also provided in these tables. These specification limits are listed for reference only since no specification requirements are currently available for BRA modified asphalt binder.

Based on the test results in the tables and the figure, the following observations were derived:

Table 3a. Penetration Test Results for BRA Modified Asphalt.

BRA Content (%)	BRA Pure Natural Bitumen (%)	Penetration (0.1 mm)			Penetration Index
		15°C	25°C	30°C	
0		24.5	65.5	132	-1.15
15	4.77	21	57.9	101.6	-0.69
20	6.75	20.6	53.9	96.6	-0.669
25	9.0	20	51.1	93	-0.625
30	11.57	19.6	49.3	89.9	-0.552
35	14.54	18	48.2	81	-0.536
40	18.0	17.6	44.9	75.6	-0.322
45	22.09	17.2	43.2	70.3	-0.115
50	27.00	16.9	42.5	64.2	0.205
No. 30 Asphalt Technical Requirements			20-40		-1.5-1.0
SBS Modified Asphalt Technical Requirements			30-60		≥ 0
5% SBS Modified Asphalt Test Result			45		0.9

Note: The values in the second column represent the contents of the asphalt binder extracted from the BRA, as percentages of neat asphalt by weight. For example, for a BRA of 45%, the value in the second column is calculated as 45%×27% ÷ (100% - 45%) = 22.09%.

Table 3b. Asphalt Index Test Results for BRA Modified Asphalt.

BRA Content (%)		Softening Point (°C)	(5cm/min,15°C) Ductility (cm)	RTFOT-Residue 25°C Penetration Ratio (%)
0	BRA Pure Asphalt (%)	52	106	
15	4.77	53.3	50.6	69.3
20	6.75	54.4	30.2	67.9
25	9.0	55.7	26.3	66.7
30	11.57	58.4	24.9	65.9
35	14.54	60.3	23.1	65.3
40	18.0	61.9	19.6	65.0
45	22.09	63.1	14.9	64.8
50	27.00	64.8	11.3	64.5
No.30 Asphalt Technical Requirements		≥ 55	≥ 50	≥ 65
SBS Modified Asphalt Technical Requirements		≥ 60	5°C Ductility ≥ 20	≥ 65
5% SBS Modified Asphalt Test Result		66	16.3	71

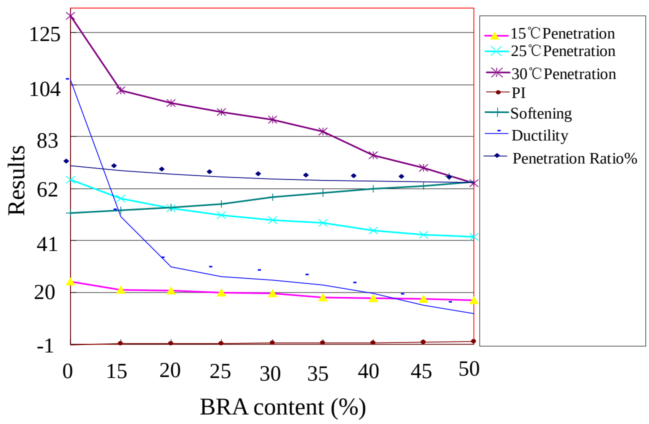

Fig. 1. The Relationship between BRA Content and Binder Performance.

Table 4. The Aggregate Gradation in BRA Modifier.

Sieve Size, mm	1.18	0.60	0.30	0.15	0.075
Passing percentage (%)	100	98.71	95.29	70.84	48.12

Note: BRA modifier processed into tiny granule.

Table 5. Bulk Density and Apparent Density of Limestone Aggregate.

Materials	Bulk Density(g/cm^3)	Apparent Density(g/cm^3)
J1(9.5-16mm)	2.692	2.722
J2(4.75-9.5mm)	2.678	2.719
J3(0-4.75mm)	-	2.657
J4 (River Sand)	-	2.602
J5(Mineral Powder)	-	2.673

(1) With increasing BRA modifier content, the penetration decreases and softening point increases, indicating that the addition of BRA modifier can increase the stiffness of the asphalt binder, and thus increases its resistance to deformation. It implies that the asphalt modified by the BRA can improve the performance of asphalt at high temperatures.

(2) With increasing BRA modifier content, the **penetration index** (PI) value gradually increases, which indicates that BRA modifier can make the modified asphalt less temperature susceptible. The PI value changes significantly when BRA content varies between 35% and 40%, indicating that the range between 35% and 40% can be the most effective for BRA content dosage.

(3) When BRA modifier content is 0-20%, its ductility at 15°C decreases rapidly. When BRA modifier content is 20-50%, it declines slowly, mainly because of a certain amount of ash contained in BRA. Low temperature bending tests were conducted to assess if the BRA will reduce the low temperature performance. In RTFOT test, the value of penetration ratio at 25°C is between 69.3 and 64.5, indicating that BRA modifier can improve the anti-aging property of the asphalt binder.

(4) Compared with the Chinese Specification for No. 30 asphalt and SBS modified asphalt, results show that some of test results of the BRA modified asphalt do not fall into the ranges in the specification. Particularly, the ductility is relatively low for BRA modified asphalt.

Testing and Performance of BRA Modified Asphalt Concrete Mixture

Materials and Preparation of the Mixture

The neat asphalt binder used in the test is Class A, No.70 Maoming Road oil bitumen, with various quantities of BRA modifier. The ratio of the BRA modifier to the neat binder is as follows: 0:100, 15:85, 25:75, 35:65, 40:60, 45:55, 50:50, 55:45, 60:40, 80:20. First, the aggregate gradation and mixture performance are tested to determine the optimal binder content, using only neat asphalt, i.e., BRA: neat asphalt = 0:100. When the BRA is added to asphalt, the mineral powder in the Budun rock should be accounted for in the mixture design gradation because there is about 73% mineral powder in the rock. The mineral powder gradation in the Budun rock is presented in Table 4.

The aggregate used in this study is limestone from Maolin Township in Yulin City and mineral powder is from Yan Guan of Xing'an County in Guilin City, China. The properties and gradation of the aggregates are displayed in Tables 5 and 6.

To facilitate the comparison of the test results, the aggregate

Table 6. Physical Characteristics of Coarse Limestone Aggregate.

Indexes	Test Value	Specification
Crushed Value, %	20.9	≤ 26
Los Angeles Abrasion Value, %	25.8	≤ 28
Adhesion with Asphalt, Level	5	≤ 5
Elongate-flat Particle, %	13	≤ 15

Table 7. Aggregate Gradation Used in the Mixture.

Sieve Size (mm)	AC-16C Passing Percentage(%)	
	Synthetic	Specification
16	100	90-100
13.2	85.8	76-92
9.5	65	60-80
4.75	38	34-62
2.36	26.5	20-48
1.18	20.2	13-36
0.6	14.5	9-26
0.3	10	7-18
0.15	8.1	5-14
0.075	6.0	4-8

Note: BRA is not included

Table 8. Asphalt Mixture Marshall Test Results.

Type	Oil-stone Ratio (%)	Void (4-6%)	Saturation (65-75%)	Stability (>8 kN)	Flow Value (1.5-4.0 mm)
AC-16C	3.5	5.02	59.66	20.63	2.27
	4.0	4.36	66.19	14.40	3.19
	4.5	3.43	73.83	13.99	2.56

Table 9. Asphalt Mixture Marshall Immersion Test Results.

Type	Oil Stone Ratio (%)	Void (4-6%)	Saturation (65-75%)	Residual Stability (>80%)	Freeze-thaw Splitting Strength Ratio (%)
AC-16C	4.13	4.0	67.89	90.6	84.8

Table 10a. Rutting Test Results.

Specimen	Dynamic Stability (Times/mm)	
	Single	Average
AC-16C-1#	1,755	1,716
AC-16C-2#	1,690	
AC-16C-3#	1,703	

Table 10b. Low Temperature Crack Resistance Performance.

<table>
<tr><th rowspan="3">Specimen</th><th colspan="2">Failure Strain (με)</th><th colspan="3">Standard Requirement</th></tr>
<tr><th rowspan="2">Single</th><th rowspan="2">Average</th><th colspan="3">Years Extreme Low Temperature (°C)</th></tr>
<tr><th>＜-37.0</th><th>-21.5/-37.0</th><th>＞-21.5</th></tr>
<tr><td>AC-16C-1#</td><td>2,170</td><td rowspan="3">2,142</td><td rowspan="3">≥ 2,600 με</td><td rowspan="3">≥ 2,300 με</td><td rowspan="3">≥ 2,000 με</td></tr>
<tr><td>AC-16C-2#</td><td>2,095</td></tr>
<tr><td>AC-16C-3#</td><td>2,161</td></tr>
</table>

1. Size:（30×35×250）mm; Test Method: T0728;
2. Test Temperature: -10°C; Loading Speed: 50mm/min;
3. Strain Meets the Requirement of 2,300 με for Cold Area.

gradation for all mixtures with different BRA content are kept the same. This means that the gradation of the raw aggregate needed to be adjusted for each individual asphalt concrete mixture with different BRA content. The target gradation of the mixture is AC16-C according to the Chinese specification, as shown in Table 7.

Asphalt Mixture Design

Optimal asphalt content is determined using the Marshall test, according to the Chinese JTJ052-2000 test procedure. Test results are shown in Table 8. In the mix design, the minimum and maximum optimal oil-stone ratios are 3.9% and 4.2%, respectively. When the oil-stone ratio is 4.2%, the air void of asphalt mixture is 4%, as expected. So, an average oil-stone ratio of 4.13% is adopted as the optimal asphalt content.

Furthermore, the moisture stability test is conducted to ensure that the mix design meets the Chinese specification. In the moisture stability test, also referred to as immersion Marshall Test, the specimen with optimal asphalt content is tested to evaluate the residual stability and freeze-thaw splitting strength. The relevant parameters and test results are shown in Table 9.

Table 9 indicates that the residual Marshall Stability of the asphalt mixture with optimal asphalt is greater than 80%, and that the freeze-thaw splitting strength ratio is greater than 75%, which both meet the specification requirements.

Also, the Chinese specification requires that the asphalt mixture should meet the minimum high-temperature stability requirement. According to the Test Method of Asphalt and Asphalt Mixture for Highway Engineering (JTJ052-2000), rutting tests are performed to evaluate the high temperature stability based on dynamic stability index. The specimen molding and testing configurations are listed in the following: specimen mold size, 300×300×50 mm; testing contact pressure, 0.7±0.05 MPa; wheel rolling speed, 42±1 times/minute (one-way), testing temperature 60°C. The rutting test results are shown in Table 10a.

As shown in Table 10a, dynamic stability values are more than 1,000 times per millimeter, which meets the design specification requirement.

In order to test low temperature crack resistance of the asphalt mixture, in accordance with the highway engineering asphalt and asphalt mixture test specification (JTJ 052-2000), the low temperature bending test is carried out. The results are shown in Table 10b.

Testing and Analysis of BRA Modified Asphalt Concrete Mixture

In order to evaluate the effect of BRA modifier on the performance of the mixture, the moisture, low temperature crack resistance, and high-temperature stability are investigated for the mixtures with varying BRA and SBS modified asphalt contents. It should be noted that in Southern China, where a warm climate prevails all year long, the moisture and high-temperature performance is of critical importance, while low temperature performance (such as cracking) is not a concern. The test results on immersion Marshall residual stability, freeze-thaw splitting strength ratio, and dynamic stability

Table 11. Mixture Performance with Varying BRA Dosages and SBS Modified Asphalt.

BRA : Asphalt	Immersion Marshall Residual Stability (%)	Freeze-thaw Splitting Strength Ratio (%)	Dynamic Stability (Times/mm)	Low Temperature Bending Testing Failure Strain (με)
80:20	93.8	99.3	4,069	-
60:40	90.1	98.8	3,508	-
55:45	95.1	99.4	3,862	2,701
50:50	95.3	99.1	4,505	-
45:55	98.1	98.0	4,666	2,802
40:60	97.3	98.2	4,639	2,729
35:65	96.8	96.2	4,019	-
25:75	96.5	95.1	2,798	2,393
15:85	90.2	93.9	2,391	-
0:100	83.6	81.6	1,716	2,142
5% SBS Modified Asphalt	97.8	96.0	4,619	3,112

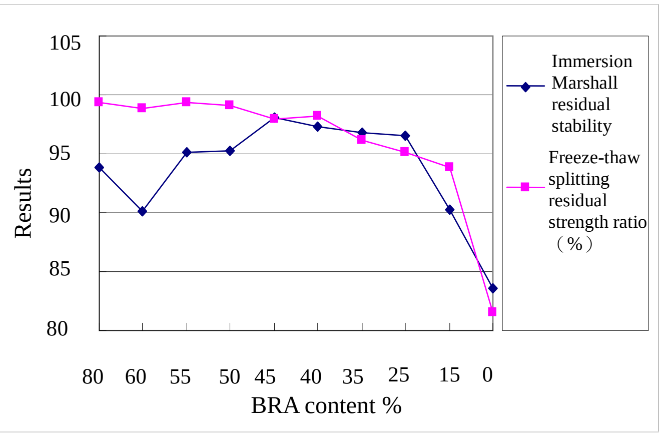

Fig. 2a. Relationship between BRA Dosage and Moisture Stability.

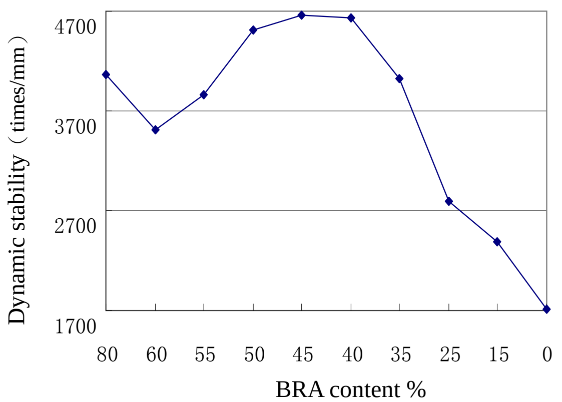

Fig. 2b. Relationship between BRA Dosage and High-temperature Stability.

are exhibited in Table 11 for all the asphalt concrete mixtures with different BRA contents. To facilitate analysis, the relationship between BRA dosage and mixture performance is illustrated in Fig. 2.

From Table 11 and Fig. 2, the following observations are made:

1) Compared with mixture without BRA modifier, BRA modified asphalt mixture demonstrates better moisture stability. The immersion Marshall residual stability ratio is more than 90%, which meets the requirement of the specifications for wet areas in China. When BRA modifier content reaches 25%, the immersion Marshall residual stability ratio improves by 25%, and freeze-thaw splitting strength ratio increases 16.6% more than the mixture without BRA modification. When BRA modifier content is between 25% and 45%, the immersion Marshall residual stability ratio reaches its highest range between 96.5% and 98.1%.
2) Compared with asphalt mixture without BRA modification, the BRA modified asphalt mixture shows better high-temperature stability, i.e., higher dynamic stability. In particular, as BRA content reaches 35%, the dynamic stability of the mixture is higher than 2,800 times per millimeter, which meets the specification requirement for hot areas in China.
3) In summary, both the high-temperature stability and moisture stability are improved for mixtures containing BRA modifier. From the perspective of immersion Marshall residual stability, the higher BRA contents leads to higher moisture stability. From the perspective of freeze-thaw splitting residual strength ratio, it is shown that approximately 45% is the optimal BRA content for moisture stability. From the perspective of dynamic stability, it is also indicated that 45% is the optimal BRA content for high temperature stability. With increase of BRA content, low temperature performance increases and reaches its maximum when the content is 45%, then gradually declines. It satisfies the standard requirement for low temperature performance when the natural BRA content is around 40-55%. Performance of mixtures with 40%-45% BRA content is slightly less than that of mixtures with 5% SBS modified asphalt. By combining these three aspects, it is suggested that a BRA content of around 45% provides the best improvement on the mixture performance in terms of both moisture and high-temperature stability.

Economic Analysis

A cost calculation was conducted to compare the economic efficiency between alternatives with and without BRA or between alternatives modified with BRA and other modifiers. The price for neat asphalt binder is about 5,000 Yuan (RMB) per ton; and the price for natural BRA modifier is about 3,000 Yuan per ton in market currently. The calculated results based on total binder cost, including both BRA and neat binder in asphalt mixture per ton and per kilometer in a typical pavement construction are presented in Table 12. To simplify, the cost for the latter is illustrated in Fig. 3. It is performed to analyze different BRA dosages and cost trends and obtain the economic and reasonable dosage range.

Overall, with the increase of BRA content, the total cost increases. In detail, Fig. 3 shows that the cost increases sharply when BRA content is between 15% and 25%, and between 60% and 80%, while the cost increases gradually when BRA content is between 25% and 60%. Combining the performance study and engineering practice, it is suggested that the BRA content around 40-45% be adopted

Table 12. Cost for Asphalt Binders with Varying BRA Content.

BRA: Asphalt	Total Asphalt Cost Per Ton Asphalt Mix (Yuan)	Total Asphalt Cost Per Kilometer Pavement (Yuan)
80:20	275.54	619,975
60:40	238.26	536,085
55:45	233.20	524,703
50:50	231.47	520,808
45:55	232.66	523,480
40:60	228.01	513,014
35:65	225.18	506,666
25:75	221.98	499,464
15:85	197.3	443,937
0:100	198.31	446,197

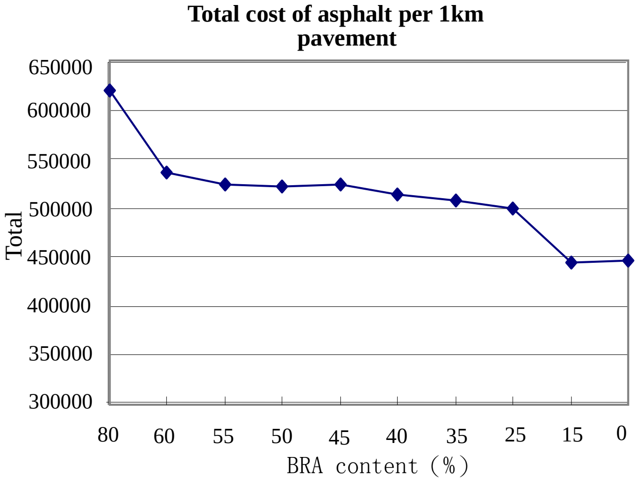

Fig. 3. The Relationship between Total Binder Cost Per Kilometer Asphalt Pavement with Varying BRA Content.

Table 13. Total Cost of Asphalt in SBS Modified Asphalt Mixture.

Modified Types	Modifier Price (Ton / Yuan)	Total Asphalt Cost Per Ton Asphalt Mix (Yuan)	Total Asphalt Cost Per Kilometer Pavement (Yuan)
25%TLA Modified Asphalt	8,000	232.02	522,051
5%SBS Modified Asphalt	20,000	257.80	580,056

because the cost is acceptable and mixture performance is optimally improved.

The widely used modifier SBS is referenced for comparison in this study. More often than not, 5% SBS dosage is used in modified asphalt. As shown in Table 13 or Fig. 3, BRA modifier can be more appealing than SBS in terms of cost efficiency.

Conclusions

This study investigates the properties of a natural asphalt modifier, i.e., BRA, which has seen increased use in China's pavement construction. A series of laboratory tests are conducted on the performance of modified asphalt with varying BRA contents. These tests mainly focus on properties of binder and asphalt mixture. In addition, economic analysis is performed to compare the cost of different materials. The major conclusions are summarized as follows:

1) With the increase of BRA modifier content, penetration decreases; softening point rises; and the PI value gradually increases, which indicate that BRA modified asphalt is stiffer and less temperature susceptible, and thus more resistant to deformation. It implies that asphalt modified by the BRA can improve the performance of asphalt at high temperature. Testing of RTFOT indicates that BRA modifier has a good anti-aging property and is relatively stable.
2) Because BRA contains a certain amount of ash, the ductility at 15°C decreases rapidly when BRA modifier content is 15-20%. When BRA modifier content is 20-50%, it declines slowly. Testing of low-temperature bending shows that it meets the standard requirement for low temperature performance, when the natural BRA content is around 40-55%.
3) Compared with No. 30 asphalt and SBS modified asphalt, the technical requirements of modified asphalt and low-grade asphalt for BRA asphalt need to be modified. The ductility is relative low for BRA asphalt, and thus it is suggested to establish a more suitable specification requirement for BRA modified asphalt and asphalt mixtures.
4) BRA modifier can improve both high-temperature and moisture stability of asphalt mixtures.
5) When natural BRA content is around 40-45%, BRA modified asphalt mixtures demonstrate optimal high temperature stability and moisture damage resistance.
6) Although total cost increases with the increase of BRA content, using BRA content of 40-45% in the modified asphalt is appealing by considering both performance and economic efficiency.

Acknowledgement

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