第 12 卷 第 3 期
2012 年 6 月

交 通 运 输 工 程 学 报
Journal of Traffic and Transportation Engineering

Vol. 12 No. 3
Jun. 2012

文章编号:1671-1637(2012)03-0001-08

改性沥青中 SBS 剂量检测方法

武建民[1],张雪林[2],陈忠达[1],林　杰[1],张洪亮[1]

(1. 长安大学 特殊地区公路工程教育部重点实验室,陕西 西安　710064; 2. 诸城市交通运输局,山东 诸城　262200)

摘　要:对 3 种基质沥青在不同 SBS 剂量下的性能指标进行了测试,运用灰色关联分析法,以 SBS 剂量作为参考数列,以改性沥青的性能指标针入度、软化点、延度、弹性恢复、135 ℃运动粘度作为比较数列,计算了 SBS 剂量与主要性能指标的关联度,并对关联度进行排序。通过对关联度系数进行归一化处理,计算得到各项性能指标所占的权重,建立了 SBS 剂量与常规性能指标的关系式,提出了基于多指标的 SBS 剂量检测方法,并采用已知 SBS 剂量的样品组对方法进行了验证。分析结果表明:与 SBS 剂量关联度显著的主要性能指标分别为软化点、弹性恢复、135 ℃运动粘度;对 3 种改性沥青采用该方法确定的 SBS 剂量绝对偏差均在 0.15%以内,可见,检测方法可靠。

关键词:道路工程;改性沥青;SBS 剂量;性能指标;灰色关联分析法;权重系数

中图分类号:U416.217　　　**文献标志码**:A

Test method of SBS content in modified asphalt

WU Jian-min[1], ZHANG Xue-lin[2], CHEN Zhong-da[1], LIN Jie[1], ZHANG Hong-liang[1]

(1. Key Laboratory for Special Area Highway Engineering of Ministry of Education, Chang'an University, Xi'an 710064, Shaanxi, China; 2. Transportation Bureau of Zhucheng, Zhucheng 262200, Shandong, China)

Abstract: The performance indexes of three kinds of base asphalts modified with different SBS contents were tested, grey correlation analysis method was used, SBS content was as reference sequence, the performance indexes of modified asphalt, such as penetration, softening point, ductility, elasticity recovery and kinematic viscosity at 135 ℃, were as comparison sequence, correlation grades between SBS content and main performance indexes were calculated and sequenced. The weight of each performance index was calculated by normalizing correlation grade coefficients, the relationship between conventional performance indexes and SBS content was set up, a test method of SBS content based on multiple indexes was put forward, and the method was validated by using sample groups with known SBS contents. Analaysis result indicates that the main performance indexes with significant correlation to SBS content are softening point, elasticity recovery and kinematic viscosity at 135 ℃. The absolute deviations of SBS contents for three kinds of modified asphalts are all within 0.15%, so the method is reliable. 13 tabs, 20 refs.

Key words: road engineering; modified asphalt; SBS content; performance index; grey correlation analysis method; weight coefficient

0 Introduction

SBS modified asphalt can effectively improve pavement performance, it is widely used in pavement construction and maintenance[1-2]. SBS content plays an important role in SBS modified

Receipt Date: 2011-12-22

Research Projects: National Natural Science Foundation of China(51108039); Special Fund for Basic Scientific Research of Central Colleges (CHD2011ZD010)

Author Resume: WU Jian-min(1971-), Male, Xingtai, Hebei, Associate Professor of Chang'an University, PhD, Research on Road Materials and Structure, +86-29-82336851, L08@gl.chd.edu.cn.

asphalt[3-4], which is an important control parameter in the production and use of modified asphalt[5]. However, there is no effective method to test SBS content in modified asphalt, process control in the production of modified asphalt is the common way to insure SBS content, which needs supervisors to check operation staffs whether they add SBS according to the given content, so the influences of human factors are significant, and results can not be evaluated effectively. Xiao et al used infrared spectrometer to test SBS content in modified asphalt[6]. Xiao et al proposed a quality control method for SBS modified asphalt based on micro-disperse state analysis[7], due to test equipment and technical requirements, the method was difficult to practice. More researchers studied the relationship between SBS content and the performance of modified asphalt. Yuan et al researched the influence of SBS content on the ductility and other properties of SBS modified asphalt[8-9]. Li et al researched the viscosity and temperature properties of SBS modified asphalts[10]. Zhang et al researched the softening point characteristics of SBS modified asphalt[11]. Lu et al researched the low temperature characteristics of SBS modified asphalt[12-13]. Xiao et al researched the relationship between SBS micro-disperse state and the performance of SBS modified asphalt[14]. Existing researches show that SBS content in modified asphalt has a certain effect on conventional performance indexes, such as penetration, softening point, ductility at 5 ℃, elasticity recovery and kinematic viscosity at 135 ℃. So, some researchers put forward the method to test or control SBS content by using a signal index such as softening point, kinematic viscosity at 135 ℃, or more indexes, but the discretenesses of test results are too large, and it is difficult to establish a unified standard for different modified asphalts. In this paper, a test method of SBS content based on multiple indexes is put forward, in the method, several performance indexes of modified asphalt which are significantly influenced by SBS contents are chosen by using grey correlation analysis method, and an equation between the indexes and SBS content is established. Through the equation and indoor test, SBS content in modified asphalt can be accurately identified.

1 Performance tests of raw materials and modified asphalts

Three kinds of base asphalts are used in this research, they are named A, B, C respectively. A, B are 70# base asphalts which are made in China, and C is 90# base asphalt which is imported. The modifier is SBS 1301, it is white pillar. All materials are tested, and can satisfy the requirements of *Technical Specification for Construction of Highway Asphalt Pavements* (JTG F40—2004). Modified asphalts with 3%-5% SBS contents and 0.5% interval are prepared by high-speed shear method, and their main performance indexes are tested. To ensure the reliability of test results, three samples of each kind of asphalt are tested, and average values are taken as test results. Test results are shown in Tabs. 1-3.

From the performance indexes of three modified asphalts with different contents, it can be seen that kinematic viscosity at 135 ℃, softening

Tab. 1 Performance indexes of modified asphalt A

SBS content/%	Ductility(5 ℃)/cm		Kinematic viscosity (135 ℃)/(Pa·s)	Softening point/℃	Elasticity recovery (25 ℃)/%	Penetration (25 ℃)/0.1 mm
	Before aging	After aging				
3.0	30.0	20.7	0.997	59.1	78	55.3
3.5	39.1	24.7	1.385	70.7	82	54.1
4.0	32.3	20.5	1.601	84.4	85	53.7
4.5	34.7	23.4	1.925	85.5	90	53.0
5.0	31.7	22.3	2.353	89.4	93	53.1

Tab. 2 Performance indexes of modified asphalt B

SBS content/ %	Ductility(5 ℃)/cm		Kinematic viscosity (135 ℃)/(Pa · s)	Softening point/ ℃	Elasticity recovery (25 ℃)/%	Penetration (25 ℃)/0.1 mm
	Before aging	After aging				
3.0	36.4	24.2	1.045	56.4	75	58.7
3.5	40.7	28.5	1.250	61.3	78	58.3
4.0	34.7	23.9	1.504	64.1	82	58.0
4.5	40.0	28.2	1.740	70.6	87	57.2
5.0	35.8	26.5	2.087	90.1	92	57.0

Tab. 3 Performance indexes of modified asphalt C

SBS content/ %	Ductility(5 ℃)/cm		Kinematic viscosity (135 ℃)/(Pa · s)	Softening point / ℃	Elasticity recovery (25 ℃)/%	Penetration (25 ℃)/0.1 mm
	Before aging	After aging				
3.0	44.3	25.3	0.876	45.2	74	71.5
3.5	50.2	30.1	1.200	56.2	76	68.0
4.0	42.6	24.9	1.400	79.2	80	65.8
4.5	37.8	22.7	1.608	89.6	83	64.0
5.0	36.0	21.7	2.050	90.8	85	62.5

point, elasticity recovery at 25 ℃ change obviously with the change of SBS content, penetration, ductility before or after aging at 5 ℃ do not change obviously with the change of SBS content, as these performance indexes are very important to evaluate modified asphalt performance[8,15-19]. Kinematic viscosity at 135 ℃, softening point, elasticity recovery, penetration, ductility before aging at 5 ℃ are chosen as correlation analysis indexes. In order to simplify working, ductility after aging at 5 ℃ is not as analysis index.

2 Grey correlation analysis between SBS content and performance indexes

2.1 Grey correlation analysis method

Gray correlation analysis method derives from the grey system theory, it measures correlation grades according to similarity or diversity between factors. Through calculating grey correlation grades between target (reference sequence) and influence factors (comparison sequence), main influence factors are chosen from sorted grey correlation grades. The comparison between the sequences in essence is the comparison between the geometry shapes of sequence curves, which is considered that the nearer the geometry shapes are, the bigger the correlation grades are. Basic principles are as follows

Reference sequence X_0 is

$$X_0 = \{X_0(1), X_0(2), \cdots, X_0(n)\}$$

where n is 5; $X_0(n)$ is SBS content; $X_0(1)$-$X_0(n)$ are 3.0%, 3.5%, 4.0%, 4.5%, 5.0% respectively.

Comparison sequence X_i is

$$X_i = \{X_i(1), X_i(2), \cdots, X_i(n)\}$$

where $i=1,2,\cdots,n$; $X_i(1)$-$X_i(n)$ are penetration at 25 ℃, softening point, ductility at 5 ℃ (before aging), elasticity recovery at 25 ℃ and kinematic viscosity at 135 ℃ respectively[20].

New reference sequence Y_0 can be got from above sequence by an equalization processing, Y_0 is

$$Y_0 = \{Y_0(1), Y_0(2), \cdots, Y_0(n)\} = \left\{\frac{X_0(1)}{\bar{X}_0}, \frac{X_0(2)}{\bar{X}_0}, \cdots, \frac{X_0(n)}{\bar{X}_0}\right\} \tag{1}$$

$$\bar{X}_0 = \frac{X_0(1) + X_0(2) + \cdots + X_0(n)}{n}$$

New comparison sequence Y_i is

$$Y_i = \{Y_i(1), Y_i(2), \cdots, Y_i(n)\} = \left\{\frac{X_i(1)}{\bar{X}_i}, \frac{X_i(2)}{\bar{X}_i}, \cdots, \frac{X_i(n)}{\bar{X}_i}\right\} \tag{2}$$

$$\bar{X}_i = \frac{X_i(1) + X_i(2) + \cdots + X_i(n)}{n}$$

Correlation coefficient $\xi_i(k)$ in time k (index and space) between comparison sequence and reference sequence is

$$\xi_i(k)=\left[\min_i \min_k |Y_0(k)-Y_i(k)|+\zeta \max_i \max_k |Y_0(k)-Y_i(k)|\right]\Big/\left[|Y_0(k)-Y_i(k)|+\zeta \max_i \max_k |Y_0(k)-Y_i(k)|\right] \quad (3)$$

where $k=1,2,\cdots,n$; ζ is resolution ratio, it is used to improve the significance of difference between correlation coefficients, and is usually taken as 0.5; $\min_i \min_k |Y_0(k)-Y_i(k)|$ is the minimum D-value between two stages (two gradations); $\max_i \max_k |Y_0(k)-Y_i(k)|$ is the maximum D-value between two stages (two gradations).

Grey correlation grade is

$$\gamma_i=\frac{1}{n}\sum_{k=1}^{n}\xi_i(k) \quad (4)$$

where γ_i is grey correlation grade between comparison sequence X_i and reference sequence X_0. The orders of correlation grades decide the significance of influence factors, the bigger the γ_i is, the closer the development tendencies of X_i and X_0 are, the greater the influence of X_0 on X_i is.

2.2 Analysis between SBS content and performance indexes

From Eqs. (1), (2), X_0 and X_i are equalized, Y_0 and Y_i are got, the equalization sequence results of three modified asphalts can be seen in Tabs. 4-6. In these tables, Y_0 is equalized from SBS content, Y_1, Y_2, Y_3, Y_4 and Y_5 are equalized from penetration at 25 ℃, softening point, ductility at 5 ℃ (before aging), elasticity recovery and kinematic viscosity at 135 ℃.

Tab. 4 Equalization sequences of modified asphalt A

Y_0	0.750	0.875	1.000	1.125	1.250
Y_1	1.027	1.005	0.997	0.984	0.986
Y_2	0.759	0.909	1.085	1.099	1.149
Y_3	0.894	1.165	0.962	1.034	0.945
Y_4	0.911	0.958	0.993	1.051	1.086
Y_5	0.603	0.838	0.969	1.165	1.424

Tab. 5 Equalization sequences of modified asphalt B

Y_0	0.750	0.875	1.000	1.125	1.250
Y_1	1.015	1.008	1.003	0.989	0.985
Y_2	0.823	0.895	0.936	1.031	1.315
Y_3	0.970	1.085	0.925	1.066	0.954
Y_4	0.906	0.942	0.990	1.051	1.111
Y_5	0.688	0.805	0.990	1.145	1.373

Tab. 6 Equalization sequences of modified asphalt C

Y_0	0.750	0.875	1.000	1.125	1.250
Y_1	1.077	1.025	0.992	0.964	0.942
Y_2	0.626	0.778	1.097	1.241	1.258
Y_3	1.050	1.190	1.010	0.896	0.853
Y_4	0.930	0.955	1.005	1.043	1.068
Y_5	0.614	0.840	0.981	1.127	1.437

Grey correlation coefficients between performance indexes of three modified asphalts and SBS contents can be calculated by Eq. (3), the results are shown in Tabs. 7-9.

Tab. 7 Grey correlation coefficients between performance indexes of modified asphalt A and SBS contents

i	Correlation coefficient $\xi_i(k)$					Correlation grade γ_i
1	0.362 0	0.550 4	1.000 0	0.529 8	0.373 3	0.563 1
2	0.962 8	0.833 8	0.654 7	0.871 1	0.613 4	0.787 2
3	0.524 5	0.351 4	0.816 3	0.638 6	0.339 9	0.534 1
4	0.496 0	0.660 3	0.974 9	0.686 5	0.491 3	0.661 8
5	0.519 2	0.820 6	0.847 4	0.807 8	0.476 3	0.694 2

Tab. 8 Grey correlation coefficients between performance indexes of modified asphalt B and SBS contents

i	Correlation coefficient $\xi_i(k)$					Correlation grade γ_i
1	0.365 6	0.537 4	1.000 0	0.531 7	0.365 6	0.560 1
2	0.683 3	0.898 8	0.712 3	0.624 0	0.708 9	0.725 4
3	0.410 3	0.421 8	0.677 1	0.729 5	0.340 1	0.515 8
4	0.496 7	0.702 3	0.955 7	0.680 2	0.526 1	0.672 2
5	0.719 0	0.692 7	0.955 7	0.898 8	0.557 2	0.764 7

Tab. 9 Grey correlation coefficients between performance indexes of modified asphalt C and SBS contents

i	Correlation coefficient $\xi_i(k)$					Correlation grade γ_i
1	0.381 5	0.575 3	0.970 9	0.557 7	0.395 9	0.576 3
2	0.621 7	0.678 5	0.678 5	0.637 5	0.970 9	0.717 4
3	0.402 2	0.390 5	0.961 6	0.469 0	0.336 7	0.512 0
4	0.529 7	0.719 9	0.985 3	0.714 8	0.526 9	0.695 3
5	0.599 4	0.858 7	0.921 8	1.000 0	0.520 1	0.780 0

In Tab. 7, the order from big to small of correlation grades for modified asphalt A is γ_2, γ_5, γ_4, γ_1, γ_3, so the significant influences of SBS content in turns are softening point, kinematic viscosity at 135 ℃, elasticity recovery, penetration, ductility.

In Tab. 8, the order from big to small of correlation grades for modified asphalt B is γ_5, γ_2, γ_4, γ_1, γ_3, so the significant influences of SBS content in turns are kinematic viscosity at 135 ℃, softening point, elasticity recovery, penetration, ductility.

In Tab. 9, the order from big to small of correlation grades for modified asphalt C is γ_5, γ_2, γ_4, γ_1, γ_3, so the significant influences of SBS content in turns are kinematic viscosity at 135 ℃, softening point, elasticity recovery, penetration, ductility.

From Tabs. 7-9, it can be seen that softening points, elasticity recovery and kinematic viscosity at 135 ℃ of modified asphalt constantly increase with the increase of SBS content, and have higher correlation grades with SBS content, so these indexes can be chosen as main control indexes to test SBS content in modified asphalt. At the same time, there is no obvious change for ductility at 5 ℃ with the change of SBS content, and correlation grade between ductility at 5 ℃ and SBS content is smaller, so it can not be chosen as main control index. Asphalt consistency gradually increases, and penetration decreases with the increase of SBS content, when SBS content is more than 4%, the change range of penetration becomes smaller, and correlation grade between penetration and SBS content is also smaller, so it is not suitable to be chosen as main control index.

3 Test method of SBS content in modified asphalt

In order to test SBS content in modified asphalt, three main control indexes such as kinematic viscosity at 135 ℃, softening point, elasticity recovery are chosen from above analysis, and are used to set up an equation with SBS content. In the equation, the weights of main control indexes are got by normalizing grey correlation grades, and SBS content in modified asphalt can be effectively determined by using the equation.

3.1 Relationship between SBS content and performance indexes

In order to test SBS content in modified asphalt A, an equation is established among SBS content and softening point, elasticity recovery, kinematic viscosity at 135 ℃ through the relationship analysis between SBS content and performance indexes, the equation is shown as follow

$$I_C = I_{SP}\gamma'_2 + I_E\gamma'_4 + I_V\gamma'_5 \tag{5}$$

where γ'_2, γ'_4, γ'_5 respectively represent weight coefficients of softening point, elasticity recovery, kinematic viscosity at 135 ℃; I_C represents SBS content in modified asphalt; I_{SP} represents SBS content which is ensured according to softening point figure interpolation in two adjacent SBS contents; I_E represents SBS content which is ensured according to elasticity recovery figure interpolation in two adjacent SBS contents; I_V represents SBS content which is ensured according to kinematic viscosity at 135 ℃ figure interpolation in two adjacent SBS contents.

According to Tab. 7, grey correlation grades among SBS content and softening point, elasticity recovery, kinematic viscosity at 135 ℃ of modified asphalt A are shown as follows

$$\gamma_i = \{\gamma_2, \gamma_4, \gamma_5\} = \{0.7872, 0.6618, 0.6942\}$$

By the homogenization processing of these correlation grades, three weight coefficients such as 0.37, 0.31, 0.32 can be got, so the specific expression of Eq. (5) is shown as follow

$$I_C = 0.37 I_{SP} + 0.31 I_E + 0.32 I_V \quad (6)$$

With the same principle, according to Tab. 8, grey correlation grades among SBS content and softening point, elasticity recovery, kinematic viscosity at 135 ℃ of modified asphalt B are shown as follows

$$\gamma_i = \{\gamma_2, \gamma_4, \gamma_5\} = \{0.7254, 0.6722, 0.7647\}$$

By the homogenization processing of these correlation grades, three weight coefficients such as 0.34, 0.31, 0.35 can be got, so the specific expression of Eq. (5) is shown as follow

$$I_C = 0.34 I_{SP} + 0.31 I_E + 0.35 I_V \quad (7)$$

With the same principle, according to Tab. 9, grey correlation grades among SBS content and softening point, elasticity recovery, kinematic viscosity at 135 ℃ of modified asphalt C are shown as follows

$$\gamma_i = \{\gamma_2, \gamma_4, \gamma_5\} = \{0.7174, 0.6953, 0.7800\}$$

By the homogenization processing of these correlation grades, three weight coefficients such as 0.32, 0.32, 0.36 can be got, so the specific expression of Eq. (5) is shown as follow

$$I_C = 0.32 I_{SP} + 0.32 I_E + 0.36 I_V \quad (8)$$

3.2 Relationship verification

In order to verify the rationalities of Eqs. (6)-(8), three modified asphalt samples with 4.3% SBS content are produced by using three kinds of base asphalts A, B, C. The test results of softening point, elasticity recovery at 25 ℃, kinematic viscosity at 135 ℃ are shown in Tabs. 10-12.

Tab. 10 Verification of SBS content in modified asphalt A

Performance index	SBS content/%			Verification sample/%		Absolute error/%
	4.0	4.5	5.5	4.3	Interpolation SBS content	
Softening point/℃	84.4	85.5	89.4	84.5	4.06	0.24
Elasticity recovery/%	85	90	93	87	4.20	0.10
Kinematic viscosity/(Pa • s)	1.601	1.925	2.353	1.756	4.24	0.06

Tab. 11 Verification of SBS content in modified asphalt B

Performance index	SBS content/%			Verification sample/%		Absolute error/%
	4.0	4.5	5.0	4.3	Interpolation SBS content	
Softening point/℃	64.1	70.6	90.1	67.6	4.27	0.03
Elasticity recovery/%	82	87	92	86	4.40	0.10
Kinematic viscosity/(Pa • s)	1.504	1.740	2.087	1.585	4.18	0.12

Tab. 12 Verification of SBS content in modified asphalt C

Performance index	SBS content/%			Verification sample/%		Absolute error/%
	4.0	4.5	5.0	4.3	Interpolation SBS content	
Softening point/℃	79.2	89.6	90.8	87.2	4.38	0.08
Elasticity recovery/%	80	83	85	83	4.50	0.20
Kinematic viscosity/(Pa • s)	1.400	1.608	2.050	1.514	4.27	0.07

To modified asphalt A, according to Tab. 10, SBS content can be calculated by Eq. (6)

$$I_C = 0.37 \times 4.06\% + 0.31 \times 4.20\% + 0.32 \times 4.24\% = 4.16\%$$

so SBS content in verification sample A is 4.16%.

To modified asphalt B, according to Tab. 11, SBS content can be calculated by Eq. (7)

$$I_C = 0.34 \times 4.27\% + 0.31 \times 4.40\% + 0.35 \times 4.18\% = 4.28\%$$

so SBS content in verification sample B is 4.28%.

To modified asphalt C, according to Tab. 12, SBS content can be calculated by Eq. (8)

$$I_C = 0.32 \times 4.38\% + 0.32 \times 4.50\% + 0.36 \times 4.27\% = 4.38\%$$

so SBS content in verification sample C is 4.38%.

Using above equations which are set up through grey correlation grade analysis, SBS contents in verification samples A, B, C can be determined, the results are 4.16%, 4.28%, 4.38%, which have little deviations to actual SBS content 4.30%, absolute deviations are all within 0.15%, the results are accurate. Compared with SBS contents which are determined by single index such as softening point, elasticity recovery, kinematic viscosity at 135 ℃, it shows that latter result has certain discreteness, this is often due to the errors of sampling and experimental operation. So three high correlation indexes are synthesized, and multiple indexes are used to identify SBS content instead of a number of dispersed single index, these can make test results more accurate and reasonable.

3.3 Application in practical engineering

Cangzhou-Langfang Expressway is about 50 km long and has six lanes. The upper layer pavement is modified asphalt concrete with 4.5% design content of SBS, the total amount of modified asphalt in the expressway is more than 6 000 t. In order to ensure the quality and performance of modified asphalt, and prevent asphalt suppliers to cut corners, the requirement for SBS content in modified asphalt is no less than 4.2%. The method is applied in quantitative detection (testing once every 500 t) and random check, 16 tests are carried out in the practical engineering. For every test, three groups of samples are taken, and average value is taken as test result. At the same time, three groups of samples are backuped, when test results are unqualified, test is repeated for verification, test results are shown in Tab. 13.

Tab. 13 Test results of SBS content in practical engineering

Number	Test result/%	Deviation with design value/%	Number	Test result/%	Deviation with design value/%
1	4.37	−0.13	9	4.42	−0.08
2	4.23	−0.27	10	4.56	0.06
3	4.09	−0.41	11	4.40	−0.10
4	4.52	0.02	12	4.36	−0.14
5	4.43	−0.07	13	4.42	−0.08
6	4.16	−0.34	14	4.28	−0.12
7	4.22	−0.28	15	4.47	−0.03
8	4.36	−0.14	16	4.40	−0.10

According to the test results in practical engineering, the third and sixth test results don't meet the requirements because the deviations between test results and design content are more than 0.3%. During the fourth and fifth tests, the SBS with design content is added under the on-site supervision of researchers, test results are closer to design content, this also proves the reliability of the method. The latter test results all meet the requirements, so SBS content has been effectively controlled by using the method.

4 Conclusions

The change of SBS content in modified asphalt has a certain effect on its main performance indexes. Through the indoor performance tests of three modified asphalts and the calculation analysis of grey correlation grades, it shows that softening point, elasticity recovery, kinematic viscosity at 135 ℃ constantly increase with the increase of SBS content, and change rule is obvious, these performance indexes have higher correlation grades with SBS content, so they can be taken as main control indexes to identify SBS content in modified asphalt. The change rules of penetration and ductility at 5 ℃ with SBS content are not obvious, and their correlation grades are lower, so these performance indexes can not be used to identify SBS content.

The models among softening point, elasticity recovery, kinematic viscosity at 135 ℃ and SBS content can be established, the weight coefficients of three performance indexes can be got through the homogenization processing of grey correlation grades, and the models can be realized to a specific equation. The method of identifying SBS content in modified asphalt is verified to be accurate and reliable. It can avoid the deviation by using signal performance index to identify SBS content, and also can solve the problem that is difficult to accurately determine SBS content in modified asphalt production process, so it provides a practical and reliable method for quality control in modified asphalt production and using.

References:

[1] COLLINS J H, BOULDIN M G, GELLES R, et al. Improved performance of paving asphalts by polymer modification[J]. Journal of the Association of Asphalt Paving Technologists, 1991, 60: 43-79.

[2] NAHAS N C, BARDER T J, ECKMANN B, et al. Polymer modified asphalts for high performance hot mix pavement binders[J]. Journal of the Association of Asphalt Paving Technologists, 1990, 59: 509-525.

[3] BAHIA H U, HANSON D I, ZENG M, et al. Characterization of modified asphalt binders in superpave mix design[R]. Washington DC: TRB, 2001.

[4] YUAN Jan-an, JI Dong, ZHU Zhi-gang. Effect of different dosage SBS on properties of modified asphalt[J]. Journal of Chang'an University: Natural Science Edition, 2005, 25(3): 19-22, 48.

[5] BRULE B, BRION Y, TANGUY A. Paving asphalt polymer blends: relationships between composition, structure and properties[J]. Journal of the Association of Asphalt Paving Technologists, 1988, 57: 41-64.

[6] XIAO Peng, KANG Ai-hong, LI Xue-feng. Cross blend mechanism of SBS modified asphalt based on infrared spectra[J]. Journal of Jiangsu University: Natural Science Edition, 2005, 26(6): 529-532.

[7] XIAO Yun, ZHENG Guo-liang. Quality control of SBS modified asphalt based on micro-disperse state analysis[J]. Journal of Highway and Transportation Research and Development, 2005, 22(12): 17-19.

[8] YUAN Jian-an. A rustics opinion on ductility of SBS modified asphalts[J]. Journal of Chongqing Jiaotong University, 2005, 24(5): 25-28.

[9] YUAN Jian-an, ZHOU Ji-ping, LI Yu-zhen. Analysis of interaction between SBS and asphalt[J]. China Journal of Highway and Transport, 2005, 18(4): 21-26.

[10] LI Ning-li, LI Tie-hu, CHEN Hua-xin, et al. A study on the viscosity and temperature properties of SBS modified asphalts[J]. China Civil Engineering Journal, 2007, 40(10): 86-90.

[11] ZHANG Zheng-qi, CUI Wen-she, MA Liang, et al. Experimental feature of softening point of SBS modified asphalt[J]. Journal of Chang'an University: Natural Science Edition, 2007, 27(6): 6-10.

[12] LU Xiao-hu, ISACSSON U, EKBLAD J. Low-temperature properties of styrene-butadiene-styrene polymer modified bitumens[J]. Construction and Building Materials, 1998, 12(8): 405-414.

[13] CHAMPION L, GERARD J F. Low temperature fracture properties of polymer-modified asphalts relationships with the morphology[J]. Journal of Materials Science, 2001, 36(2): 451-460.

[14] XIAO Yun, YUAN Yan, ZHANG Xiao-ning. Relationship between the micro disperse state of SBS and the performance of modified asphalt[J]. Journal of South China University of Technology: Natural Science Edition, 2005, 33(8): 83-86.

[15] HUANG Wei-dong, SUN Li-jun, ZHANG Zhi-quan, et al. Study on penetration index[J]. Journal of Tongji University: Natural Science, 2005, 33(3): 306-310.

[16] XIONG Ping, HAO Pei-wen. Measures and mechanism analysis of improvingthe storage stability of styrene-butadiene-styrene polymer modified asphalt[J]. Journal of Tongji University: Natural Science, 2006, 34(5): 613-618.

[17] CHEN Pei-lin, ZHOU Jin-chuan, ZHANG Xiao-ning, et al. Experimental investigation into asphalt binder by force-ductility test[J]. Journal of South China University of Technology: Natural Science Edition, 2006, 34(4): 38-42.

[18] ZHAO Yong-zhen, LU Rong-yan, LI Yan-wei. Analysis and application of boundary surface method on pavement performance of modified asphalt mixture[J]. Road Machinery and Construction Mechanization, 2007, 24(4): 17-19.

[19] WANG Xiao-yan, WANG Lin. Research of compatibility between polymer modifier and asphalt[J]. Road Machinery and Construction Mechanization, 2010, 27(2): 42-44, 47.

[20] LIN Jie. Study on SBS modified asphalt technical performance evaluation and quality control[D]. Xi'an: Chang'an Uinversity, 2011.