Performance Test on SBS Modified Asphalt Based on the Different Evaluation methods

Chen Zhang
Xi’an Aeronautical University
No.259 West Erhuan
Xi’an, Shaanxi, 710077, China
E-mail: zlw19861108@aliyun.com

Hainian Wang
Chang’an University
South Erhuan Middle Section
Xi’an, Shaanxi, 710064, China
E-mail: wanghainian@aliyun.com

Muhammad Irfan
National University of Sciences and Technology (NUST)
NUST Campus, Risalpur-24080
Pakistan.
Emails: mirfan@mce.nust.edu.pk

ABSTRACT

To uniform the evaluation indicators of SBS modified asphalt, the SK70# and SK90# matrix asphalt are modified by different SBS modifier dosage in this study, and the test methods in China and Superpave are used to test the performance of SBS modified asphalt respectively, which the appropriate evaluation index of SBS modified asphalt could be determined. The results show that the addition of SBS modifier can improve the high temperature performance and lower the temperature sensitivity of asphalt binder, while increase the viscosity in high temperature of asphalt binder. Due to the variability is appeared in the results of penetration test by the swelling of SBS modified asphalt, the penetration test is not suggest to evaluate the performances of SBS modified asphalt. The softening point of SBS modified asphalt with the modifier dosage of 4.5%, 5%, 5.5% and 6% increased 5.7%, 12.8%, 22.5% and 26.4% respectively compared the matrix asphalt for SK70# matrix asphalt, and increased 21.2%, 26.3%, 33.6% and 46.6% respectively compared the matrix asphalt for SK90# matrix asphalt. The effects of SBS modifier on the softening point of SK90# matrix asphalt is significant better than that of SK70# matrix asphalt. The improvement effect of SBS modifier on low temperature performance of matrix asphalt is decreased with the decrease of test temperature. When study the influence of SBS modifier on the low temperature performance of asphalt binder, it is recommended to use BBR test to evaluate the low temperature performance of SBS modified asphalt.

KEYWORDS: Highway Engineering, SBS Modified Asphalt, Laboratory test, Evaluation index.
1 INTRODUCTION

Styrene-Butadiene-Styrene (SBS) is a common modifier with high molecular polymer, which could make the asphalt binder modified by miscible with asphalt binder[1]. The SBS modified asphalt could improve the high temperature rutting resistance, low temperature crack resistance and anti-fatigue performance of asphalt pavement[2]. The SBS modified asphalt has been used widely in many high-grade pavement in China at present to satisfy the increasing traffic. SBS modified asphalt has wide scope of application[3]. In recent years, many scholars in domestic and abroad research much about SBS modified asphalt. Khodaii (2009) conduct dynamic creep test on unmodified and SBS modified samples, and the creep behavior of the samples was estimated by the Zhou three-stage creep model. The result shows that dense graded mixtures had higher permanent deformation susceptibility than coarse graded mixtures, and lower stress levels in dynamic creep test can not show the real behavior of asphalt mixtures and particularly the modified mixtures[4]. Forough (2014) using the creep curves derived from the dynamic creep tests to investigate the effects of loading frequency and temperature on the moisture sensitivity of dense-graded polymer-modified asphalt mixtures. The results showed that both the variables of loading frequency and temperature had significant effects on the permanent strains of both the dry and wet asphalt mixtures[5]. Huang (2015) using multiple stress creep recovery (MSCR) test to investigate the effect of cross-linking agent and SBS content on SBS modified asphalt. The result shows the effect of increasing SBS content is more prominent for binders at lower SBS content. MSCR test failed to distinguish 5.0% and 5.5% SBS modified asphalt in the study[6]. Wang (2017) conducted three points bending test and DEformaciones test to evaluate the low-temperature performance and the fatigue resistance of recycled SBS-modified asphalt mixture. The results showed that fatigue resistance of modified recycling of asphalt mixture with different RAPs did not vary much under low temperature while displaying an obvious difference under higher temperature[7]. However, the test index be used to evaluate the performance of SBS Modified Asphalt are diversified, and lack of unification. This study based on the domestic test methods of penetration test, softening point test, ductility test, elastic recovery test and abroad test methods of dynamic shear rheometer test (DSR), Brookfield rotary viscosity test, Bending Beam Rheometer (BBR) test, to analyze the influence of SBS modifier on asphalt performance. By comparing each performance index to provide theoretical support for unify the performance evaluation index of SBS Modified Asphalt.

2 RAW MATERIAL

2.1 Matrix asphalt

The matrix asphalt used in this study is SK70# and SK90#, and the technical indicators are as shown in Table 1.

<table>
<thead>
<tr>
<th>Technical indicators</th>
<th>Units</th>
<th>SK90#</th>
<th>SK70#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration (15℃, 100g, 5s)</td>
<td>0.1mm</td>
<td>31</td>
<td>26</td>
</tr>
<tr>
<td>Penetration (25℃, 100g, 5s)</td>
<td>0.1mm</td>
<td>91</td>
<td>73</td>
</tr>
<tr>
<td>Penetration (30℃, 100g, 5s)</td>
<td>0.1mm</td>
<td>162</td>
<td>129</td>
</tr>
</tbody>
</table>
2.2 SBS modifier

The line type SBS modifier is used in this study, and the SBS modifier dosages are 4.5%, 5%, 5.5% and 6%. The technical indicators of SBS modifier is as shown in Table 2.

<table>
<thead>
<tr>
<th>Technical parameters</th>
<th>S/B mass ratio</th>
<th>Volatile (%)</th>
<th>Tensile strength (Mpa)</th>
<th>Ash (%)</th>
<th>300% stress at definite elongation (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Results</td>
<td>30/70</td>
<td>≤0.7</td>
<td>18.5</td>
<td>≤0.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>

3 RESULTS AND DISCUSSION

3.1 Performance test of SBS modified asphalt with domestic Evaluation methods

(1) Penetration

The test temperature are 15℃, 20℃, 25℃ and 30℃ in this study. The penetration of matrix asphalt and SBS modified asphalt at different test temperature are as shown in Fig.1. For SK70# and SK90# matrix asphalt, the SBS modifier could lower the penetration of them, which lead the asphalt binder hardened. Take the test temperature of 25℃ and SK90# matrix asphalt as example, the penetration of SBS modified asphalt with SBS dosage of 4.5%, 5%, 5.5% and 6% are decreased by 10.3%, 12.9%, 14.4% and 15.5% respectively compared the matrix asphalt.
For study the influence of SBS modifier dosage on penetration of asphalt binder, the variance analysis of temperature and SBS modifier dosage on penetration of SK70# and SK90# matrix asphalt are conducted respectively, as shown in Table 3.

Table 3 Variance analysis of penetration for SBS modified asphalt

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBS modifier dosage</td>
<td>70# matrix asphalt</td>
<td>4</td>
<td>7.65</td>
</tr>
<tr>
<td></td>
<td>90# matrix asphalt</td>
<td>4</td>
<td>5.89</td>
</tr>
<tr>
<td>Temperature</td>
<td>70# matrix asphalt</td>
<td>2</td>
<td>37.64</td>
</tr>
<tr>
<td></td>
<td>90# matrix asphalt</td>
<td>2</td>
<td>16.88</td>
</tr>
</tbody>
</table>

The result shows that, the temperature has a significantly influence on penetration of SBS modified asphalt, while the SBS modifier dosage has no significantly influence on it. In addition, the aromatic hydrocarbon and resin in matrix asphalt could be absorbed by SBS modifier, and lead to the swelling behavior, which cause the great variability to the test result of penetration.

(2) Softening point

Softening point is one of the indicator which is be used to characterize the high temperature performance of asphalt binder. Softening point is the critical temperature which the physical state of asphalt from viscid-plastic to viscous flow. The higher the softening point, the better the high temperature performance of asphalt binder[8]. The softening point of asphalt binder with different SBS modifier dosage are as shown in Figure 2.
From Figure 2, for SK70# and SK90# matrix asphalt, the addition of SBS modifier dosage could increase the softening point of asphalt binder. The softening point of SBS modified asphalt with the modifier dosage of 4.5%, 5%, 5.5% and 6% increased 5.7%, 12.8%, 22.5% and 26.4% respectively compared the matrix asphalt for SK70# matrix asphalt, and increased 21.2%, 26.3%, 33.6% and 46.6% respectively compared the matrix asphalt for SK90# matrix asphalt. The single factor variance analysis be conducted in the condition of different asphalt binder type and different SBS modifier dosage for softening point of asphalt binder, and the results are as shown in table 4.

Table 4 Variance analysis of softening point for SBS modified asphalt

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBS modifier dosage 70# matrix asphalt</td>
<td>4</td>
<td>268.47</td>
<td>0.25</td>
</tr>
<tr>
<td>SBS modifier dosage 90# matrix asphalt</td>
<td>4</td>
<td>8641.65</td>
<td>0.02</td>
</tr>
</tbody>
</table>

From Table 4, the SBS modifier has significant influence on the softening point both of SK70# and SK90# matrix asphalt, which means the addition of SBS modifier could improve the temperature performance of asphalt binder[9]. The F-value of two kinds of asphalt binder in the variance analysis are compared and the result shows the F-value of SK90# matrix asphalt is bigger than that of SK70# matrix asphalt. Therefore, the improving effects of SBS modifier on the softening point of SK90# matrix asphalt is significant better than that of SK70# matrix asphalt, which means the SBS modifier has the better improving effects on fluxed bitumen.

(3) Ductility and Elastic recovery

Ductility is a test index used to characterize the low temperature performance of asphalt binder. The bigger the ductility, the better the low temperature crack resistance of asphalt binder. The elastic recovery of asphalt binder is a mechanical index, which could reflect the elasticity capacity of asphalt binder from atress to recover[10]. The elastic recovery index direct reflect the high temperature performance, low temperature performance, fatigue performance and durability. The temperature of ductility test is 5°C, the stretching velocity is 5cm/min, and the temperature of elastic recovery test is 25°C. The results of ductility test and elastic recovery test of matrix asphalt and SBS modified asphalt are as shown in figure 3.
From figure 3, the ductility and elastic recovery of 90# matrix asphalt are bigger than that of 70# matrix asphalt. The ductility and elastic recovery of asphalt binder increases with the increase of SBS modifier dosage, that means the addition of SBS modifier could improve the low temperature performance and elastic recovery performance of asphalt binder. The variance analysis for the influence of SBS modifier on the ductility and elastic recovery of asphalt binder as shown in Table 5.

Table 5 Variance analysis result of ductility and elastic recovery for SBS modified asphalt

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ductility</td>
<td>70# matrix asphalt</td>
<td>3</td>
<td>72.58</td>
</tr>
<tr>
<td></td>
<td>90# matrix asphalt</td>
<td>3</td>
<td>36.47</td>
</tr>
<tr>
<td>Elastic recovery</td>
<td>70# matrix asphalt</td>
<td>3</td>
<td>874.62</td>
</tr>
</tbody>
</table>
It can be seen that SBS modifier have an significant influence on the ductility and elastic recovery of asphalt binder. For the ductility and elastic recovery of asphalt binder, the F-value of 70# matrix asphalt is bigger than that of 90# matrix asphalt, which means the effects of SBS modifier on the ductility and elastic recovery of SK70# matrix asphalt is significant greater than that of SK90# matrix asphalt.

3.2 Test result of Superpave method for SBS modified asphalt

(1) Dynamic shear rheological (DSR) test

The anti-rutting factor $G^*/\sin\delta$ of SBS modified asphalt was tested at the temperature of 45°C, 50°C, 55°C, 60°C, 65°C and 70°C respectively, to study the anti-rutting performance of SBS modified asphalt at high temperature. The larger the $G^*/\sin\delta$, the better the high-temperature performance of asphalt, which means the high-temperature rutting resistance is better\[11\]. The modifier dosage are 4.5%, 5%, 5.5% and 6%, and the matrix asphalt is SK90# asphalt binder. The test results is shown in Figure 4.

![Figure 4: The rutting resistance factor of matrix asphalt and SBS modified asphalt at different temperatures](image)

From figure 4, for the matrix asphalt and SBS modified asphalt, the $G^*/\sin\delta$ decreases with the increase of temperature, and the addition of SBS modifier can significantly improve the $G^*/\sin\delta$ of asphalt binder, and improve the high-temperature rutting resistance of asphalt.

The difference analysis of $G^*/\sin\delta$ is conducted in different SBS modifier dosage, and the analysis results are shown in Table 6. The results shows that when the SBS modifier dosages increase from 0% to 5.5%, the high-temperature rutting resistance of SBS modified asphalt increase continuously, and the difference between each pair of them is significant. When the SBS modifier dosages increase from 5.5% to 6%, there is no obvious difference between each pair of them, which means the increase of high-temperature rutting resistance of asphalt is not significant when the modifier dosages increase from 5.5% to 6%.

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Difference analysis of $G^*/\sin\delta$ at different SBS modifier dosages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>0%</td>
<td>−</td>
</tr>
</tbody>
</table>
Another index to measure the performance of asphalt binder is the viscosity. The smaller the viscosity of asphalt at high temperature, the better the asphalt mixture can be mixed and compacted [12]. Therefore, the SHRP method requires the rotary viscosity at 135°C shall not exceed 3 Pa.s. The Brookfield rotary viscometer is adopted in this paper to determine the rotational viscosity of SBS modified asphalt. In the test, the rotor speed is 20 rpm/min, the rotor of SBS modified asphalt is 27#, and the mass was 10.5 g, the mass of 90# matrix asphalt sample is 8.5 g, using 21# rotor. The test temperature were 135°C, 140°C, 150°C, 160°C, 170°C, 177°C and 190°C respectively, and the dosages of SBS modifier were 0%, 4.5%, 5%, 5.5% and 6%, the test results are shown in Figure 5.

(a) Viscosity of SBS modified asphalt with different modifier dosages
(b) Viscosity of SBS modified asphalt with different temperature

Figure 5: The rotary viscosity of asphalt binder

From Figure 5, the addition of SBS modifier could significantly improve the rotary viscosity of asphalt binder. Compared to the rotary viscosity at 135°C of matrix asphalt, when the SBS modifier dosages are 4.5%, 5%, 5.5% and 6% respectively, the rotary viscosity of asphalt binder increased by 2.42 times, 9.14 times, 16.96 times and 22.31 times respectively. And with the SBS modifier dosage increases, the rotary viscosity of asphalt binder increases significantly. In general, the viscosity-temperature curve is used to characterize the relations of viscosity and temperature of SBS modified asphalt, as shown in equation (1)[13].

$$\log \log(\eta) = n - VTS \log(T)$$

(1)

Which, $\eta$ is the asphalt viscosity (cPa.s); $T$ is the test temperature; $n$ is the regression coefficient; $VTS$ is represents the temperature sensitivity of asphalt binder.

The viscosity of SBS modified asphalt with different SBS modifier dosage is fitted by equation (1), and the relations of viscosity and temperature is determined. The result are as shown in Table 7.

<table>
<thead>
<tr>
<th>SBS modifier dosage</th>
<th>n</th>
<th>VTS</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5%</td>
<td>3.426</td>
<td>0.869</td>
<td>0.997</td>
</tr>
<tr>
<td>5%</td>
<td>3.351</td>
<td>0.743</td>
<td>0.997</td>
</tr>
<tr>
<td>5.5%</td>
<td>3.254</td>
<td>0.715</td>
<td>0.995</td>
</tr>
<tr>
<td>6%</td>
<td>3.139</td>
<td>0.637</td>
<td>0.993</td>
</tr>
</tbody>
</table>

From table 7, the fitting coefficient R2 of viscosity-temperature curve of SBS modified asphalt are all greater than 0.99, which means the viscosity-temperature relationship of SBS modified asphalt could be characterized better by Refutas curve. The VTS is represents the temperature sensitivity of SBS modified asphalt, and the bigger value of VTS, the more distinct temperature sensitivity. From Table 7, the VTS value is decrease with the increase of SBS modifier dosage, which means the SBS modifier could significant lower the temperature sensitivity of asphalt binder.

(3) Bending Beam Rheometer test (BBR)

The Bending Beam Rheometer test (BBR) is used to analyze the stiffness of SBS modified
asphalt in SHRP test methods, which the low temperature performance of SBS modified asphalt could be characterized[14]. The SBS modified asphalt sample is conducted short term aging with RTFOT method first, and then conduct stress aging with pressure aging vessel (PAV).

The test is loaded 240 seconds at the stress of 100g (980mN), and the creep stiffness S(t) at t=60 seconds is used as one of the evaluation index of low temperature performance of SBS modified asphalt. The smaller the S(t), the better low temperature performance of SBS modified asphalt. The m value is the other index of BBR test, which the change of S(t) over time could be characterized. The S(t) value is required not more than 300MPa, and the m value is required more than 0.3 in SHRP method. The test temperature of -12oC and -18oC are used in this study, and three parallel-samples are prepared for the test. The test result of S(t) of SK90# matrix asphalt and SBS modified asphalt are as shown in Figure 6.

![Figure 6: The creep stiffness S(t) of SK90# matrix asphalt and SBS modified asphalt](image)

From Fig.6, the S(t) value at -18oC is bigger than that at -12oC, and the S(t) value are both decreases with the increase of SBS modifier dosage at the temperature of -12oC and -18oC, which means the low temperature performance of SBS modified asphalt has been improved. To analyze the influence of SBS modifier dosage on S(t), the single factor variance analysis for S(t) at different temperature is conducted. The result is shown in Table 8.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBS modifier</td>
<td>-18℃</td>
<td>4</td>
<td>198.68</td>
</tr>
<tr>
<td>dosage</td>
<td>-12℃</td>
<td>4</td>
<td>376.57</td>
</tr>
</tbody>
</table>

From Table 8, the P-value are both 0.001, which means the SBS modifier dosage has significant influence on S(t) of asphalt binder. Through the compared of two F-value at -12℃ and -18℃, the influencing effect of SBS modifier dosage on stiffness S(t) at -18℃ is less than that at -12℃. Therefore, the improvement effect of SBS modifier dosage on the low temperature performance of asphalt binder reduce with the test temperature decrease.

4 CONCLUSIONS

(1) According to the performance evaluation tests conducted at home and abroad, the addition of SBS modifier can significantly improve the high-temperature performance of asphalt, and can also
significantly reduce the temperature sensitivity of asphalt, but increase the viscosity of asphalt at high
temperature, as well as increase the difficulty of mixing and compaction of asphalt mixture.

(2) For SK70# and SK90# matrix asphalt, the addition of SBS modifier can reduce the
penetration of asphalt binder in a certain extent, but the effect is not obvious, and the penetration index
of asphalt binder has no obvious rules in different modifier contents. In addition, the swelling effect of
SBS modified asphalt will lead to great variability of penetration test results, so the penetration test is
not recommended to evaluate the performance of SBS modified asphalt.

(3) The addition of SBS modifier can significantly improve the softening point of asphalt binder,
and this conclusion is in line with the dynamic shear rheological (DSR) test results in Superpave.
Therefore, the softening point can be taken as an evaluation index for high-temperature performance
of SBS modified asphalt. The Variance analysis shows the effects of SBS modifier on the softening
point of SK90# matrix asphalt is significant better than that of SK70# matrix asphalt.

(4) SBS modifier can significantly improve the ductility and elastic recovery of asphalt binder,
which is in line with the bending beam rheometer (BBR) test results in Superpave. The analysis of
variance shows that the influence of SBS modifier on the ductility and elasticity recovery of 70#
asphalt is greater than that of 90# asphalt, and the influence of SBS modifier on stiffness S(t) value is
greater than that of ductility value. Therefore, in the study of the influence of SBS modifier on the low
temperature performance of asphalt binder, the effect of bending beam rheological (BBR) test is more
obvious than the low temperature ductility test. In addition, the low temperature ductility value of SBS
modified asphalt is small and it is easy to produce greater errors during the tests. Therefore, it is
recommended to use the bending beam rheological (BBR) test to evaluate the low-temperature
performance of SBS modified asphalt.

REFERENCES
modified asphalt mixtures using dynamic creep test[J]. Construction & Building Materials,
23(7):2586-2592.
sensitivity of SBS-modified asphalt mixtures[J]. Journal of Materials in Civil Engineering,
26(5):897-903.


