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# Durability of Composite-Modified Asphalt Mixture Based on Inherent and Improved Performance

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## Abstract

The composite performance of modified asphalt and composite-modified asphalt mixture (CMAM) is divided into inherent performance and improved performance. The inherent performance refers to the original performance of the virgin asphalt and asphalt mixture. The improved performance refers to the performance obtained by modifying the virgin asphalt. In the study, the modified asphalt and asphalt mixture were tested through a series of experiments. The antiaging durability of the modified asphalt is explored based on the inherent performance and improved performance at high and low temperatures. The antiaging durability of the modified asphalt mixture is explored based on the inherent performance and improved performance at the mechanical performance. Meanwhile, based on inherent and improved performances, this chapter uses three kinds of CMAM (4% SBS/3% SBR, 4% SBS/15% rubber, and 4% SBR/15% rubber) as research objects to test the change rule of mechanical properties. This chapter outlines CMAM design, mechanical property tests, and comparative durability analysis.

**Keywords:** composite-modified asphalt mixture, inherent and improved performances, durability, test, comparative analysis

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## 1. Introduction

With the extensive use of asphalt pavement, improving the performance of asphalt is very important for driving safety and driving comfort. The properties of asphalt are divided into many types. The service life of asphalt pavement is decided on the durability of asphalt and asphalt mixture. Study on durability of asphalt and asphalt mixture is very important in the day [1–4].

Zhang et al. [5] investigated the change in molecular weight during the aging process of asphalt and found some new functional groups that were produced inside the asphalt; they also found that the change in molecular structure will lead to changes in the morphology and performance of the asphalt. Chen's paper concluded that temperature has a great influence on the aging of asphalt. When the temperature was above 100°C, a dehydrogenated chemical reaction of the asphalt was produced. When the temperature was below 100°C, an oxidation reaction of the asphalt was produced, as well as some oxygenated compounds. The chemical reaction produced by asphalt aging has an important influence on the performance of the asphalt [6]. According to Zhu et al., as the aging time is increased, the residual needle penetration and residual ductility are decreased and the softening point is increased. This means that the high-temperature performance of the asphalt is increased and the low-temperature performance is decreased after aging [7]. Zhang et al. [8] indicated that the variation of the performance of the asphalt during the aging progress is mainly due to the change of its interior components. When asphalt is aging, the content of its lighter components is decreased, such as oil and gelatin, and the content of the heavier components is increased, such as asphaltene. This results in a harder asphalt, which is easily broken at low temperatures. Meanwhile, the aging of the asphalt threatens the safety of the road surface. In the aging process, the low-temperature performance and water stability of the asphalt mixture are decreased. The asphalt pavement creates the risk of road fractures and the formation of a loose mixture of asphalt in cold and wet areas [9–11]. Therefore, it is of great significance to improve the service life and performance of asphalt pavement via improving the aging durability of asphalt.

This chapter will discuss the formation mechanism and durability of two properties of modified asphalt, and further analyze the technical characteristics of different modifiers. On the basis of this research, a new modified asphalt material based on composite modifiers is proposed to optimize the road performance of modified asphalt. And in this work, SBS, SBR, and rubber powder modifiers were selected as composite modifiers. 4% SBS/3% SBR, 4% SBS/15% rubber, and 4% SBR/15% rubber were used for testing. Based on the inherent and improved performance of each mixture, a comparative analysis was carried out to study the changing mechanical performance of CMAM. Findings offer theoretical and practical value for research on asphalt mixture durability [12–20].

## 2. Test materials and methodology

### 2.1. Test materials

#### 2.1.1. Asphalt

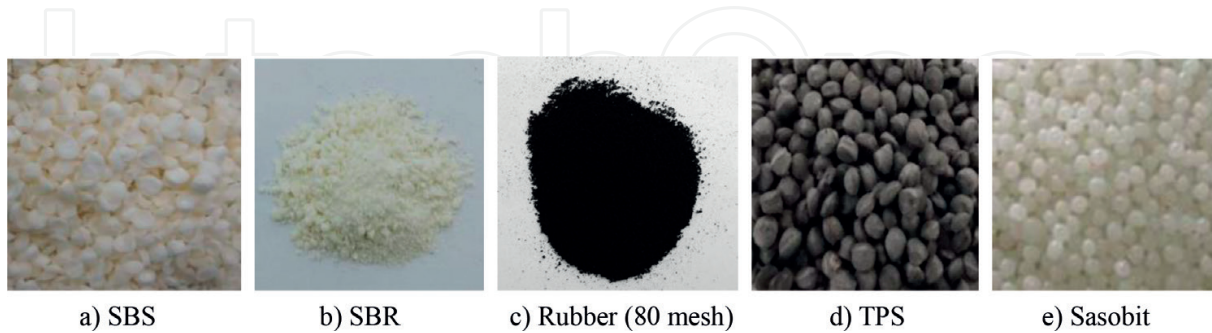
Virgin asphalt 90# was selected in this test; asphalt indices are displayed in **Table 1**.

#### 2.1.2. Modifiers

Overall, SBS, SBR, TPS, Sasobit and rubber modifiers were tested (**Figure 1**). Corresponding indices are shown in **Tables 2–6**.

Asphalt	Penetration (25°C/0.1 mm)	PI	Ductility (cm)		Softening point (°C)	Viscosity (135°C/Pa s)
			5°C	15°C		
90#	93	-0.77	9	165	44.5	0.328

**Table 1.** Technical indexes of virgin asphalt.



**Figure 1.** Modifier types. (a) SBS, (b) SBR, (c) rubber (80 mesh); (d) TPS; (e) Sasobit.

Tensile strength (MPa)	Elongation at break (%)	Hardness (A)	Styrene/butadiene	Density (kg/cm <sup>3</sup> )
33	800	76	31/69	0.94

**Table 2.** Technical indices of SBS modifier (LG501).

Moisture quality fraction (%)	Molecular weight ( $\times 10^4$ )	Tensile strength (MPa)	Elongation at break (%)	Ethylene propylene mass fraction (%)	Dry rubber (%)	Grains (mesh)
$\leq 2$	20–30	31	320	22.5–24.5	$\geq 75$	$< 40$

**Table 3.** Technical indices of SBR modifier (1502).

Physical index				Chemical index			
Relative density (kg/cm <sup>3</sup> )	Moisture (%)	Metal (%)	Fiber (%)	Ash (%)	Acetone extract (%)	Carbon black (%)	Rubber hydrocarbon (%)
289	0.27	0.02	0	10	10.02	32.86	51

**Table 4.** Technical indices of rubber.

### 2.1.3. Aggregates

The CMAM (AC-13) included the above aggregate gradations. Optimum asphalt content was determined to be 5.6% using the Marshall design method. Asphalt mixture AC-13 was selected, with the aggregate gradation shown in **Table 7**.

	Particle size (mm)	Density (g/cm <sup>3</sup> )	Water absorption rate (%)
Technical indicators	≤5	0.7~1.0	<1

Table 5. Technical indexes of modifier TPS.

	Freezing point (°C)	Penetration (0.1 mm)		Viscosity (135°C/ cp)	Density (25°C/(g/ cm <sup>3</sup> ))	Melting point (°C)
		25°C	65°C			
Prescribed value	≤99	≤1	≤10	10~14	—	98~110
Measured value	98	<0.7	7	12	0.94	100

Table 6. Technical indexes of modifier Sasobit.

Mixture type	Percentage of passing through sieve (mm)/%											
	26.5	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
AC-13			100	95	76.5	53	37	26.5	19	13.5	10	6

Table 7. Aggregate gradations.

2.2. Test methodology

2.2.1. Modified asphalt test methodology

The 4% SBS asphalt, 4% TPS asphalt, 16% rubber asphalt, and 2% Sasobit asphalt were selected as the research objects to carry out aging tests (aging times were 0, 5, 20 h). Then, the durability comparison of the asphalt was carried out based on inherent durability and inherent performance.

The antiaged durability of the modified asphalt based on inherent and improved performances is compared and analyzed. The penetration index was used to evaluate the performance at high temperature of the asphalt and the ductility index was used to evaluate the performance at low temperature. The change curves of modified asphalt with different aging times are linear regressions, and it is also used to evaluate the inherent and improved performances of the modified asphalt.

2.2.2. CMAM test methodology

The performance of composite-modified asphalt mixture was tested and analyzed based on inherent and improved performances. A comparative study was tested through the aging durability, plastic deformation durability, and fatigue durability.

1. In terms of aging durability, taking dynamic stability, bending strain, TSR as indicators to explore the change rule of inherent, improved, and composite performances of

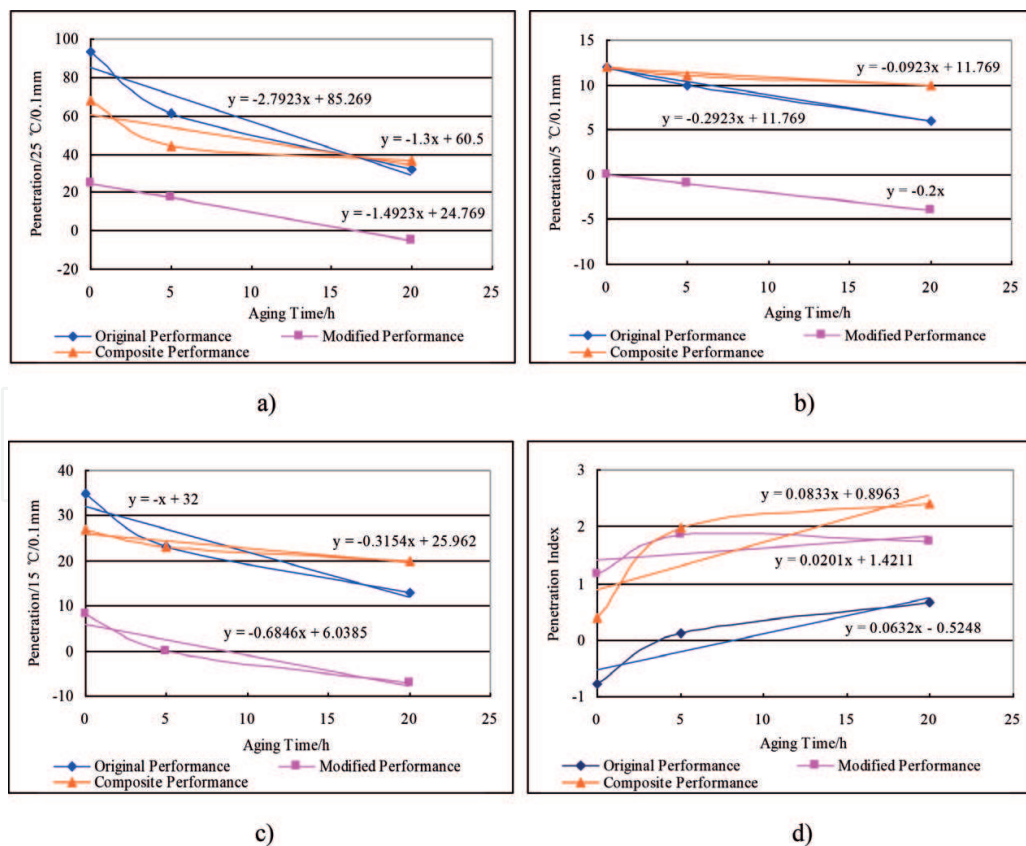
different composite-modified asphalt mixtures in aging process by controlling the aging time (0, 5, 20 hours).

2. In terms of plastic deformation durability, taking plastic deformation of asphalt mixture as an indicator to do a comparative analysis on the change rule of inherent, improved, and composite performances of different composite-modified asphalt mixtures by controlling repeated load times.
3. In terms of fatigue durability, taking fatigue life of different asphalt mixtures as indicators to do a comparative analysis on the change rule of inherent, improved, and composite performances of different composite-modified asphalt mixtures.

### 3. Comparative analysis on inherent and improved performances of asphalt

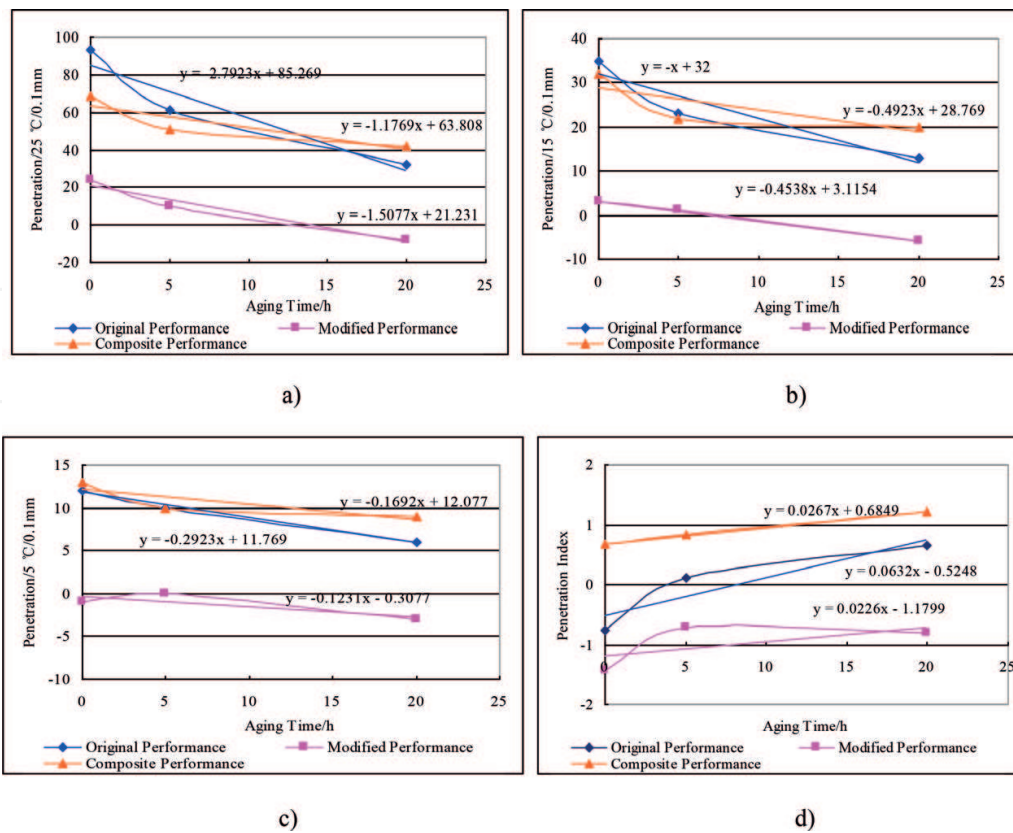
#### 3.1. Comparative analysis of the penetration and PI base on inherent and improved performances

The penetration and PI of the SBS asphalt (90#), TPS asphalt (90#), rubber asphalt (90#), and Sasobit asphalt (90#) based on different performance and aging times are shown in **Figures 2–5**.



**Figure 2.** Relationship between penetration, PI, and aging times of 4% SBS asphalt (90#) with different performances: (a) penetration/25°C; (b) penetration/15°C; (c) penetration/5°C; (d) penetration index.

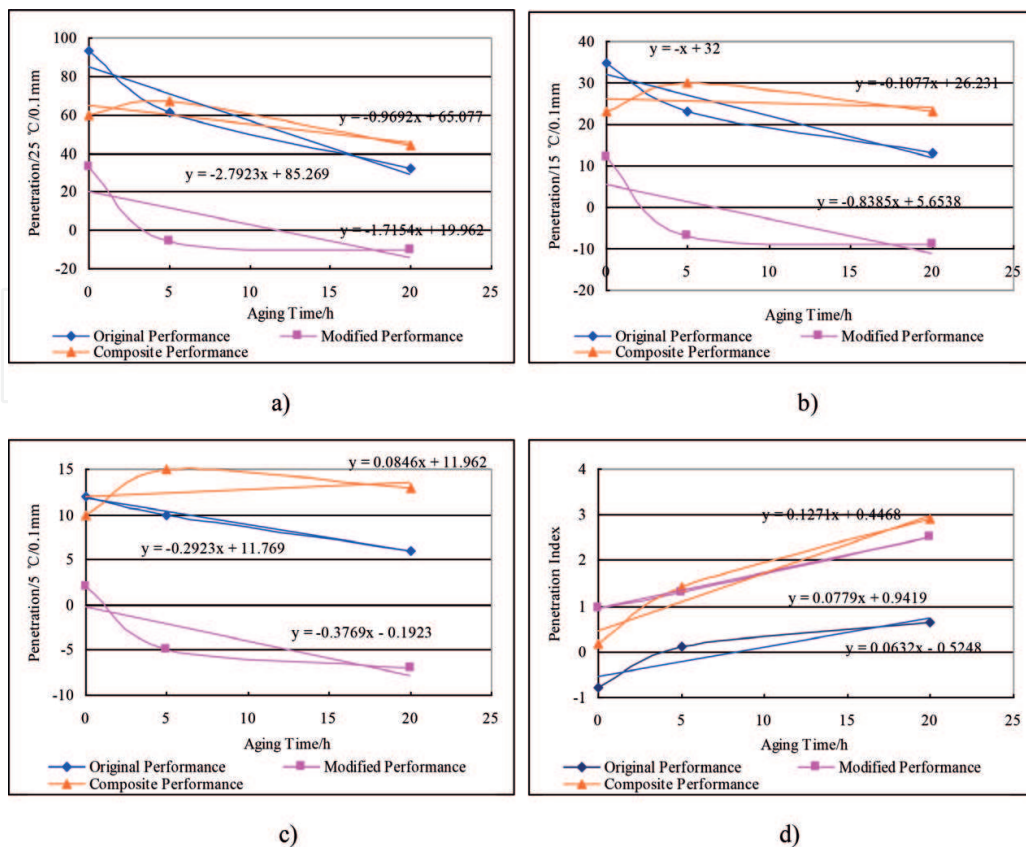




**Figure 3.** Penetration and PI of TPS asphalt (90#) based on different performances and aging times: (a) penetration/25°C; (b) penetration/15°C; (c) penetration/5°C; (d) penetration index.

The following conclusions can be drawn by comparing the data in **Figures 2–5**.

1. In regard to the penetration data (25, 15, and 5°C), the results show that the penetration change rate of the SBS asphalt (90#), TPS asphalt (90#), rubber asphalt (90#), and Sasobit asphalt (90#) based on improved performance (performance at high temperatures) at different temperatures is smaller than that of inherent performance. But the smaller the penetration change rate is, the better the performance at high temperatures. If penetration drops too rapidly during the aging process, this indicates a poor antiaging durability of penetration. So the inherent performance of the SBS asphalt (90#), TPS asphalt (90#), rubber asphalt (90#), and Sasobit asphalt (90#) was better than that of improved performance.
2. In regard to the change rate of the PI regression equation, the results show that the penetration change rate of the SBS asphalt (90#), TPS asphalt (90#), and Sasobit asphalt (90#) based on improved performance at the value of PI is smaller than that of inherent performance. The rubber asphalt (90#) based on improved performance at the value of PI is bigger than that of inherent performance. The smaller the value of PI change rate is, the better the temperature sensitivity of asphalt. So the SBS asphalt (90#), TPS asphalt (90#), and Sasobit asphalt (90#) based on improved performance at the temperature sensitivity is smaller than that of inherent performance. The rubber asphalt (90#) based on improved performance at



**Figure 4.** Penetration and PI of rubber asphalt (90#) based on different performance and aging times: (a) penetration/25°C; (b) penetration/15°C; (c) penetration/5°C; (d) penetration index.

the temperature sensitivity is bigger than that of inherent performance. The results show that the SBS asphalt (90#), TPS asphalt (90#), and Sasobit asphalt (90#) at the temperature sensitivity of improved performance is weak and the antiaging durability of performance at high temperature is better.

### 3.2. Comparative analysis of the ductility based on inherent and improved performances

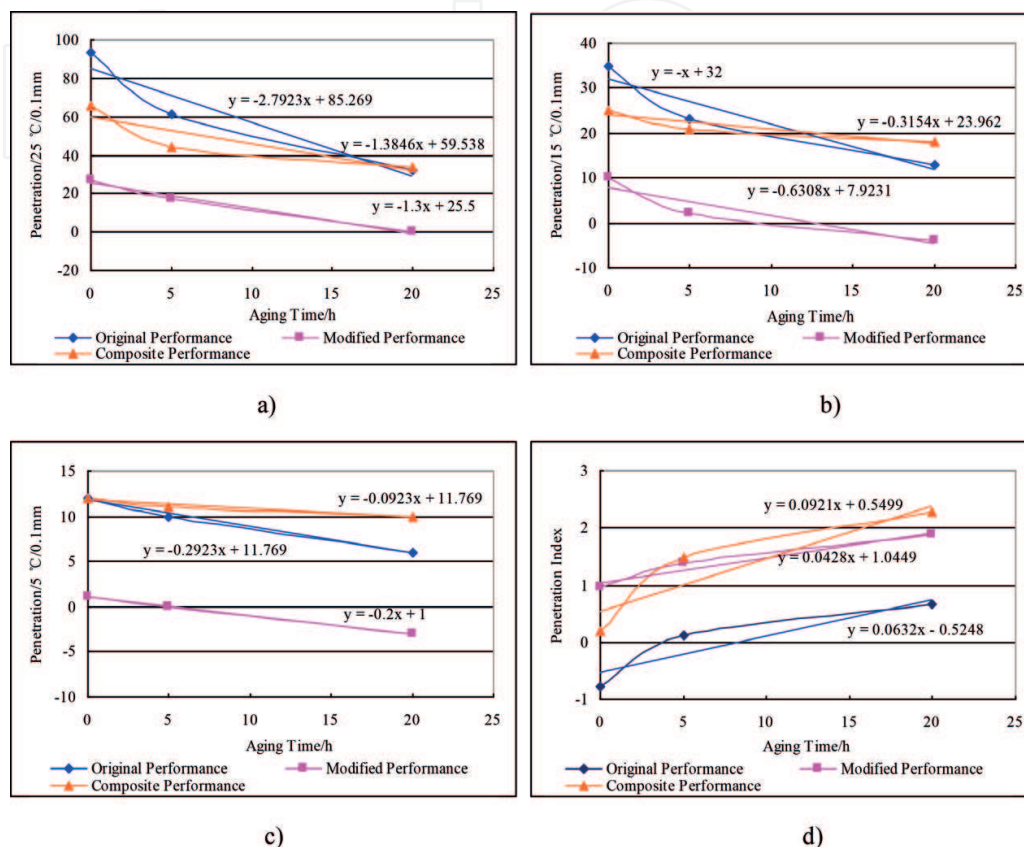
The ductility of SBS asphalt (90#) based on different performance and aging times is shown in **Figure 6**.

The following conclusions can be obtained by comparing the data in **Figures 6–9**.

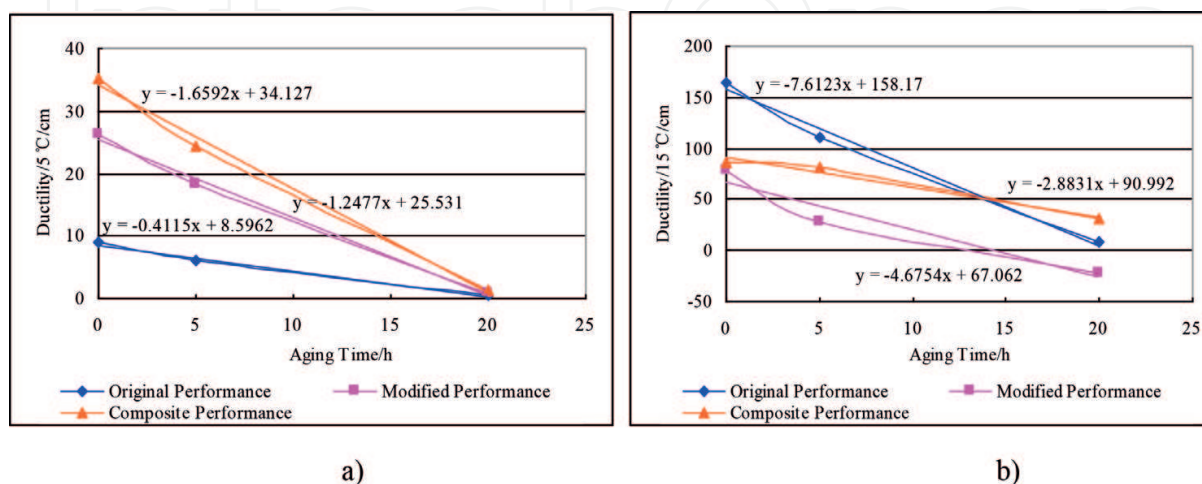
1. In terms of the ductility (5°C, 15°C) data, the results show that the ductility change rate of the SBS asphalt (90#) and TPS asphalt (90#) at 5°C ductility based on inherent performance is smaller than that of the improved performance. The ductility change rate of the rubber asphalt (90#) and Sasobit asphalt (90#) at 5°C ductility based on improved performance is bigger than that of the inherent performance. The larger the ductility at 5°C, the better the performance at low temperatures. So the results show that the antiaging durability of the



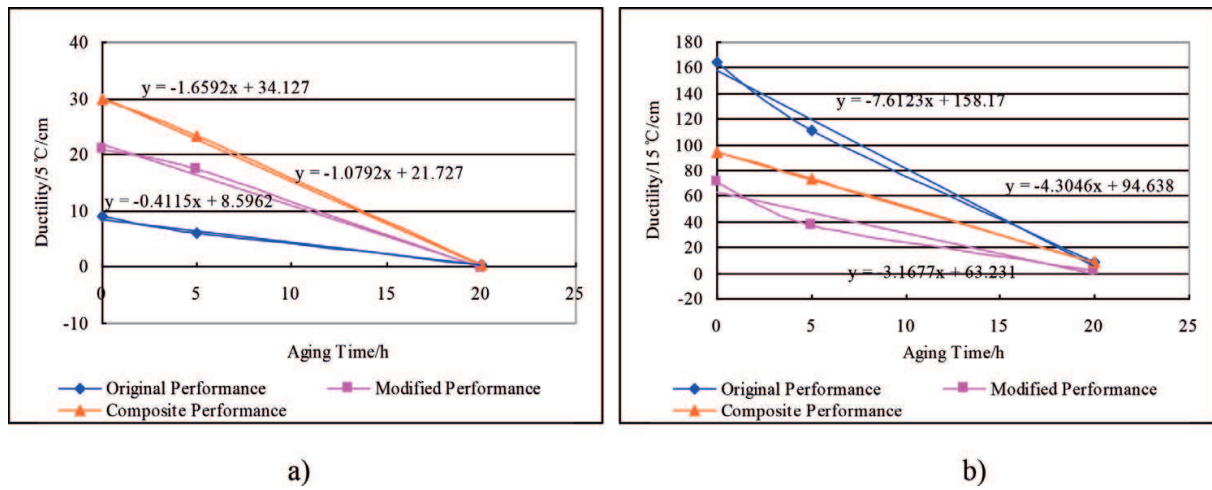
SBS asphalt (90#) and TPS asphalt (90#) at 5°C ductility based on inherent performance (performance at low temperatures) is better than that of the improved performance. The antiaging durability of the rubber asphalt (90#) and Sasobit asphalt (90#) at 5°C ductility based on improved performance (performance at low temperatures) is better than that of the inherent performance.



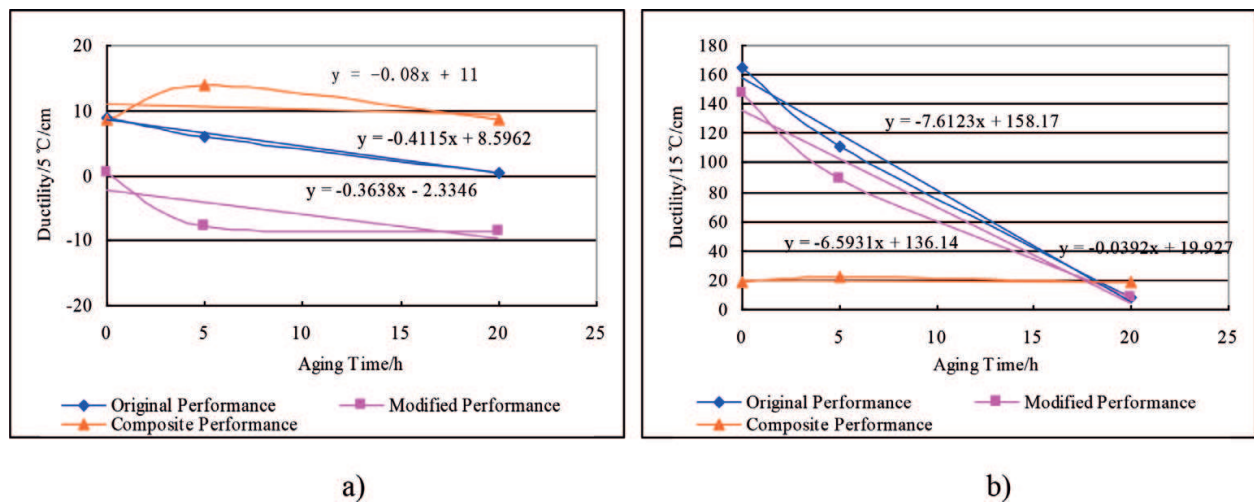
**Figure 5.** Penetration and PI of Sasobit asphalt (90#) based on different performances and aging times: (a) penetration/25°C; (b) penetration/15°C; (c) penetration/5°C; (d) penetration index.



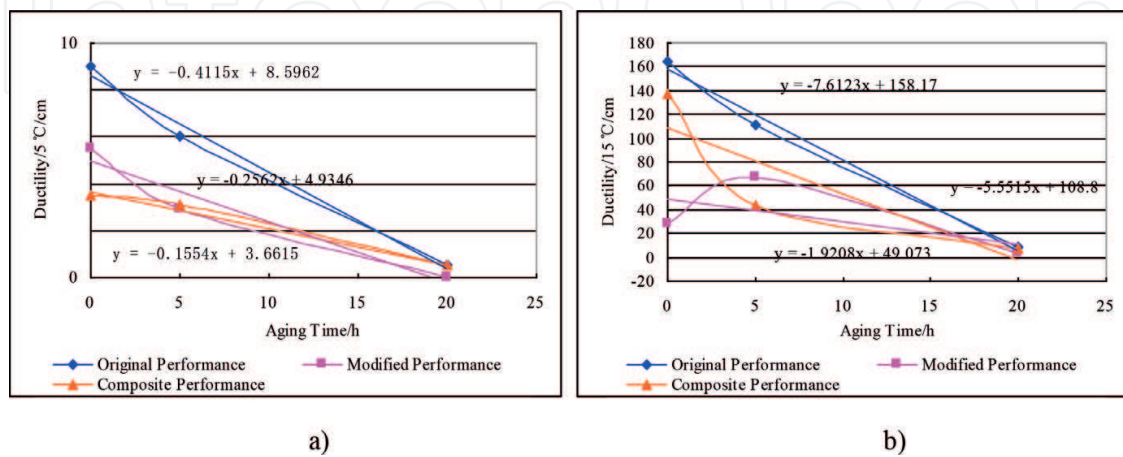
**Figure 6.** Relationship between ductility and aging times of 4% SBS asphalt (90#) with different performances: (a) ductility 5°C and (b) ductility 15°C.



**Figure 7.** Ductility of TPS asphalt (90#) based on different performance and aging times: (a) ductility 5°C and (b) ductility 15°C.



**Figure 8.** Ductility of rubber asphalt (90#) based on different performance and aging times: (a) ductility 5°C and (b) ductility 15°C.



**Figure 9.** Ductility of Sasobit asphalt (90#) based on different performances and aging times: (a) ductility 5°C and (b) ductility 15°C.

2. According to the ductility of 15°C, the results show that the ductility change rate of the SBS asphalt (90#), TPS asphalt (90#), rubber asphalt (90#), and Sasobit asphalt (90#) at 15°C ductility based on improved performance is smaller than that of the inherent performance. The ductility of 15°C is replaced as the elasticity of asphalt. The larger the ductility at 15°C is, the better the performance at the elasticity of asphalt is. So according to the elasticity of asphalt, the SBS asphalt (90#), TPS asphalt (90#), rubber asphalt (90#), and Sasobit asphalt (90#) at the elasticity based on improved performance is smaller than that of the inherent performance.

3.3. Comparative analysis of the softening point and viscosity based on inherent and improved performances

The test results are shown in Figures 10–13.

1. In regard to the comparison of the data, the results show that the softening point change rate of the SBS asphalt (90#), TPS asphalt (90#), rubber asphalt (90#), and Sasobit asphalt (90#) at 5°C ductility based on improved performance is smaller than that of the inherent performance. The larger the softening point, the better the performance at high temperatures. So the high temperatures of the SBS asphalt (90#), TPS asphalt (90#), rubber asphalt (90#), and Sasobit asphalt (90#) based on improved performance are better than that of the inherent performance.
2. According to the 135°C viscosity of asphalt, the results show that the viscosity (135°C) change rate of the TPS asphalt (90#) and Sasobit asphalt (90#) at 135°C viscosity based on improved performance is smaller than that of the inherent performance. The SBS asphalt (90#) and rubber asphalt (90#) based on inherent performance is bigger than that of the improved performance. The results of the 135°C viscosity replace that the hardness of asphalt. The larger the 135°C viscosity is, the better the performance of resistance to load is. So the performance of resistance to load of the TPS asphalt (90#) and Sasobit asphalt (90#) based on improved performance is better than that of the inherent performance. The SBS asphalt (90#) and rubber asphalt (90#) based on inherent performance is better than that of the improved performance.

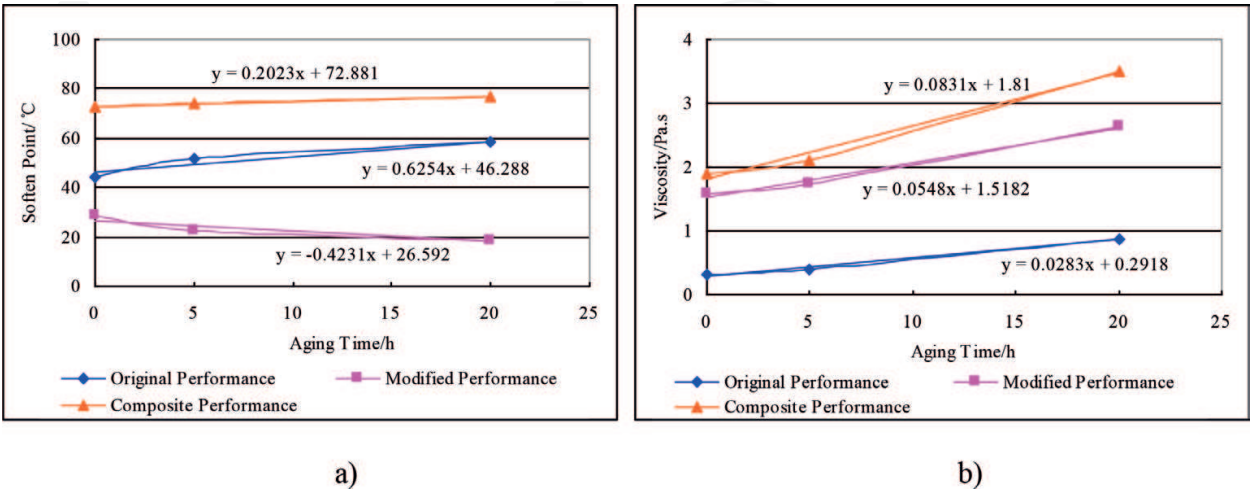
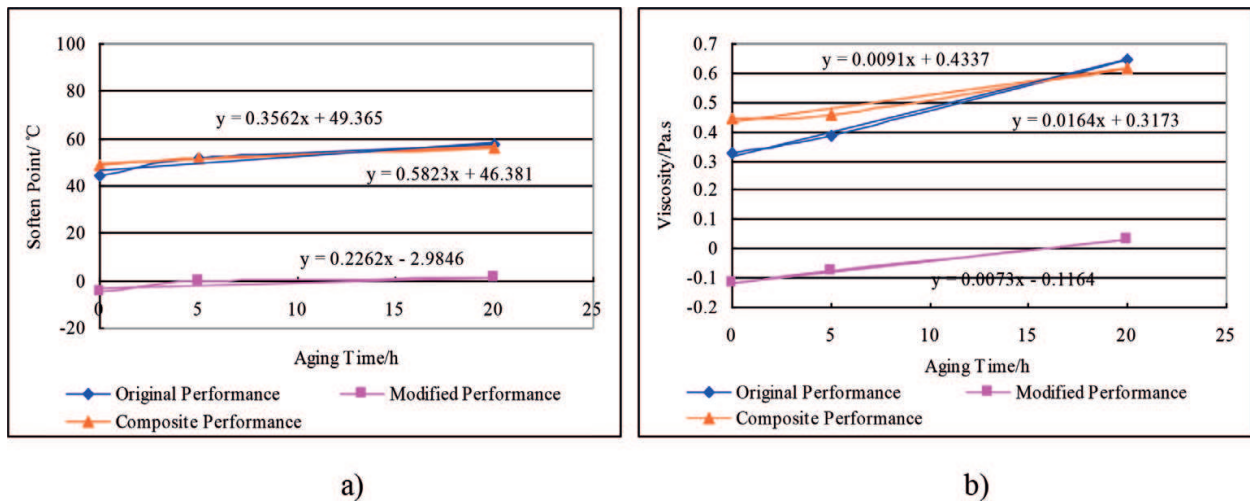
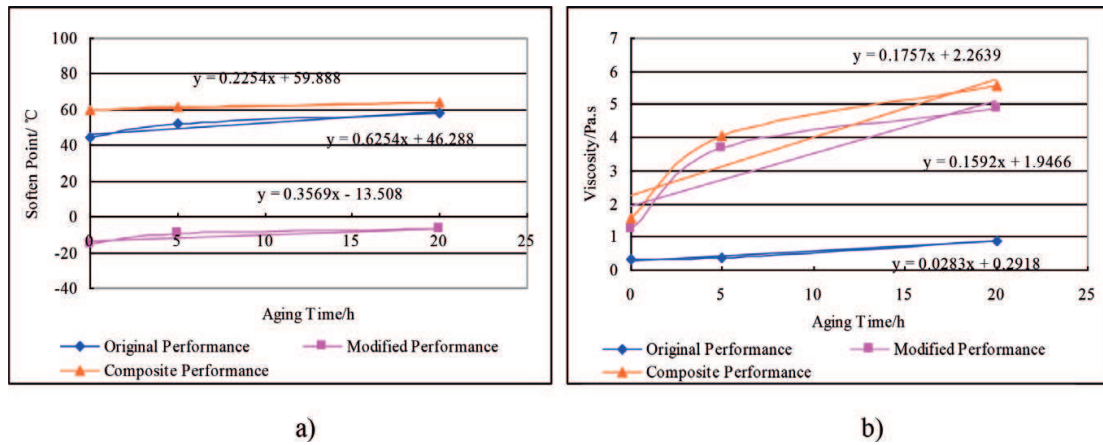


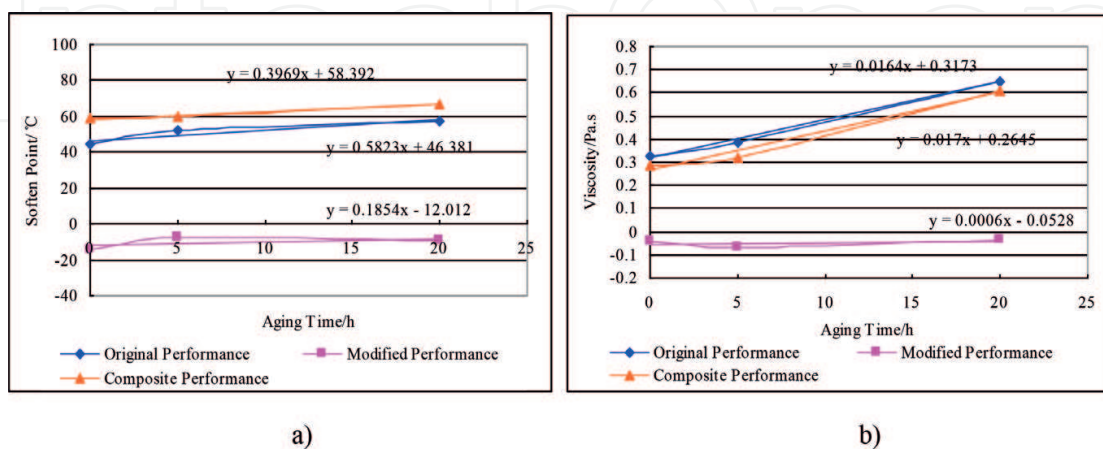
Figure 10. Softening point and viscosity of SBS asphalt (90#) based on different performances and aging times: (a) softening point and (b) viscosity.



**Figure 11.** Softening point and viscosity of TPS asphalt (90#) based on different performances and aging times: (a) softening point and (b) viscosity.



**Figure 12.** Softening point and viscosity of rubber asphalt (90#) based on different performance and aging times: (a) softening point and (b) viscosity.



**Figure 13.** Softening point and viscosity of Sasobit asphalt (90#) based on different performance and aging times: (a) softening point and (b) viscosity.



## 4. Comparative analysis on inherent and improved performances of HMA

### 4.1. Comparative analysis of aging durability

#### 4.1.1. Comparative analysis of durability of 4% SBS/3% SBR asphalt mixture

Test results of the aging durability of the 4% SBS/15% SBR asphalt under different loading times are shown in **Figure 14**.

1. In regard to high-temperature stability and low-temperature stability, the change rate of improved performance under different aging times was better than that of inherent performance. Thus, the aging durability of the 4% SBS/3% SBR asphalt mixture on inherent performance was greater than that of improved performance.
2. In regard to water stability, the change rate of the inherent performance with different aging times was better than the improved performance. As such, the aging durability of the mixture based on improved performance was better than the inherent performance.

#### 4.1.2. Comparative analysis of durability of 4% SBS/15% rubber asphalt mixture

Test results of the aging durability of the 4% SBS/15% rubber asphalt under different loading times are shown in **Figure 15**.

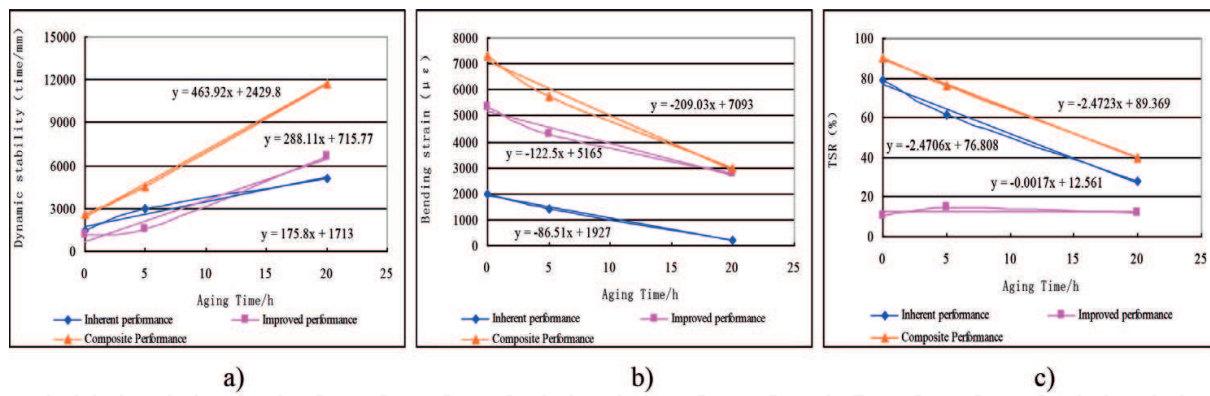
1. Regarding to high-temperature stability, in terms of change rate of the 4% SBS/15% rubber asphalt mixture, the 4%SBS/15% rubber asphalt mixture of inherent performance was less than that of improved performance. Thus, the aging durability of the inherent performance of the mixture was better than the improved performance.
2. Regarding to low temperature and the water stability change rate, the change rate of inherent performance became better than that of improved performance with different aging times. Therefore, in terms of the aging durability of the 4% SBS/15% rubber asphalt mixture, the improved performance of the mixture was better than that of inherent performance.

#### 4.1.3. Comparative analysis of durability of 4% SBR/15% rubber asphalt mixture

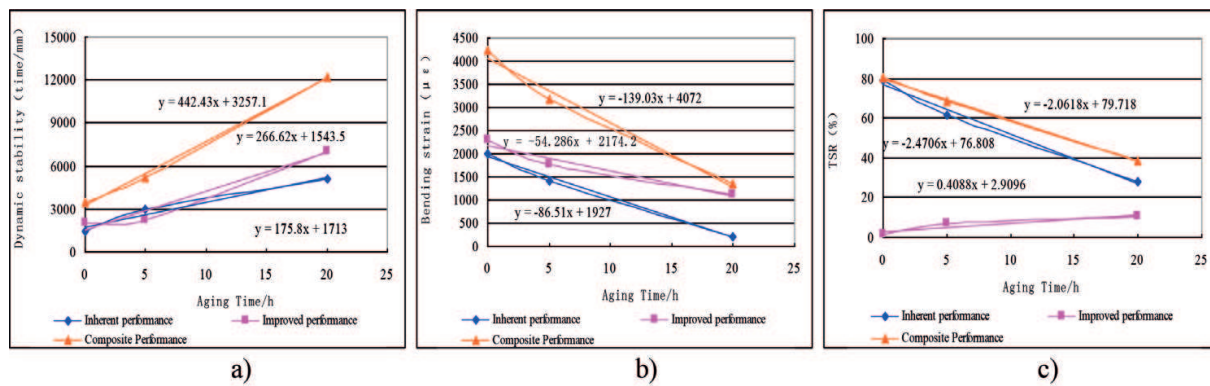
Test results of the aging durability of the 4% SBR/15% rubber asphalt mixture at different aging times are given in **Figure 16**.

1. Regarding to high- and low-temperature stability, in terms of change rate of the 4% SBR/15% rubber asphalt mixture, the change rate of inherent performance was less than improved performance as aging time prolonged. The inherent performance of the mixture was better than that of improved performance.
2. Regarding to water stability, in terms of change rate of the 4% SBR/15% rubber asphalt mixture, the rate change of inherent performance was greater than that of improved performance with different aging times. The aging durability of the improved performance of the 4% SBR/15% rubber asphalt mixture was better than the inherent performance.

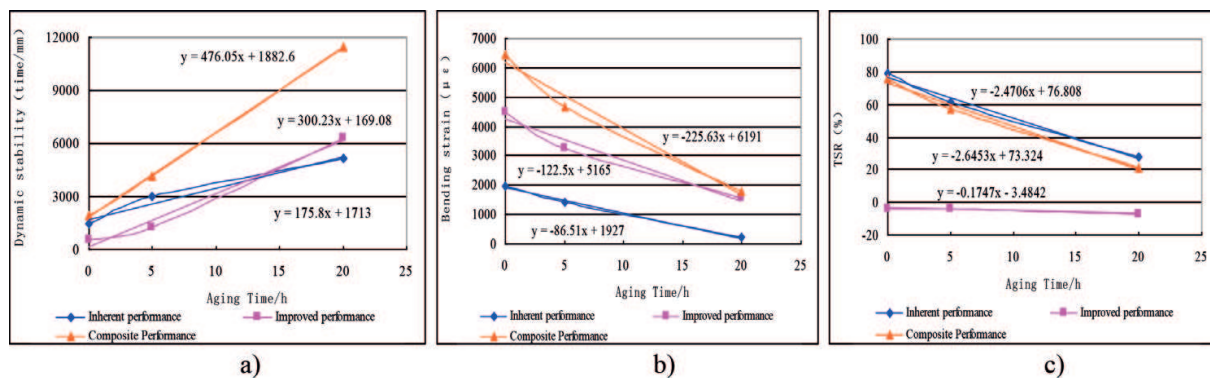




**Figure 14.** Relationship between mechanical properties of 4% SBS/3% SBR asphalt mixture and aging time: (a) dynamic stability; (b) bending strain; (c) TSR.



**Figure 15.** Relationship between mechanical properties of 4% SBS/15% rubber asphalt mixture and aging time: (a) dynamic stability; (b) bending strain; (c) TSR.



**Figure 16.** Relationship between mechanical properties of 4% SBR/15% rubber asphalt mixture and aging time: (a) dynamic stability; (b) bending strain; (c) TSR.

#### 4.2. Comparative analysis of plastic deformation durability

The test results are shown in **Figures 17–19**. With the different time, in terms of the plastic deformation durability, the change rate of 4% SBS/3% SBR, 4% SBS/15% rubber, and 4% SBR/15% rubber of the inherent performance was greater than that of improved performance, implying that the improved performance of the mixture was better than the inherent performance in terms of plastic deformation durability **Tables 8–12**.

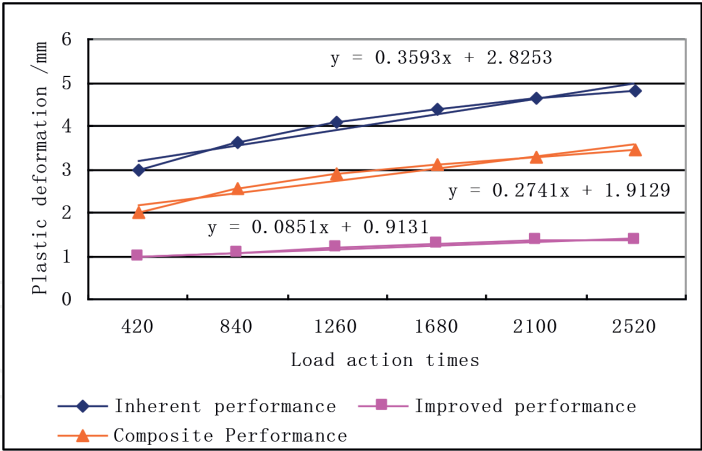


Figure 17. Test results of plastic deformation durability of 4% SBS/3% SBR asphalt mixture.

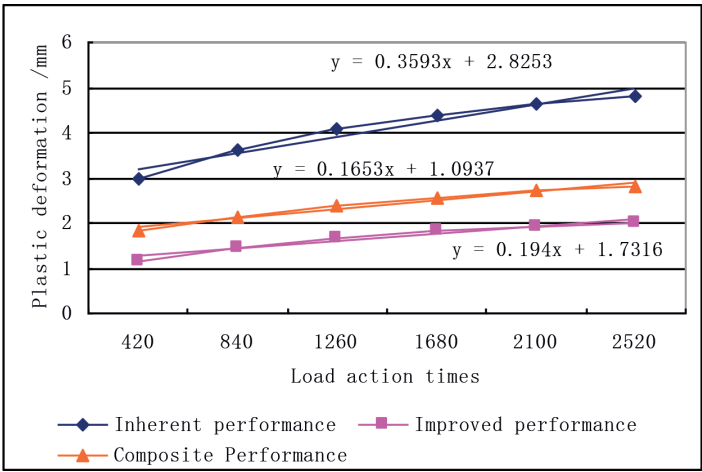


Figure 18. Test results of plastic deformation durability of 4% SBS/15% rubber asphalt mixture.

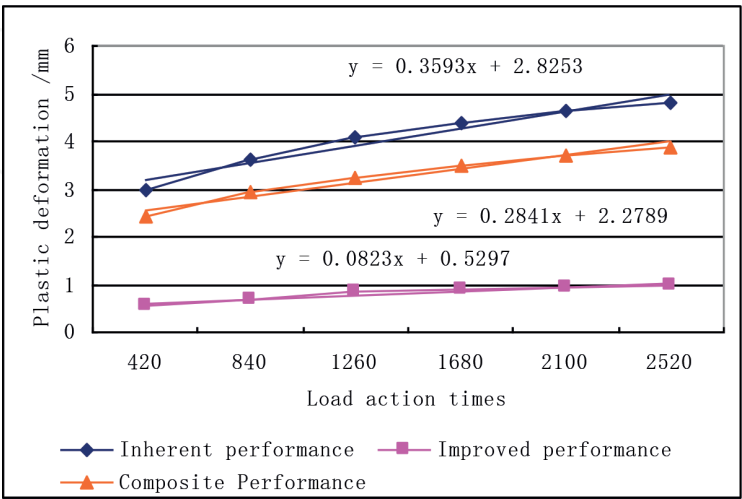


Figure 19. Test results of plastic deformation durability of 4% SBR/15% rubber asphalt mixture.

Asphalt types	Penetration at 5°C	Penetration at 15°C	Penetration at 25°C	PI
SBS asphalt (90#)	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance
TPS asphalt (90#)	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance
Rubber asphalt (90#)	Inherent performance is better than improving performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Inherent performance is better than improving performance
Sasobit asphalt (90#)	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance

**Table 8.** Comparison of penetration and PI based on inherent and improved performances.

Asphalt types	Ductility 5°C	Ductility 15°C
SBS asphalt (90#)	Inherent performance is better than improving performance	Improving performance is better than inherent performance
TPS asphalt (90#)	Inherent performance is better than improving performance	Improving performance is better than inherent performance
Rubber asphalt (90#)	Improving performance is better than inherent performance	Improving performance is better than inherent performance
Sasobit asphalt (90#)	Improving performance is better than inherent performance	Improving performance is better than inherent performance

**Table 9.** Comparison of ductility (5°C, 15°C) based on inherent and improved performances.

Asphalt types	Softening point	Viscosity
SBS asphalt (90#)	Improving performance is better than inherent performance	Inherent performance is better than improving performance
TPS asphalt (90#)	Improving performance is better than inherent performance	Improving performance is better than inherent performance
Rubber asphalt (90#)	Improving performance is better than inherent performance	Inherent performance is better than improving performance
Sasobit asphalt (90#)	Improving performance is better than inherent performance	Improving performance is better than inherent performance

**Table 10.** Comparison of softening point and viscosity based on inherent and improved performances.

Asphalt types	Dynamic stability	Bending strain	TSR
4% SBS/3% SBR asphalt mixture	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance
4% SBS/15% rubber asphalt mixture	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance
4% SBR/15% rubber asphalt mixture	Improving performance is better than inherent performance	Improving performance is better than inherent performance	Improving performance is better than inherent performance

Table 11. Comparison of penetration rate based on inherent and improved performance.

Asphalt types	Dynamic stability	Bending strain
4% SBS/3% SBR asphalt mixture	Plastic deformation durability	Fatigue durability
4% SBS/15% rubber asphalt mixture	Improving performance is better than inherent performance	Improving performance is better than inherent performance
4% SBR/15% rubber asphalt mixture	Improving performance is better than inherent performance	Improving performance is better than inherent performance

Table 12. Comparison of dynamic stability and bending strain based on inherent and improved performance.

4.3. Comparative analysis of fatigue durability

The test results are shown in **Figures 20–22**. The smaller the *k*-value is, the better the performance of fatigue durability is. The test results show that the *k*-value of 4% SBS/3% SBR, 4% SBS/15% rubber, and 4% SBR/15% rubber based on the inherent performance of the mixture exceeded that of improved performance. Therefore, in regard to fatigue life, the inherent performance of

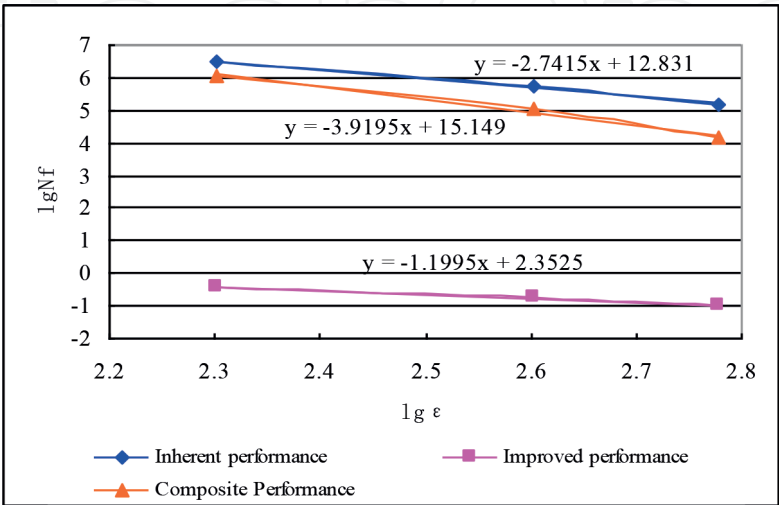
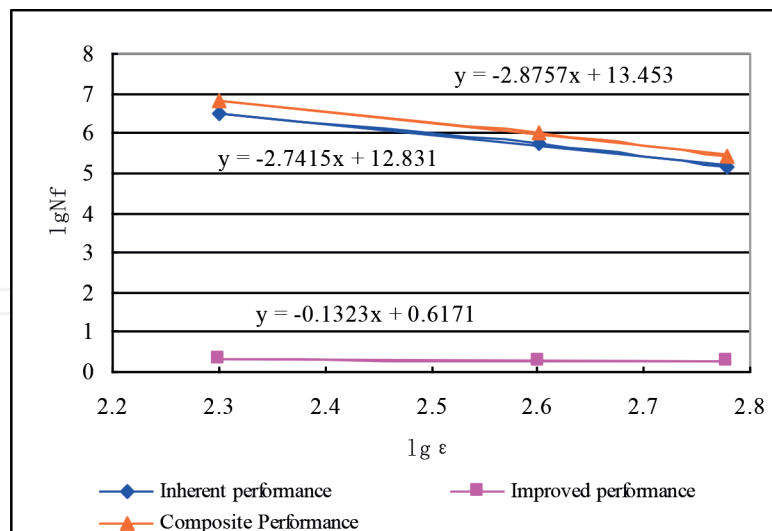
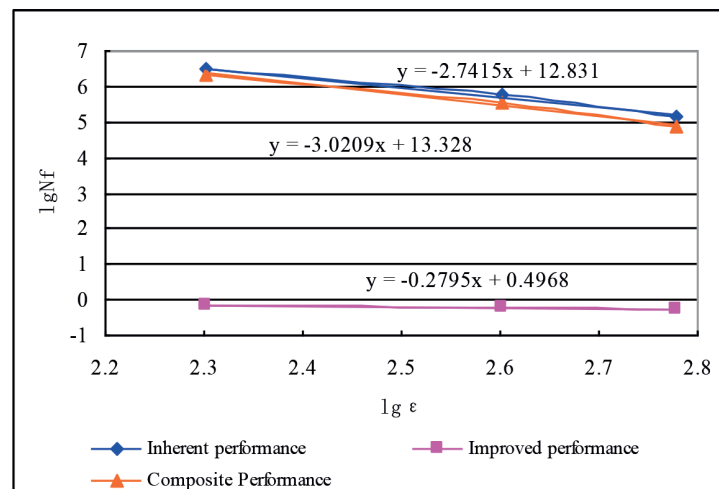


Figure 20. Test results of fatigue durability of 4% SBS/3% SBR asphalt mixture.



**Figure 21.** Test results of fatigue durability of 4% SBS/15% rubber asphalt mixture.



**Figure 22.** Test results of fatigue durability of 4% SBS/15% rubber asphalt mixture.

4% SBS/3% SBR, 4% SBS/15% rubber, and 4% SBR/15% rubber was better than the improved performance. According to the  $n$ -value, the inherent performance of the mixture exceeded the improved performance. The fatigue sensitivity based on the inherent performance of the asphalt mixture was larger than that of improved performance. In regard to the greater the fatigue sensitivity, the worse the fatigue durability. The fatigue durability of the 4% SBS/3% SBR asphalt mixture on improved performance was hence better than the inherent performance.

## 5. Conclusions

1. Through comparative analysis of the antiaged durability of different modified asphalts based on inherent and improved performances, the conclusion can be obtained: for SBS- and TPS-modified asphalt, taking penetration (performance at high temperature) and



5°C ductility (performance at low temperature) as indexes, the antiaged durability of the penetration based on inherent performance is less than that of the improved performance. The antiaged durability of 5°C ductility based on inherent performance is better than that of improved performance. The analysis result of rubber asphalt is contrary to this, which shows the particularity of rubber-modified asphalt.

2. The comparative test results for the durability of composite-modified asphalt based on inherent and improved performances reveal the following: In regard to aging progress, the high and low stabilities of the 4% SBS/3% SBR asphalt mixture and 4% SBR/15% rubber mixture based on inherent performance were better than that of improved performance. Water stability based on improved performance was better than inherent performance. The high-temperature stability of the 4% SBS/15% rubber asphalt mixture based on improved performance was better than that of inherent performance. Low-temperature and water stability based on improved performance were also better than that of inherent performance. Plastic deformation and fatigue durability based on improved performance of these three asphalt mixtures were better than that of inherent performance.
3. The test results of the improved performance durability of CMAMs reveal that the 4% SBS/15% rubber composite modifier was more stable in improving aging durability at high and low temperatures than the other two modifiers. The 4% SBS/3% SBR modifier was more stable in improving water stability. The 4% SBS/15% rubber composite modifier was more stable in improving plastic deformation durability and fatigue durability and should be adopted when selecting composite modifiers with better stability.

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## Conflict of interest

The authors claim no conflicts of interest.

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