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RESEARCH ARTICLE

Rutting and Fatigue Performance Evaluation of Qingchuan Rock Modified Asphalt Mixture

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Abstract: To solve the problem of rutting and fatigue damage to asphalt pavement, rutting and fatigue performances of Qingchuan rock asphalt modified asphalt were studied, based on the dynamic shear rheometer test, the dynamic creep test, the rutting test, the indirect tensile fatigue test, the small-sized acceleration loading test, the compressive resilient modulus test, the BISAR3.0 Program and the rutting calculation method based on dynamic finite element method. The results indicate that Qingchuan rock asphalt modifier can obviously improve the anti-fatigue performance and anti-rutting performance of asphalt pavement. Taking the anti-rutting performance and the raw-material price of asphalt into consideration, a rock asphalt optimum content ranging from 5% to 8% is suggested. Qingchuan rock asphalt is a good modifier to solve the rutting and the fatigue damage of asphalt pavement.

Keywords: Asphalt mixture, Fatigue, Pavement structure, Performance evaluation, Qingchuan rock asphalt, Rutting.

1. INTRODUCTION

With the constant increasing of traffic flow and axle load, the early rut and fatigue failure of asphalt pavement is becoming increasingly serious in China. To solve the problem of early rut and the early fatigue to asphalt pavement, it is an effective method that the rut and the fatigue performances of an asphalt mixture are improved by a rock asphalt modifier. Many studies of rock asphalt have been performed until now. Studies by Siswosoebrotho *et al*. [1], Widyatmoko *et al*. [2], and Yilmaz *et al*. [3] investigated the effect of modifying asphalt mixtures with Gilsonite rock asphalt and found improved performance at higher temperatures. However, there is limited information in the literature that describes the characteristics of other rock asphalts. To solve the rutting distress in asphalt pavements, evaluation of rheological properties and field applications of Buton rock asphalt was performed by Zou Guilian *et al*. [4], and the results show that the Buton rock asphalt modified asphalt concrete mixtures had good rutting performance. To overcome the contradictions between the asphalt standard and the actual performance of the asphalt pavement, based on SHRP testing method, the rheological performance of rock asphalt modified asphalt was studied by Zhongke *et al*. [5], and the results show that thermal stability of asphalt modified by rock asphalt is obviously improved. M. Amer *et al*. [6] found that UM rock asphalt increased the rutting resistance of binder in order to evaluate the potential impact of different rock asphalts (Buton, QC and UM) on the properties and performance of asphalt mixtures, Ruixia Li *et al*. [7] studied rheological and low temperature properties of asphalt composites containing rock asphalts, and the results show that rock asphalts can be used to improve the stiffness and particularly high temperature rutting resistance of asphalt mixtures, and that increased stiffness due to the addition of rock asphalts may adversely affect the low temperature cracking resistance of asphalt composite. The mechanical properties of rock asphalts vary considerably, depending on the type and proportion of its constituents and the type of physical and chemical alteration the rock asphalt undergoes

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over time [1, 8]. Sichuan Qingchuan County in China has rich reserves of rock asphalt. However, the research on this rock asphalt is very limited, especially in the anti-rutting and anti-fatigue performances. Therefore, it is very necessary to study the rutting and the fatigue performances of asphalt modified by Qingchuan rock asphalt systematically.

2. MATERIALS

In this research, Esso AH70 asphalt was chosen as the base asphalt sample, and Qingchuan rock asphalt of Sichuan in China was used as the modifier. The characteristic properties of the Qingchuan rock asphalt are given in Tables **1** and **2**. Coarse aggregate, fine aggregate, and mineral filler used for this study are the crushed limestone. The test values in Tables **3**-**5** reflect the properties of the individual aggregate and mineral filler. Fig. (**1**) shows the two mixtures gradations that were used to produce rock asphalt modified asphalt mixtures.

Table 1. Base asphalt properties.

Properties	Criteria	Results of Esso AH70
Penetration degree at 25 °C (0.1 mm)	60~80	60.0
Ductility at 15 °C (cm)	≥100	>150
Softening point (°C)	≥46	49
Dynamic viscosity at 60 °C (Pas)	≥160	223
Mass loss due to TFOT aging (%)	≤±0.8	-0.36
Penetration degree ratio at 25 °C due to TFOT aging (%)	≥58	61.5
Ductility at 15 °C due to TFOT aging (cm)	≥15	16.2

Table 2. Qingchuan rock asphalt properties.

Properties	Colour	Water content (%)	Flash point (°C)	Passing percentage of sieves (%)		
				1.18 mm	0.3 mm	0.075 mm
Results	Block blown	1.2	>260	100	99.7	24.1

Table 3. Coarse aggregate properties.

Technical indexes	Criteria	Results
Apparent density (g/cm^3)	≥2.5	2.745
Crush value (%)	≤28	20.0
Content of acicular and flaky shape particles (%)	≤15	12.6
Losses of Los Angeles Abrasion Test (%)	≤30	17
Water absorption (%)	≤2	0.36
Asphalt adhesion (graduation)	≥4	4
Impact value (%)	≤28	14.2
Firmness (%)	≤12	0.1
Mud content (%)	≤2	0.4

Table 4. Fine aggregate properties.

Properties	Apparent density (t/m^3)	Water absorption (%)	Sand equivalent (%)	Firmness (%)
Criteria	≥2.50	≤2	≥60	≤12
Results	2.721	0.62	78.4	1.2

Table 5. Mineral filler properties.

Properties	Apparent density (t/m^3)	Water content (%)	Hydrophilic coefficient	Size distributions (%)		
				<0.6mm	<0.15mm	<0.075mm
Criteria	≥2.50	≤1	<1	100	90~100	75~100
Results	2.699	0.932	0.622	100	99.62	77.17

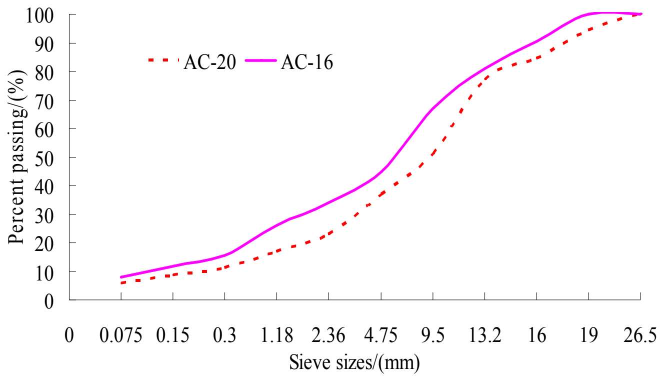

Fig. (1). Aggregate gradations for two trial asphalt mixtures.

Qingchuan rock asphalt modified asphalt was prepared using a FLUKO FM300 high shear emulsifier (Shanghai, China). Prior to shearing with the emulsifier, the base asphalt was heated in a small container until 140 °C. Then, according to the required dose, the rock asphalt was added to the base asphalt. The rock asphalt was melted and mixed, and the rock asphalt penetrated into the base asphalt in the stirring time of 40 minutes and a shearing rate of 3750 r/min, at 175 °C~180 °C. The rock asphalt modifier was gradually combined with the base asphalt during the shearing process to ensure that the modifier was uniformly dispersed in the asphalt.

3. ANTI-RUTTING AND ANTI-FATIGUE PERFORMANCE OF ROCK ASPHALT MODIFIED ASPHALT

3.1. Dynamic Shear Rheometer Test

The dynamic shear rheometer (DSR) is an instrument that measures the viscous and elastic properties of the asphalt binder. A dynamic shear rheometer test was conducted according to AASHTOT315 by using a Bohlin DSRI from the British Malvern company Fig. (**2**) in the strain control mode. During the DSR test, the strain control value of the original asphalt, RTFO-aged asphalt and PAV-aged asphalt was set for 12%, 10% and 1%, respectively, and the speed of concussion was fixed at 10 rad/s. In the DSR test results, the complex shear modulus (G^*) is defined as the ratio of maximum shear stress to maximum strain and provides a measure of the total resistance to deformation. The phase angle (δ) is the phase shift between the applied stress and strain responses during a test and is a measure of the viscoelastic balance of the material behavior [9]. The δ value is larger, and the viscous component of the asphalt increases. When the δ value is smaller, the viscous component of the asphalt decreases. $G^* / \sin\delta$ is defined as the rutting factor, and a high value of $G^* / \sin\delta$ means a strong deformation resistance ability. $G^* \cdot \sin\delta$ is defined as the fatigue factor. According to Superpave specifications, the $G^* / \sin\delta$ value of 1 kPa is limit for unaged sample, and the $G^* / \sin\delta$ value of 2.2 kPa is limit for short term aged sample. The $G^* \cdot \sin\delta$ minimum value must be 5 MPa. The test results are given in Tables **6** and **7**.

Table 6. Rutting factor of asphalt with different rock asphalt content (kPa).

`Temperature (°C)		58	64	70	76	82
Original asphalt	Esso AH70# asphalt	2.7500	1.2475	0.5666		
	+2%rock asphalt		2.0048	1.0023	0.4535	
	+4%rock asphalt		2.8498	1.4584	0.6747	
	+6%rock asphalt		4.0158	1.9776	0.9845	
	+8%rock asphalt		4.7726	2.4055	1.1212	0.6091
RTFO aged asphalt	Esso AH70# asphalt	5.8289	2.3366	0.9396		
	+2%rock asphalt		4.3480	2.2812	0.8743	
	+4%rock asphalt		6.2398	2.5703	0.9690	
	+6%rock asphalt		8.0410	3.3141	1.5570	
	+8%rock asphalt		9.6605	4.3108	2.1075	

Table 7. PAV test results of asphalt with different rock asphalt content.

Asphalt type	Phase angle δ/(°)			Complex shear modulus G^*/(MPa)			Fatigue factor G^* .Sin δ /(MPa)		
	25°C	28°C	31°C	25°C	28°C	31°C	25°C	28°C	31°C
Esso AH70# asphalt	55.16	57.59	59.51	4.783	3.483	2.704	3.926	2.940	2.330
+2%rock asphalt	54.21	56.96	59.12	6.211	4.116	3.211	5.038	3.450	2.756
+4%rock asphalt	53.35	56.23	58.79	7.345	4.867	3.641	5.892	4.053	3.114
+6%rock asphalt	52.81	55.79	58.60	8.249	5.325	3.890	6.571	4.403	3.320
+8%rock asphalt	52.10	55.24	58.35	9.165	5.791	4.270	7.232	4.758	3.635

Fig. (2). Dynamic shear rheometer.

Table **6** shows that for asphalt with rock asphalt modification, the performance high temperature grade increases with an increase in the rock asphalt content. Compared with base asphalt and modified asphalt, the performance high temperature grade of original and RTFO-aged asphalt with 8% rock asphalt modification is PG76 and PG70, respectively, and the performance high temperature grade is improved by two and one temperature grades, respectively. At the same temperature, for the original or RTFO aged asphalt with rock asphalt modification, as the rock asphalt content increases, the rutting factor (G^* / sinδ) increases. Therefore, after the base asphalt is modified by rock asphalt, its high temperature performance is significantly improved, and its anti-rutting performance is obviously enhanced with the increase in the rock asphalt content.

Table **7** shows that the δ value of PAV-aged asphalt with rock asphalt modification decreases with an increase in the rock asphalt content, indicating that the viscous component of the rock asphalt modified asphalt increases, and the elastic component decreases with an increase in the rock asphalt content. The anti-fatigue performance is enhanced. The G^* value obviously increases with an increase in the rock asphalt content, and the $G^* \cdot \sin\delta$ values of rock asphalt modified asphalt exceed the Superpave criterion of 5 MPa at 25 °C, indicating that when the rock asphalt modified asphalt is used in an intermediate temperature zone, as increase in rock asphalt content is increasing fatigue factor which is not good from fatigue point of view. Further studies for the performance of intermediate temperature fatigue cracking resistance of mixtures with rock asphalts will be needed.

3.2. Dynamic Creep Test

Dynamic creep tests of 8% rock asphalt modified asphalt mixture with optimal asphalt content were conducted by using Pneumatic servo test system made by Cooper Research Technology Limited (Fig. **3**), according to the ASTM-D4123 testing program and European standards. But the test conditions such as temperature and axial stress were changed as per suitability. The axial stress of 100 kPa at 60 °C, axial stress of 500 kPa at 15 °C and axial stress of 300 kPa at 40 °C was used for the present research work. The test results of different axial stress at different test temperature are shown in Figs. (**4** and **5**) and Table **8**.

Fig. (3). Creep test of modified asphalt mixture.

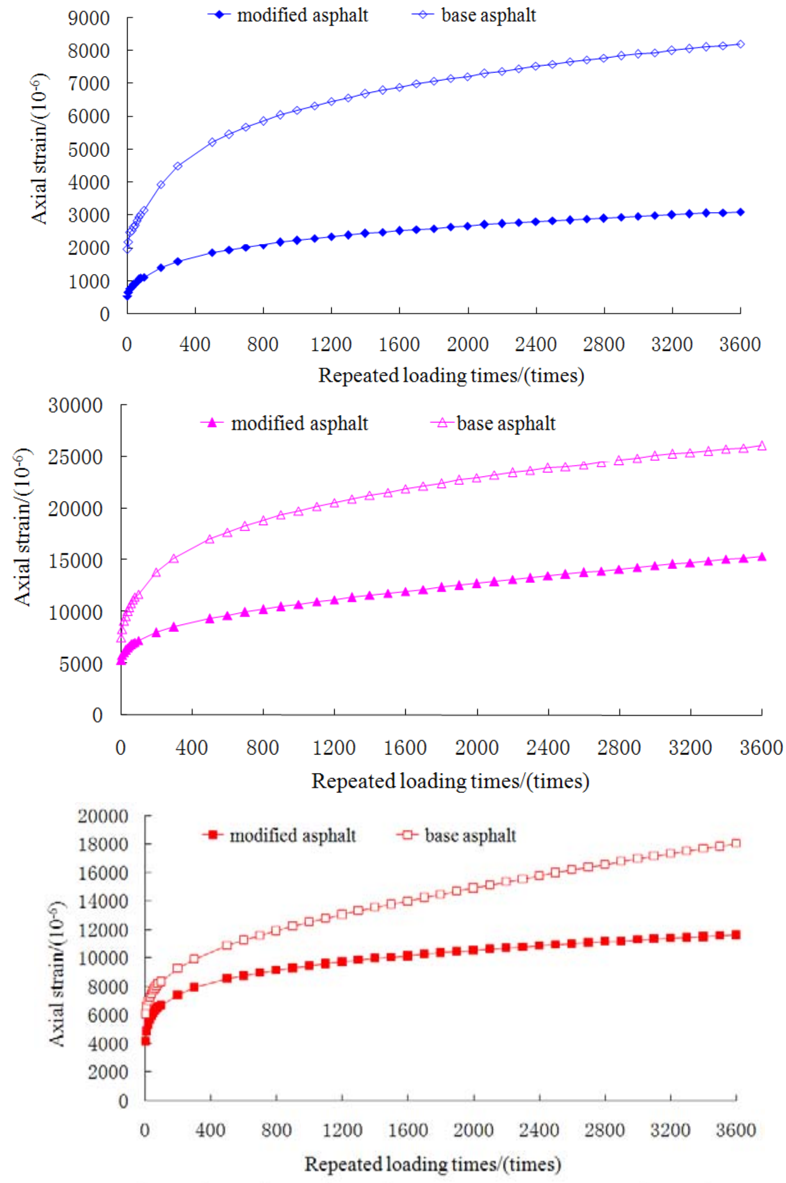

Fig. (4). Creep test results of AC-16.

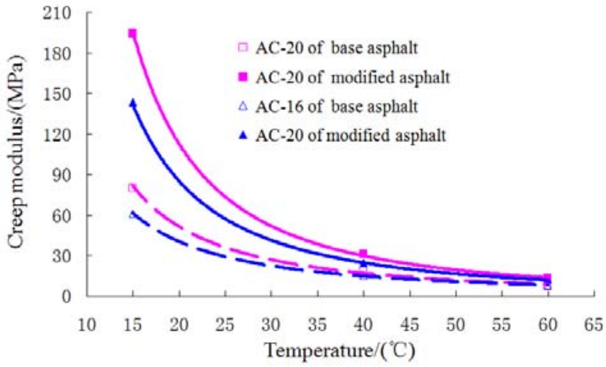

Fig. (5). Creep modulus of asphalt mixtures.

Table 8. Results of dynamic creep test.

Gradation	Test tempereature (°C)	Load level (MPa)	Rock asphalt content (%)	Creep modulus(MPa)	Increase percentage of modulus (%)
AC-16	15	0.5	0	80.08	143
			8	194.55	
	40	0.3	0	16.17	84
			8	29.73	
	60	0.1	0	8.34	61
			8	13.41	
AC-20	15	0.5	0	61.00	135
			8	143.55	
	40	0.3	0	15.27	60
			8	24.43	
	60	0.1	0	7.84	58
			8	12.40	

Fig. (**4**) shows that for the same test temperature and test stress, axial deformation of modified asphalt mixture is much smaller than the axial deformation of base asphalt mixture, and that its axial deformation is about half of the axial deformation of base asphalt mixture.

Table **8** and Fig. (**5**) show that the creep modulus of modified asphalt mixture is higher than the creep modulus of its base asphalt. For AC-16 and AC-20, the creep modulus of modified asphalt mixture at 15 °C increased by 143% and 135% respectively over that of the base asphalt mixture. As the temperature increases, the creep modulus gradually decreases. But for AC-16 and AC-20, the creep modulus of modified asphalt mixture at 60 ° Cincreased by 61% and 58%, respectively, over that of the base asphalt mixture. Therefore, after the base asphalt is modified by rock asphalt, the anti-rutting performance of the asphalt mixture is obviously improved.

3.3. Wheel Tracking Test

Wheel tracking test with wheel pressure of 0.7 MPa at 60 °C for asphalt mixture of different rock asphalt content with optimal asphalt content was conducted to estimate the rutting resistance of the asphalt mixtures by using rutting tester from China. The tests were conducted according to the standard test methods of bitumen and bituminous mixtures for highway engineering (JTJ052-2000) in China.

Fig. (**6**) shows that the dynamic stability of the rock modified asphalt mixture gradually increases with an increase in the rock asphalt content. The dynamic stability of AC-16 with 8% rock asphalt content is 3998 times/mm, which is 3.52 times that of the base asphalt. The dynamic stability of AC-20 with 8% rock asphalt content is 4769 times/mm, it is 3.05 times of the dynamic stability of the base asphalt. When the content of rock asphalt is more than 8%, the dynamic stability increase has not become obvious, and the dynamic stability of the asphalt mixture with 5% rock asphalt content is more than 2800 times/mm, which has met the hot summer area requirement of the specification (JTG F40-2004) for construction of highway asphalt pavement in China. Therefore, after the base asphalt is modified by rock asphalt, the anti-rutting performance of the asphalt mixture is obviously improved.

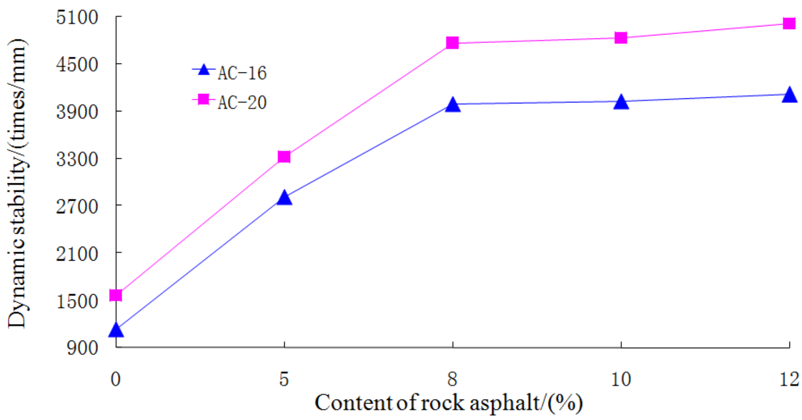

Fig. (6). Dynamic stability of wheel tracking test.

3.4. Anti-rutting Performance of Rock Asphalt Modified Asphalt Pavement

Compressive resilient modulus tests for 8% rock asphalt modified asphalt mixture with optimal asphalt content at 20°C were conducted according to the standard test methods of bitumen and bituminous mixtures for highway engineering (JTJ052-2000) in China. The results are shown in Fig. (**7**).

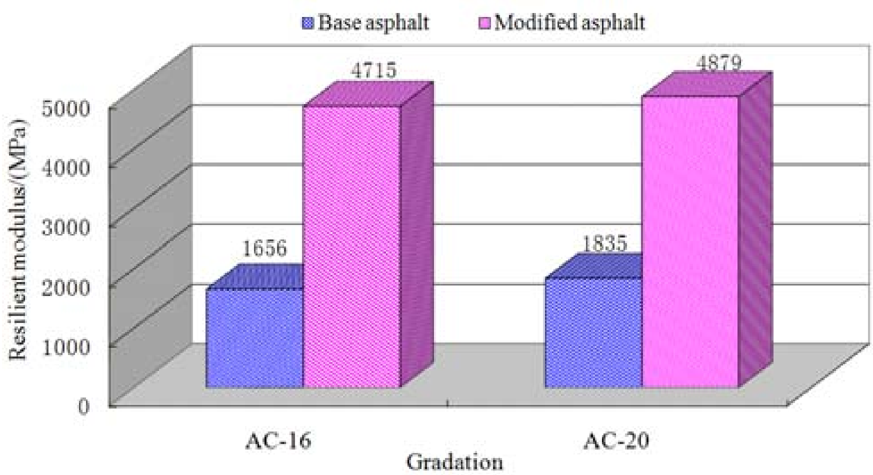

Fig. (7). Results of compressive resilient modulus experiment.

According to Table **9** and Fig. (**8**), for asphalt layers, the shear strains of sixteen points were calculated in 1cm-depth intervals by using the BISAR3.0 Program. To consider the modulus influence of an asphalt layer on shear strain, only the modulus of an asphalt layer is changed at a time. Considering that the shear strain which causes the rutting of asphalt pavement mainly occurs in the asphalt surface layer [10], only the shear strain of asphalt layer (upper surface course, middle surface course, under surface course and ATB base course) is calculated. The maximum shear strain of a point is the maximum value of 16 calculation points. The calculation results of the maximum shear strain are shown in Fig. (**9**).

Fig. (**7**) shows that For AC-16 and AC-20, the resilient modulus of 8% rock asphalt modified asphalt mixture is 2.85 times, 265 times the resilient modulus of the base asphalt mixtures, respectively. Therefore, after the base asphalt is modified by rock asphalt, the resilient modulus of the asphalt mixture is obviously increased. Fig. (**9**) shows that as asphalt resilient modulus of each layer increases, the maximum shear strains decreases significantly. Therefore, the anti-rutting performance of asphalt pavement can be obviously improved by using the rock asphalt modified asphalt mixture of high modulus.

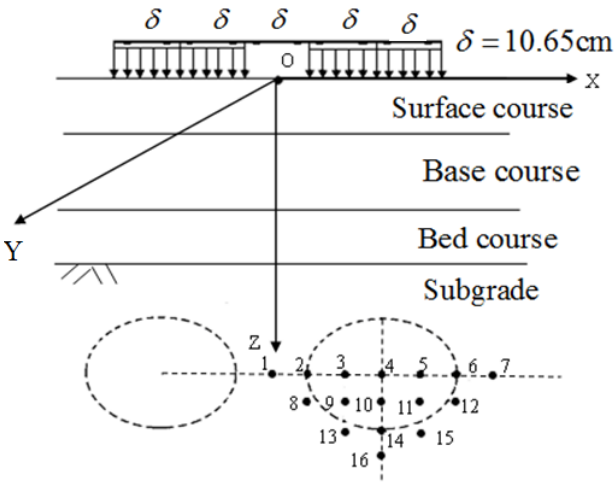

Fig. (8). Analytical model and distribution of calculation point.

Table 9. Pavement structure and its parameters for calculation.

Structure D	**Resilient modulus(MPa)**	**Poisson ratio**
4cm SMA13 (Upper surface course)	2200	0.35
6cm SUP20 (Middle surface course)	2100	0.35
8cm SUP25(Under surface course)	2000	0.35
8cm ATB25 (ATB base course)	1100	0.35
20cm Cement stabilized aggregate	1200	0.2
20cm Lime soil	200	0.3
`subgrade	45	0.4

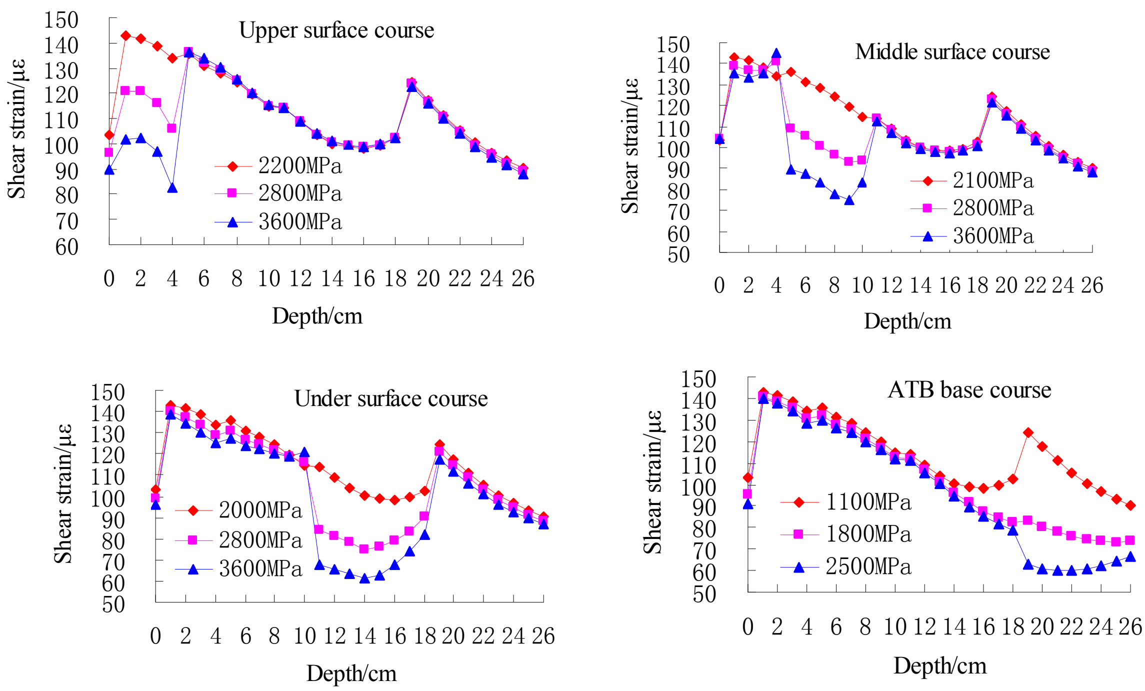

Fig. (9). Effects of asphalt layer resilient modulus on maximum shear strain.

The rutting calculation method of literature [11] is used. Structure A Table **10** parameters of pavement for calculation is shown Table **11**. The test and calculation results are shown in Fig. (**10**). The error between the calculation results and the test data is 8.5%, and it is reasonable and reliable. Materials model uses Burgers model. According to literature [11], material parameters (E_1, η_1, E_2, η_2) of Burgers model and the prony series parameters (g_1, g_2, τ_1, τ_2) of Burgers model needed in ANSYS can be obtained. The calculation pavement structure and parameters are listed in Tables **10-12**, respectively. The repetition times of axle load are 4.2×10^5 times. The rut calculation results are shown in Fig. (**11**).

Table 10. Calculation pavement structure.

Structure A	Structure B	Structure C
4 cm AC-13C	4 cm AC-13C	4 cmAC-13C
6 cm AC-20C	6 cm AC-20C	6 cm AC-20 (8% rock asphalt modified asphalt)
8 cm AC-25C	8 cm AC-25C	8 cm AC-25C
19 cm Cement Stabilized aggregate	8 cm ATB-25	8 cm ATB-25
19 cm lime-flyash stabilized aggregate	20cm Cement Stabilized aggregate	20 cm Cement Stabilized aggregate
20 cm Lime soil	20 cm Lime soil	20 cm Lime soil
subgrade	subgrade	subgrade

Table 11. Parameters of the calculation pavement structure.

Material	Elastic modulus (MPa)	E_1 (kg/cm^2)	E_2 (kg/cm^2)	η_1 (kg/cm^2.s)	η_2 (kg/cm^2.s)
AC-13C	1400	3200	624	1712311	108865
AC-20C	1200	2800	461	180651	99462
AC-25C	1000	2200	505	1712311	113490
-	Elastic modulus (MPa)	Poisson ratio	Friction angle(°)	Cohesive force (kPa)	Density (kg/m^3)
Cement Stabilized aggregate	1500	0.25	-	-	2400
lime-flyash stabilized aggregate	1400	0.25	-	-	2000
Lime soil	550	0.35	22	55	1930
`subgrade	48	0.40	16	30	1900

Table 12. Prony series of Burgers model of AC-20 (8% rock asphalt modified asphalt).

Temperature(°C)	g_1	g_2	τ_1	τ_1
15	0.19	0.81	69963.61	1059.12
40	0.29	0.71	81107.68	1365.47
60	0.29	0.71	31275.72	5434.80

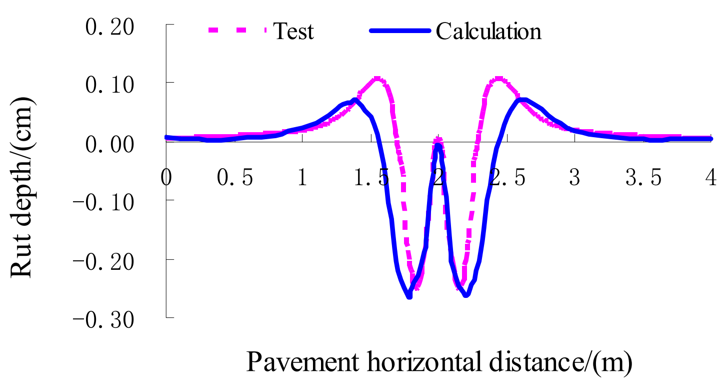

Fig. (10). Rut depth of test and calculation.

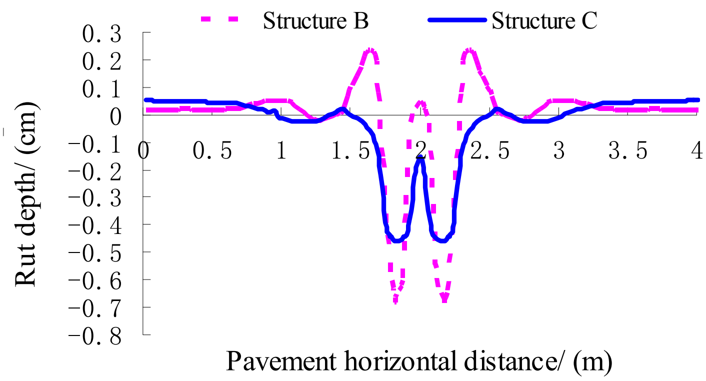

Fig. (11). Rut depth of different pavement structure.

Fig. (**11**) shows that the rut depth of structure B and C is 9.15mm, 5.12 mm, respectively. Rutting depth of pavement structure C decreases 44% than pavement structure B, but in the material of asphalt middle course, pavement structure C is different from the pavement structure B, which indicates that rock modified asphalt concrete used middle course can significantly enhance the anti-rutting performance of asphalt pavement.

3.5. Fatigue Test

The indirect tensile fatigue test was conducted to estimate the anti-fatigue performance of asphalt mixtures by using an asphalt mixture pneumatic servo-test system UN-14 (Fig. **12**) at 15°C, and the strain control mode and the half vector wave loading with an unloading time 4 times the loading are adopted. The critical value of the fatigue damage is the specimen vertical deformation of 6 mm. The indirect tensile fatigue tests with 8% rock asphalt modified asphalt mixture with optimal asphalt content were conducted according to the standard test methods of bitumen and bituminous mixtures for highway engineering (JTJ052-2000) in China. But the test condition of the horizontal tension stress is changed. The horizontal tension of 0.7 MPa, 0.85 MPa, and 1 MPa was used, respectively. The results are shown in Figs. (**13** and **14**).

Fig. (12). Asphalt mixture servo-pneumatic test system.

Fig. (**13**) shows that under the same experimental conditions, the fatigue life of the rock asphalt modified asphalt mixture of AC-16 and AC-20 are 18 times and 15.6 times, respectively, the fatigue life of the base asphalt mixture, and the fatigue life of the rock asphalt modified asphalt mixture is much higher than the fatigue life of its base asphalt mixture, indicating that the rock asphalt modifier makes a significant contribution to improving the anti-fatigue performance of the asphalt mixture.

Fig. (**14**) shows that the anti-fatigue performance of rock asphalt modified asphalt mixture obviously decreases with the increasing tension stress and is becoming more prominent under low stress. Through curve regression, the stress-fatigue equation is obtained as follows.

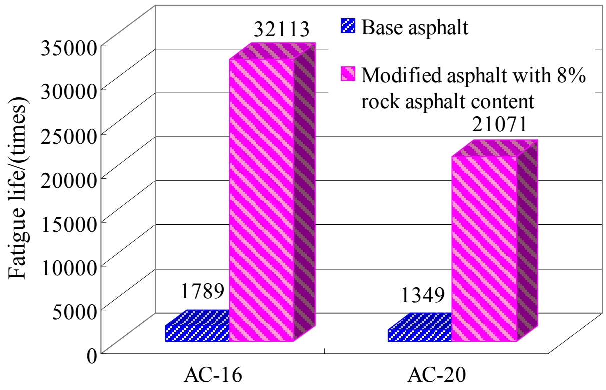

Fig. (13). Fatigue test results with horizontal tension stress 0.7MPa.

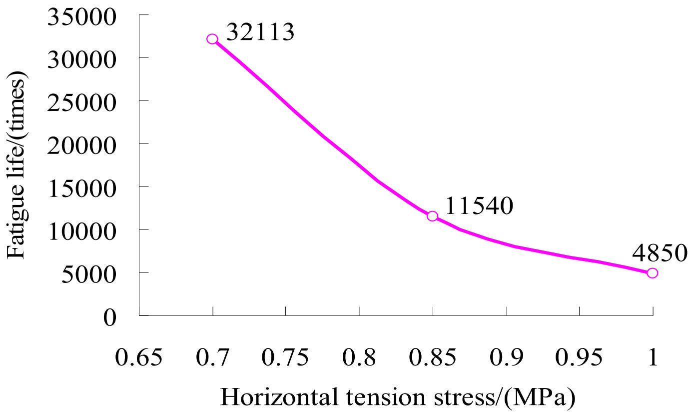

Fig. (14). Fatigue test results of AC-16.

$$\lg N = 6.411\text{-}2.7367\sigma \ (R^2 = 0.9977) \quad \textbf{(1)}$$

where

N= the fatigue life of the rock asphalt modified asphalt mixture, times;

σ=horizontal tension stress, MPa.

3.6. Long-term Performance

The small-size acceleration loading test was conducted to estimate the anti-fatigue long-term performance of asphalt mixtures by using small acceleration test equipment MMLS3 at an axle load of 0.7 MPa and a loading rate of 6000 times/h. Large Marshall test specimens of the asphalt mixture with a height of 95.3 mm were made. From a 5-cm thickness section of the middle of the large Marshall test specimen, the test specimen for the small acceleration test was made by cutting it according to the standard mold sizes. To simulate the asphalt pavement fatigue damage under the vehicle load, the acceleration loading test at a normal atmospheric temperature was performed at room temperature (15~25 °C).To simulate the anti-permanent deformation ability of the asphalt pavement at high temperatures and under heavy load, the acceleration loading test at high temperature was conducted at 60 °C, and the test specimen needs to preheat for 3 h at 60 °C before the test [12]. The optimum oil-stone ratio of the modified asphalt mixture with 0, 5%, 7.5%and 10% rock asphalt content is 4.87%, 4.62%, 4.44% and 4.32%, respectively. The results are shown in Figs. (**15** and **16**).

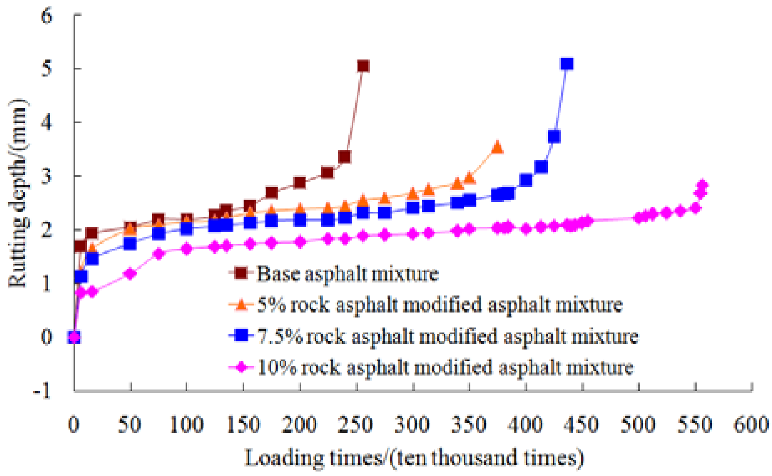

Fig. (15). Results of rutting depth at room temperature.

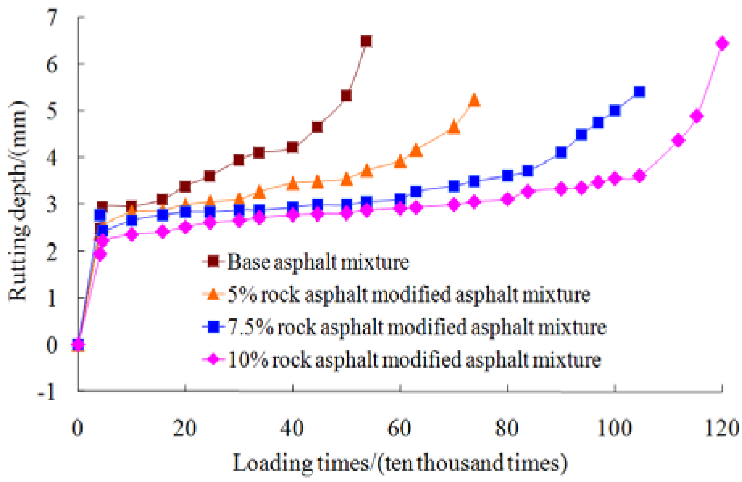

Fig. (16). Results of rutting depth at 60 °C.

Fig. (**15**) shows that the loading times for the shear instability of the base asphalt mixture, and the modified asphalt mixtures with the rock asphalt content of 5%, 7.5% and 10% are 250, 350, 400 and 550 ten thousand times, respectively. Fig. (**16**) shows that the loading times for the shear instability of the base asphalt mixture and the modified asphalt mixtures with the rock asphalt content of 5%, 7.5% and 10% are 30, 50, 80 and 100 ten thousand times, respectively. These indicate that rock asphalt modifier can significantly improve the anti-fatigue performance and anti-rutting performance of the asphalt mixture, and they increase with the increasing rock asphalt content. The anti-fatigue performance and anti-rutting performance of 10% rock asphalt modified asphalt mixture increased by 120% and 233%, respectively, over that of the base asphalt.

CONCLUSION

After the base asphalt is modified by rock asphalt, the anti-rutting performance of the asphalt mixture is obviously improved. Taking the anti-rutting performance and the raw-material price of asphalt into consideration, a rock asphalt optimum content ranging from 5% to 8% is suggested. The anti-rutting performance of asphalt pavement can be obviously improved by using the rock asphalt modified asphalt mixture of high modulus. Rock modified asphalt concrete used middle course can significantly enhance the anti-rutting performance of asphalt pavement. Rock asphalt modifier can significantly improve the anti-fatigue performance of the asphalt mixture too. The anti-fatigue performance of 10% rock asphalt modified asphalt mixture increased by 120% over that of the base asphalt.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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