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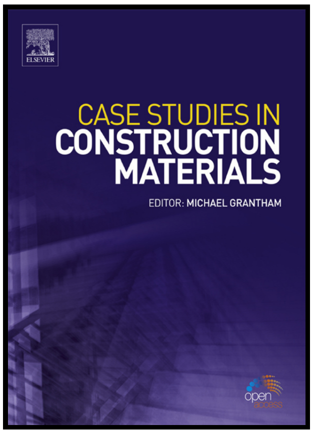

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Research on skid-resistance durability of high viscosity modified asphalt mixture by accelerated abrasion test

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Abstract: To evaluate influence of external environment and material composition on skid-resistance durability of high viscosity modified asphalt (HVMA) mixture, the accelerated abrasion test was selected to simulate decay of skid resistance for asphalt mixture by setting different test conditions. The influence of aggregate gradation, asphalt type, ambient humidity and overload on skid-resistance durability of asphalt mixture was discussed, and the significant effect of selected factors on skid-resistance durability of asphalt mixture was revealed. The results show that the skid-resistance durability of SMA-13 (Stone Mastic Asphalt) mixture is better than OGFC-13(Open Graded Friction Course) and PA-13 (Porous Asphalt) mixture under different conditions, and attenuation rate of different indexes of SMA-13 mixture is 1.6~2.2% and 0.8~2.1% lower than compared with OGFC-13 and PA-13 mixture. The attenuation rate of texture depth for asphalt mixture is closely related to aggregate gradation and asphalt, but the attenuation rate of british pendulum number for asphalt mixture with the same mineral aggregate is only significantly affected by the asphalt. The skid resistance of SMA-13 and PA-13 mixture is improved slightly by addition of high viscosity modified asphalt. The attenuation rate of texture depth of SMA-13 and PA-13 mixture with HVMA is reduced about 0.6~3.0% and 2.2~4.2% than SBS modified asphalt, but the attenuation rate of british pendulum number of above mixtures is increased about 1.2~1.6% and 0.3~1.7%. The skid-resistance durability of asphalt mixture with TPS (TAFPACK-Super) and SINOTPS high viscosity agent is better than HVA (High viscosity additive). The skid-resistance durability of asphalt mixture based on texture depth is improved under wet condition. However, the skid-resistance durability of asphalt mixture for british pendulum number gets worse due to water intrusion. The skid-resistance durability of asphalt mixture is rapidly decreased under overload condition. The influence of overload and SBS modified asphalt on skid-resistance durability of asphalt mixture is higher than ambient humidity and HVMA. This paper will provide foundation for high viscosity modified asphalt applied in asphalt pavement.

Key words: road engineering; accelerated abrasion test; high viscosity modified asphalt; skid-resistance durability

1 Introduction

The surface layer of asphalt pavement is directly contact with tire, and automobile stability during running is affected by skid resistance of asphalt pavement. The skid resistance of asphalt pavement is inevitably degraded under the synthetic effect of vehicle load, natural environment and asphalt aging, so the traffic accident is occurred frequently [1]. The skid resistance of asphalt pavement remains at a high level, and it is conducive to reduce traffic accident rate. Now, the skid resistance of asphalt mixture is required to evaluate in the quality acceptance of asphalt pavement. But the skid resistance of asphalt pavement in the early stage is inconsistent with skid-resistance durability. The skid-resistance durability of different asphalt mixture needs a long term to test. Zhu et al. [2] has evaluated the long-term skid resistance of SAS-16, GAC-16 and AC-16 mixture with SBS modified asphalt, and found that the long-term skid resistance of asphalt mixture is affected by the oil-stone ratio (asphalt-aggregate ratio), gradation type and coarse aggregate type. Besides the initial and final values as well as the attenuation trend of texture depth for AC-16, SAS-16 and GAC-16 mixture is different, which is related to that the 4.75 mm sieve passage rate of AC-16 is higher than SAS-16 and GAC-16. Huang et al. [3] has studied that frictional coefficient of AC-13I, SAC-13 and SMA-16 mixture with different coarse aggregate is little difference at the initial stage, but the BPN of AC-13I, SAC-13 and SMA-16 mixture is 15.5, 25 and 27 after repeated loading of 70×10^4 circles, which is related to surface feature and polish value of coarse aggregate. Tan et al. [4] has found that skid-resistance durability of SMA-10 mixture is lower than UTAC-10 mixture, but the initial BPN of SMA-10 mixture is better. The aggregate gradation of above mixture is fundamentally the same, but the optimum asphalt content of UTAC-10 mixture is relatively low. So it is necessary to study the skid-resistance durability and influencing factors of asphalt mixture. Besides, the skid-resistance durability of asphalt mixture is closely related to mechanical property of aggregate, volume ratio of mixture, nominal maximum aggregate size[5~7]. But the influence of external conditions on skid-resistance durability of asphalt mixture has been paid little attention.

The road performance and strength of asphalt mixture are significantly affected by the asphalt performance. With the increasing of traffic and vehicle load, the requirements for road performance is also increased, so the modified asphalt is applied widely in road pavement, such as SBS modified asphalt, rubber modified asphalt, composite modified asphalt and high viscosity modified asphalt[8~14]. The high viscosity modified asphalt has much larger viscosity, which can help to bond mineral aggregate[14~15]. The high viscosity modified asphalt is usually applied in steel deck surfacing with SMA mixture, drainage pavement and stress absorbing layers. Geng et al. [16] has pointed out that the rut resistance, fatigue resistance and moisture susceptibility of SMA-5 mixture with high viscosity modified asphalt is better than SBS modified asphalt, and dynamic stability, fatigue life and TSR of SMA-5 mixture with high viscosity modified asphalt is improved by 1.73 times, 3 times and 1.12 times than that of SBS modified asphalt mixture. Zhao et al. [17] studied road performance of OGFC-13 mixture with different modified asphalt, and found that the rut resistance and low temperature crack resistance of OGFC-13 mixture with high viscosity modified asphalt is superior to OGFC-13 mixture with SBS modified asphalt. Ma et al.[18] has studied the road performance of AC-13 asphalt mixture with SBS/rubber crumb high viscosity modified asphalt, TPS modified asphalt and SBS modified asphalt, and found that the temperature stability and fatigue life of high viscosity modified asphalt with SBS and rubber crumb is better than TPS modified asphalt and SBS modified asphalt. Du et al. [19] found that the performance of high viscosity modified asphalt, composite modified asphalt, SBS modified asphalt and rubber asphalt is sequentially decreased except temperature sensitivity and adhesion, the comprehensive performance of high viscosity modified asphalt is best.

The mechanical property and road performance of asphalt mixture are improved by the addition of high viscosity modified asphalt, but influence factor of skid-resistance durability for SMA and drainage asphalt mixture with high viscosity modified asphalt is unclear. Therefore, the skid-resistance durability of different asphalt mixture with high viscosity modified asphalt was studied by accelerated abrasion test in this paper. The texture feature of pavement is measured by the pendulum friction tester and method based on image processing technique. The effect of aggregate gradation, asphalt type, ambient humidity and overload on skid-resistance durability of asphalt mixture is analyzed under different test conditions, and attenuation of the skid resistance for asphalt mixture with high viscosity modified asphalt is also discussed. The experimental data from skid-resistance durability of different asphalt mixture is analyzed by the SPSS software. Finally the impact of different factors on skid-resistance durability of asphalt mixture is revealed. The influence of external conditions on skid-resistance durability of asphalt mixture is studied, which is conducive to understand the decay mechanism of skid resistance for asphalt pavement.

2 Materials and test method

2.1 Test Materials

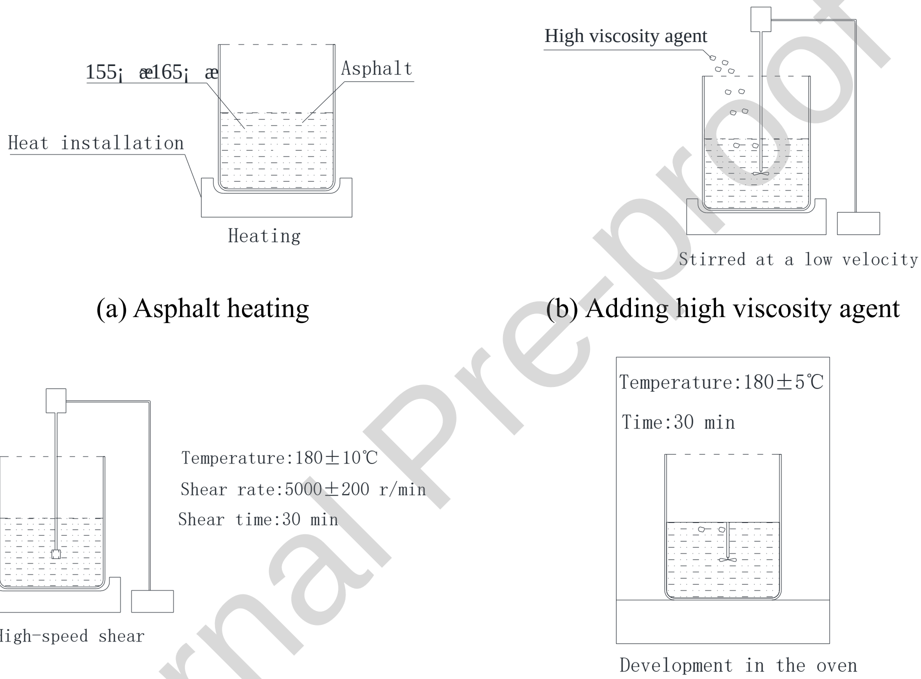
The SBS modified asphalt and high viscosity modified asphalt are selected. The SBS modified asphalt is prepared from 70# base asphalt, SBS polymer and other components by the shearing technology. The dosage of linear SBS polymer and stabilizer is 4.0% and 0.1% in the SBS modified asphalt, and the key technical indexes of base asphalt are listed in Table 1. The SBS modified asphalt is prepared at the 170~180℃, the shear rate is 5000r/min, and shearing time is 60min. The high viscosity modified asphalt is prepared from base asphalt and high viscosity agent by the wet process. The technical indexes of high viscosity agent with TPS, SINOTPS and HVA are listed in Table 2. The TPS high viscosity agent is developed by Japanese company, and high viscosity agent with SINOTPS and HVA is provided by the Chinese company. The blending ratio of different high viscosity agent and 70#base asphalt is 88%:12%, and blending scheme is determined by the literature [20~21]. The preparation process of high viscosity modified asphalt is shown in Fig.1.

Table 1 Key technique indexes of base asphalt

Test items		Technical requirement	Test value
Penetration(25℃,100g,5s)/0.1mm		60～80	65
Softening point/℃		≥46	48
Ductility(15℃,5cm/min)/cm）		＞100	＞100
Properties of the Thin-film oven test residue	Mass loss /%	≤0.8	0.37
	Residual penetration ratio /%	≥61	97
	Residual ductility (15℃)/cm	≥15	20

Table 2 Technique indexes of high viscosity agent

Test items	Test value		
	TPS (TAFPACK-Super)	SINOTPS	HVA(High viscosity additive)
Appearance	Faint yellow	Black/ Yellow	Yellow columnar
Particle size/mm	2~3	4	2~3
Density/g • cm^{-3}	0.6	0.9	0.6
Water absorption/%	-	0.3	-
Main components	Thermoplastic rubber	Thermoplastic rubber	-



(a) Asphalt heating (b) Adding high viscosity agent

(c) HVMA preparation (d) Asphalt thermal insulation

Fig.1 Preparation process of high viscosity modified asphalt based on wet process

The coarse and fine aggregate are diabase, and the mineral powder is grinded by limestone. The key technical indexes of above mineral aggregate are listed in Table 3 and Table 4. The SMA-13, OGFC-13 and PA-13 mixture are used to test in this paper. These mixtures are usually used in surface layer of asphalt pavement, and they are directly contact with vehicle tire. The gradation composition of selected mixture is listed in Table 5.

Table 3 Key technique indexes of aggregates

Material type	Testing items	Test result	Required value
Coarse aggregate	Crushing value /%	12.5	≤25
	Los angeles abrasion loss /%	10.6	≤28
	Polished stone value/BPN	53	≥42
	Ruggedness /%	1.8	≤12

Fine aggregate	Ruggedness /%	2	⩽12
	Angularity /s	39.5	⩾30
	Sand equivalent /%	74.5	⩾55
	Methylene blue value /g·kg^{-1}	1.0	⩽25

Table 4 technical requirement of mineral powder

Test items		Test value
Water content /%		0.25
Passing ratio by mass /%	0.6mm	100
	0.3mm	100
	0.15mm	100
	0.075mm	90.4
Appearance		Dry, clean, no agglomeration

Table 5 Mineral aggregate gradation of selected asphalt mixture

Mixture type	Passing ratio by mass/%									
	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
SMA-13	100	95.0	62.5	27.0	20.5	19.0	16.0	13.0	12.0	10.0
OGFC-13	100	95.0	70.0	21.0	16.0	12.0	9.5	7.5	5.5	4.0
PA-13	100	95.0	55.5	20.0	14.5	12.0	10.0	8.5	6.5	5.0

The basalt fiber is used in this paper, and the length and diameter of fiber are respectively are determined as 6mm and 17μm. The dosage of basalt fiber in the SMA, OGFC and PA mixture is identified as 0.4%, 0.3% and 0.3% based on weight of asphalt mixture by the specification and preliminary research results[22~24]. The optimum asphalt content of different mixture is determined by the Marshall Design Method, and test result is listed in Table 6. The test specimen with size of 300 mm×300 mm×50 mm is manufactured by the wheel rolling method.

Table 6 Optimal asphalt-aggregate ratio of different asphalt mixture

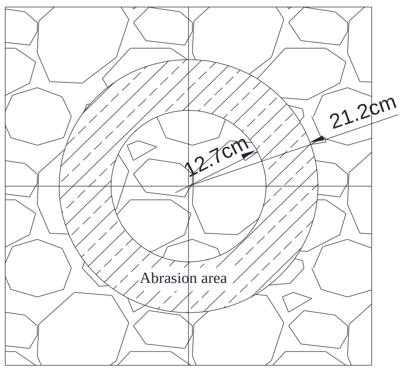
Mixture type	Asphalt binder	Optimal asphalt-aggregate ratio /%	Void rate/%	Number
SMA-13	SBS modified asphalt	6.0	4.0	①
	TPS-HVMA	6.2	4.2	②
	SINOTPS-HVMA		4.2	③
	HVA-HVMA		4.3	④
OGFC-13	TPS-HVMA	5.0	18.4	⑤
PA-13	SBS modified asphalt	5.1	18.1	⑥
	TPS-HVMA	5.3	18.3	⑦
	SINOTPS-HVMA		18.3	⑧
	HVA-HVMA		18.5	⑨

2.2 Test method and test conditions

2.2.1 Accelerated abrasion test

The accelerated abrasion test is simulated decay of skid resistance for different asphalt mixture during traffic operation, and the test device is shown in Fig.2(a). The load and speed of wheel can be adjusted. The test specimen is composed of four rutting plates, and the placement method of test specimen is shown in Fig.2(b). The abrasion area is formed on the each rutting plate after abrasion. The indexes of skid resistance for asphalt mixture is measured every 10000 circles of cyclic loading, and rutting plates is subjected to abrade for loading of 12×10^4 circles. Considering the limitation of indoor conditions, specimen size and the width of circular track in accelerated abrasion test, the pendulum friction meter and method based on image processing technique are used to determine the texture feature of pavement. The test process of texture feature for pavement is as follows: (1) The image of road surface is obtained; (2) The picture with 800×800 pixels in the core of circular track is cut by the Photoshop software; (3) The color picture is translated into the grayscale image; (4) The texture depth of road surface is calculated by the Matlab software. The detailed test method is referred to literature[25]. Unless otherwise stated, the accelerated abrasion test is conducted at 25℃, the load of loading wheel is 0.7MPa, and the surface of test piece keeps dry. The temperature of testing environment is relatively stable during acceleration. After the temperature of test specimen returns to room temperature, test specimen is measured.

(a) Accelerated abrasion test



(b) Abrasion area of specimen

Fig.2 Accelerated abrasion test and abrasion area

To analyze the skid-resistance durability difference of selected asphalt mixture, the attenuation rate of texture depth and attenuation rate of frictional coefficient are calculated by the Eq.(1) and Eq.(2).

$$H_{ar} = \frac{H_0 - H_n}{H_0} \times 100 \quad (1)$$

Here, the H_{ar} is attenuation rate of texture depth, %; H_0 is the initial value of texture depth, mm; H_n is texture depth for loading of n times when the index of texture depth reachs stable stage, mm.

$$F_{ar} = \frac{F_0 - F_n}{F_0} \times 100 \quad (2)$$

Here, the F_{ar} is attenuation rate of british pendulum number, %; F_0 is the initial value of british pendulum number, *BPN*; F_n is british pendulum number for loading of n times when the index of british pendulum number reachs stable stage, *BPN*.

2.2.2 Ambient humidity

To quantitatively evaluate the decay of skid-resistance durability for asphalt mixture under wet condition, the specimen surface is sprayed with water through drip irrigation in the laboratory (shown in Fig.3). Meanwhile, the accelerated abrasion test is conducting to simulate the abrasion of road surface under wet condition. The transparent silicone tube is used, the inside diameter and external diameter of silicone tube is 2mm and 3mm, and the water flow is selected as 53.0ml/min. The test is conducting under normal temperature condition, and soakage time of specimen is calculated as 24h.

(a) Form of drip irrigation

(b)Transparent silicone tube

Fig.3 Simulation device and material of ambient humidity

2.2.3Vehicle overload

The contact area between tire and road surface will be increased under overload, and the speed of overloaded vehicle is relatively slow[26~27]. So the wear rate of pavement texture is usually accelerated, which directly concerns good long-term skid resistance of pavement. To quantitatively evaluate the decay of skid-resistance durability of asphalt mixture under overload, the wheel load is adjusted by the addition of disk. The simulated load is selected as 0.70MPa, 0.91MPa and 1.10 MPa, and overloading rate of the last two is 30% and 60%. The test is also conducting under normal temperature condition, and the surface of test specimen should be kept dry.

3 Test result analysis

3.1 Research on the skid-resistance durability of different asphalt mixture

3.1.1 Comparison of skid-resistance durability of asphalt mixture

The selected mixture is tested by accelerated abrasion test under dry condition, and the load is selected as 0.7MPa. The decay characteristic of skid-resistance for asphalt mixture is shown in Fig.4, Fig.5 and Fig.6.

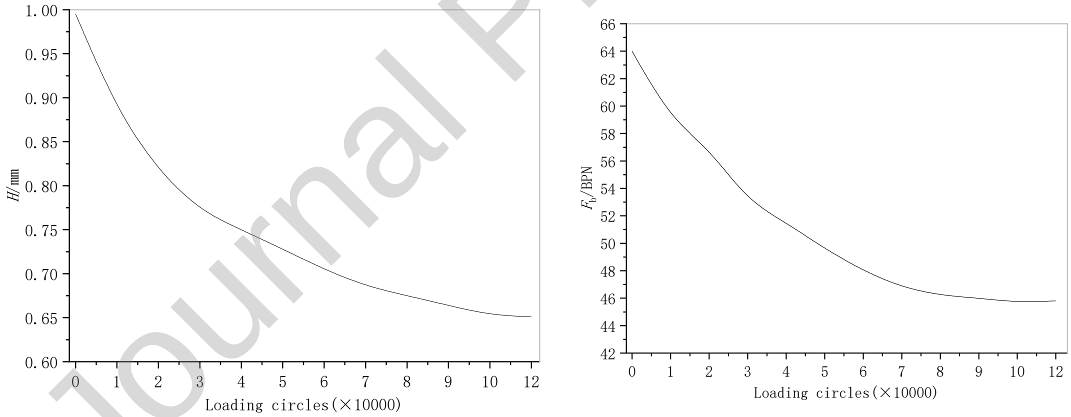


Fig.4 Decay of skid-resistance for OGFC-13 mixture

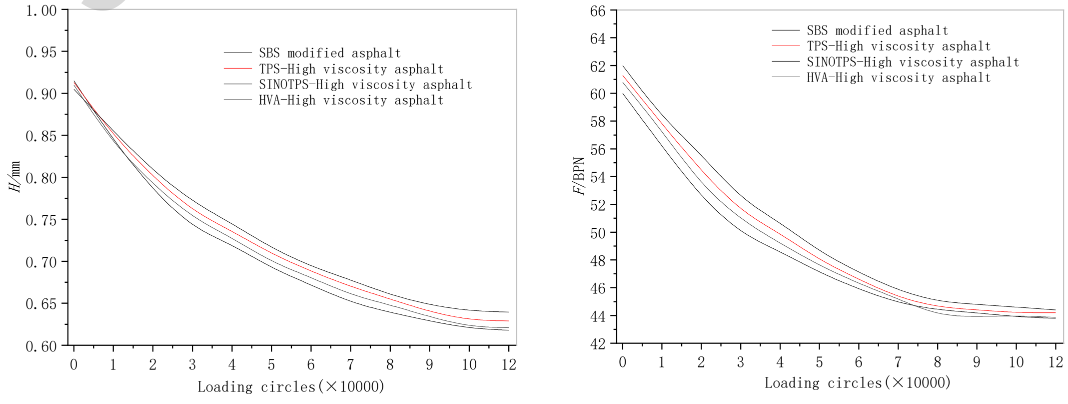


Fig.5 Decay of skid-resistance for SMA-13 mixture

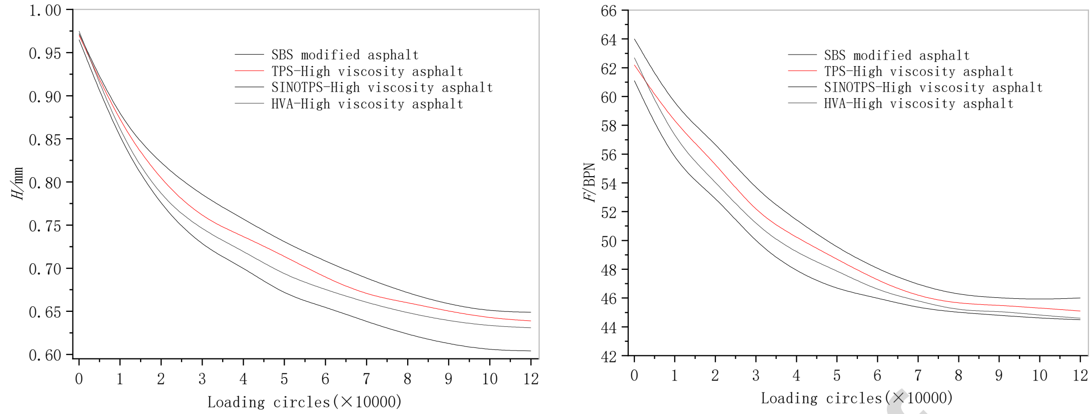


Fig.6 Decay of skid-resistance for PA-13 mixture

It can be seen from Fig. 4 that the skid resistance of different asphalt mixture shows similar tendency with the increasing of load repetition numbers. The decay of skid resistance for different asphalt mixture has declined rapidly, decreased slowly and tended to be stable, which is same as the finding of literature[7]. But the skid resistance of texture depth and british pendulum number is tended to be stable at 100000 passes and 80000 passes.

The initial skid resistance of asphalt mixture is inconsistent with skid-resistance durability. The initial texture depth of SMA-13 and PA-13 mixture with different asphalt has little difference, but the final texture depth of above mixtures is different. It shows that skid-resistance durability of different asphalt mixture will be paid more attention to.

The attenuation rate of skid resistance for different asphalt mixture is calculated by the Eq.(1) and Eq.(2), and the results are listed in Table 7 and Table 8.

Table 7 Attenuation rate of texture depth for different asphalt mixture

Mixture	Asphalt binder	Initial value /mm	Stable value /mm	Circles of tending towards stability (×10000)	Attenuation rate /%
SMA-13	SBS modified asphalt	0.915	0.620	10	32.2
	TPS-HVMA	0.913	0.630	10	31.0
	SINOTPS-HVMA	0.905	0.641	10	29.2
	HVA-HVMA	0.910	0.622	10	31.6
OGFC-13	TPS-HVMA	0.995	0.653	10	34.4
PA-13	SBS modified asphalt	0.965	0.605	10	37.3

TPS-HVMA	0.970	0.642	10	33.8
SINOTPS-HVMA	0.972	0.650	10	33.1
HVA-HVMA	0.975	0.633	10	35.1

Table 8 Attenuation rate of british pendulum number for different asphalt mixture

Mixture	Asphalt binder	Initial value /mm	Stable value /mm	Circles of tending towards stability (×10000)	Attenuation rate /%
SMA-13	SBS modified asphalt	60.0	44.4	8	26.0
	TPS-HVMA	61.3	44.6	8	27.2
	SINOTPS-HVMA	62.0	45.0	8	27.4
	HVA-HVMA	60.8	44.0	8	27.6
OGFC-13	TPS-HVMA	64.0	46.0	8	28.1
PA-13	SBS modified asphalt	61.1	45.0	8	26.4
	TPS-HVMA	62.2	45.6	8	26.7
	SINOTPS-HVMA	64.0	46.2	8	27.8
	HVA-HVMA	62.7	45.1	8	28.1

As shown in Table 7 and Table 8, the skid-resistance durability of SMA-13 mixture is better than OGFC-13 and PA-13 mixture, but the texture depth and british pendulum number for stable value of SMA-13 mixture is relatively small. That is because that coarse aggregates are interlocked in the SMA mixture belongs to framework dense structure, the aggregate is not easy to rotate, and the residual void is filled with fine aggregate and asphalt mastic. So the compactness and overall performance of SMA mixture will be increased, and compaction deformation and migration deformation of SMA mixture are difficult to happen. The OGFC-13 and PA-13 mixture belongs to skeleton-void structure have the greater void rate. The asphalt and asphalt mastic are flowed in above mixture with large void, and mineral aggregates are again arranged. It will increase the probability of compaction deformation and migration deformation of above mixtures. Besides, the rutting is obviously appeared in the OGFC-13 and PA-13 mixture during the experiment. The rut resistance of SMA mixture is much better than OGFC mixture [28]. This research findings of paper is different from literature[29]. The skid-resistance durability of OGFC-16 mixture is better than SMA-16 mixture, but the skid-resistance durability of SMA-13 mixture is much better than OGFC-13 mixture in this paper. Because the load repetition numbers in this paper is greater, and the nominal maximum size of aggregate and test method are also different.

Another explanation is that skid-resistance durability of asphalt mixture may be related to optimum asphalt content. The thickness of asphalt film on the aggregate surface in the asphalt mixture with high asphalt content is relatively large, so the contact resistance between mineral aggregate and vehicle wheel becomes small, and the mineral aggregate is not easy to be polished.

3.1.2 Analysis on influence of mineral aggregate and asphalt on skid-resistance durability

The influence of mineral aggregate and asphalt type on skid-resistance durability of asphalt mixture was analyzed by the SPSS software, and result of attenuation rate was used to calculate. The analysis of variance was shown in Table 9.

Table 9 Result of variance analysis

Index	Source	df	Mean Square	F	F_a
Texture depth	Corrected model	5	9.020	19.416	-
	Intercept	1	5412.290	11649.772	-
	Mixture type	2	15.964	34.362	$F_{0.05}(2,3)=19.16$
	Asphalt type	3	4.625	9.954	$F_{0.05}(3,3)=9.28$
	Error	3	0.465		-
British pendulum number	Corrected model	5	0.830	7.549	-
	Intercept	1	3638.805	33080.048	-
	Mixture type	2	0.481	4.371	$F_{0.05}(2,3)=19.16$
	Asphalt type	3	1.090	9.909	$F_{0.05}(3,3)=9.28$
	Error	3	0.110		-

Table 9 shows that the mixture and asphalt type have significant influence on the attenuation rate of texture depth for asphalt mixture, and the influence degree of mixture type on skid-resistance durability is higher than asphalt type. But the attenuation rate of british pendulum number for asphalt mixture is only significantly affected by the asphalt type, and the skid-resistance durability of asphalt mixture is affected by the asphalt. The reason is that texture depth of asphalt mixture is closely related to aggregate gradation, but the british pendulum number of asphalt mixture is closely connected to surface feature and mineral composition of aggregate. The different asphalt mixture with same aggregate is used in this paper, so the mixture type has no noticeable effect on attenuation rate of british pendulum number.

3.1.3 Influence of asphalt binder on the skid-resistance durability of asphalt mixture

The PA-13 and SMA-13 mixture with the good skid-resistance durability are selected. The influence of different asphalt binder on skid-resistance durability of above mixtures is discussed. It can be seen from Fig. 5, Fig. 6, Table 7 and Table 8 that the skid resistance of different asphalt mixture with selected asphalt binder is as follows: SINOTPS-high viscosity modified asphalt＞TPS-high viscosity modified asphalt＞HVA- high viscosity modified asphalt＞SBS modified asphalt binder. The anti-deformation ability of asphalt mixture is improved by addition of high viscosity agent, and the wear rate of pavement macrotexture is delayed. The void rate of asphalt mixture with SINOTPS and TPS additive is lower than HVA, and the asphalt mixture with SINOTPS and TPS additive is not easily deformed. The skid-resistance durability of asphalt mixture is optimized by the addition of high viscosity modified asphalt.

The improvement effect of high viscosity agent on the different indexes of skid-resistance durability for asphalt mixture is not consistent. For the attenuation rate of texture depth, the skid-resistance durability of SBS modified asphalt mixture is worst. But the skid-resistance durability of asphalt mixture with high viscosity modified asphalt is lower than SBS modified asphalt mixture according to the attenuation rate of british pendulum number. And the stable british pendulum number of different asphalt mixture has little difference. One of the reasons is that the microscopic texture of asphalt mixture is improved by the asphalt binder only in the initial stage. The asphalt film of mineral aggregate is continuously abrased with the increasing of load repetition numbers, which leads to that mineral aggregate is directly contact with vehicle wheel. On the other hand, structural strength of asphalt mixture with the same aggregate gradation is decided by asphalt binder. The anti-deformation of asphalt mixture is improved by the addition of high viscosity modified asphalt, and the temperature sensitivity of above mixtures is decreased. So the attenuation rate of texture depth for asphalt mixture with high viscosity modified asphalt is relatively small.

3.2 Influence of humidity on the skid-resistance durability of asphalt mixture

The asphalt binder and mixture with good skid-resistance durability are only selected, and the influence of ambient humidity on skid-resistance durability of asphalt mixture is analyzed. The selected SMA-13 mixtures (code-named “① and ③”) PA-13 mixtures (code-named “⑧”) are tested by accelerated abrasion test under ambient temperature. The decay of skid resistance of above asphalt mixture is shown in Fig.7 and Fig.8. The result of attenuation rate is listed in Table 10.

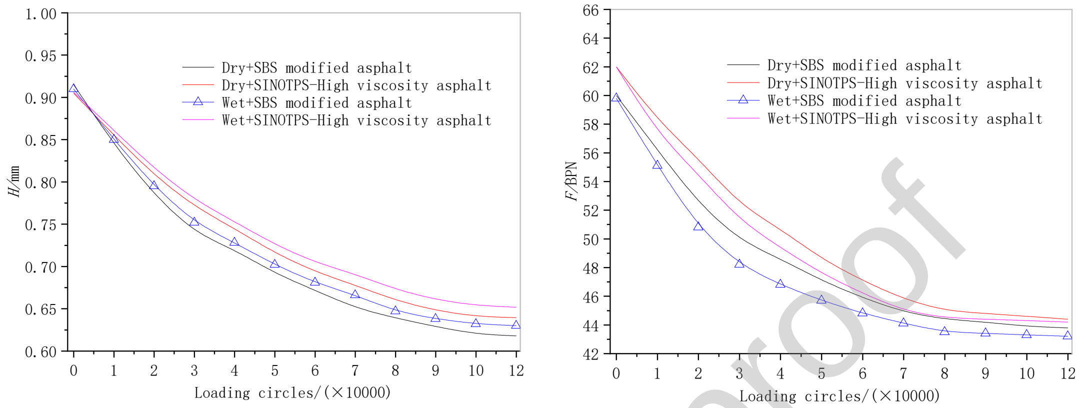


Fig.7 Decay curve of skid-resistance for SMA-13 mixture under different states

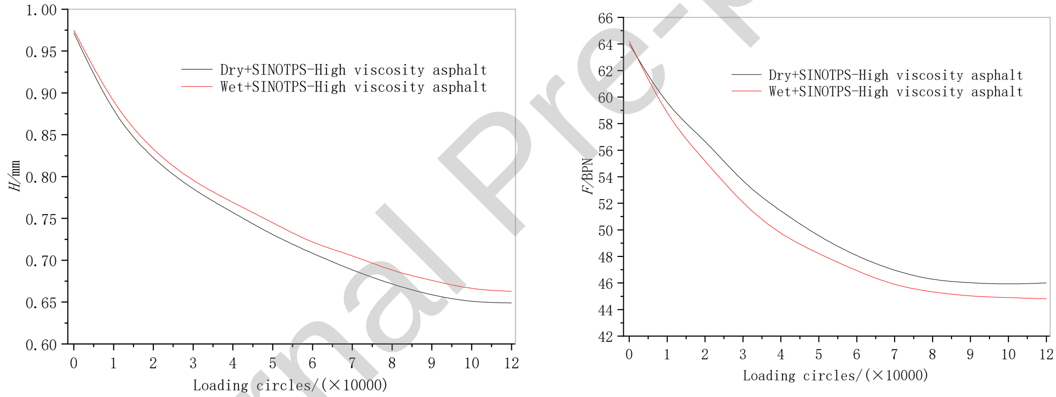


Fig.8 Decay curve of skid-resistance for PA-13 mixture under different states

Table 10 Attenuation rate skid resistance for asphalt mixture under different states

Index	Wet and dry condition	Number	Mixture type	Asphalt binder	Initial value	Stable value	Attenuation rate /%
Texture depth	Dry state	①	SMA-13	SBS modified asphalt	0.915mm	0.620 mm	32.2
		③		SINOTPS-HVMA	0.905 mm	0.641 mm	29.2
		⑧	PA-13	SINOTPS-HVMA	0.972 mm	0.650 mm	33.1
	Wet state	①	SMA-13	SBS modified asphalt	0.910 mm	0.632 mm	30.5
		③		SINOTPS-HVMA	0.906 mm	0.654 mm	27.8
		⑧	PA-13	SINOTPS-HVMA	0.975mm	0.665mm	31.8
British	Dry state	①	SMA-13	SBS modified asphalt	60.0 BPN	44.4 BPN	26.0

pen		③		SINOTPS-HVMA	62.0 BPN	45.0 BPN	27.4
dul		⑧	PA-13	SINOTPS-HVMA	64.0 BPN	46.2 BPN	27.8
um nu	Wet	①	SMA-13	SBS modified asphalt	59.8 BPN	43.5 BPN	27.3
mb	state	③		SINOTPS-HVMA	62.0 BPN	44.5 BPN	28.2
er		⑧	PA-13	SINOTPS-HVMA	63.5 BPN	45.3 BPN	28.7

As shown in Fig.7, Fig.8 and Table 10, the skid resistance and skid-resistance durability of asphalt mixture under wet condition is better than dry condition according to texture depth. That's because that the temperature of surface for asphalt mixture is reduced by the involvement of moisture during the running. The anti-deformation ability of asphalt mixture is enhanced, the mineral aggregate is limited to rearrange, and the void rate on the pavement surface is difficult to be padded by the asphalt mortar. Besides the adhesive wear of pavement texture is positively correlated with temperature. The lower the temperature of pavement is, the less wear loss of pavement texture is. The adhesive wear of pavement texture is effectively suppressed by the lubricating ability of moisture.

For british pendulum number, the skid resistance and skid-resistance durability of asphalt mixture under wet condition is relatively poor. The reason is that interface between pavement and vehicle wheel is filled with water, and the effective contact area between pavement and wheel is reduced. So the adhesion between pavement and wheel and british pendulum number of asphalt pavement are also decreased. This shows that the adhesion between pavement and wheel is affected by lubricating ability of water. When the surface of mineral aggregate is eroded under long-term action of water, the mechanical property of asphalt mixture is damaged, and the pavement texture is accelerated to be polished.

The skid-resistance durability of SMA-13 mixture is better than PA-13 mixture under different condition. The intrusive water is quickly drained from the interconnected pores in the PA-13 mixture, but the mechanical property of PA-13 mixture relatively poor, which causes the skid resistance of PA-13 mixture to be quickly decayed.

3.3 Effect of vehicle overload on the skid-resistance durability of asphalt mixture

The asphalt mixture with the same as section 3.3 is tested by accelerated abrasion test under dry condition. The effect of overload on the skid-resistance durability of asphalt mixture is discussed. The decay of skid-resistance of above asphalt mixture is shown in Fig.9, Fig.10 and Fig.11. The result of attenuation rate is listed in Table 11.

Table 11 Attenuation rate skid resistance of asphalt mixture under different loading

Simulated load	Mixture type	Asphalt binder	Initial value	Stable value	Circles of tending towards stability (×10000)	Attenuation rate /%
Standard load	SMA-13	SBS modified asphalt	0.915 mm	0.620 mm	10	32.2
		SINOTPS-HVMA	0.905 mm	0.641 mm	10	29.2
	PA-13	SINOTPS-HVMA	0.972 mm	0.650 mm	10	33.1
	SMA-13	SBS modified asphalt	60.0 BPN	44.4 BPN	8	26.0
		SINOTPS-HVMA	62.0 BPN	45.0 BPN	8	27.4
	PA-13	SINOTPS-HVMA	64.0 BPN	46.2 BPN	8	27.8
Overload 30%	SMA-13	SBS modified asphalt	0.910 mm	0.618 mm	8	32.1
		SINOTPS-HVMA	0.918 mm	0.645 mm	8	29.7
	PA-13	SINOTPS-HVMA	0.965 mm	0.655 mm	8	32.1
	SMA-13	SBS modified asphalt	59.5 BPN	43.0 BPN	8	27.7
		SINOTPS-HVMA	62.4 BPN	44.2 BPN	8	29.2
	PA-13	SINOTPS-HVMA	64.2 BPN	45.0 BPN	8	29.9
Overload 60%	SMA-13	SBS modified asphalt	0.912 mm	0.622 mm	6	31.8
		SINOTPS-HVMA	0.910 mm	0.644 mm	6	29.2
	PA-13	SINOTPS-HVMA	0.970 mm	0.658 mm	6	32.2
	SMA-13	SBS modified asphalt	60.5 BPN	42.5 BPN	6	29.8
		SINOTPS-HVMA	62.8 BPN	43.5 BPN	6	30.7
	PA-13	SINOTPS-HVMA	64.0 BPN	44.3 BPN	6	30.8

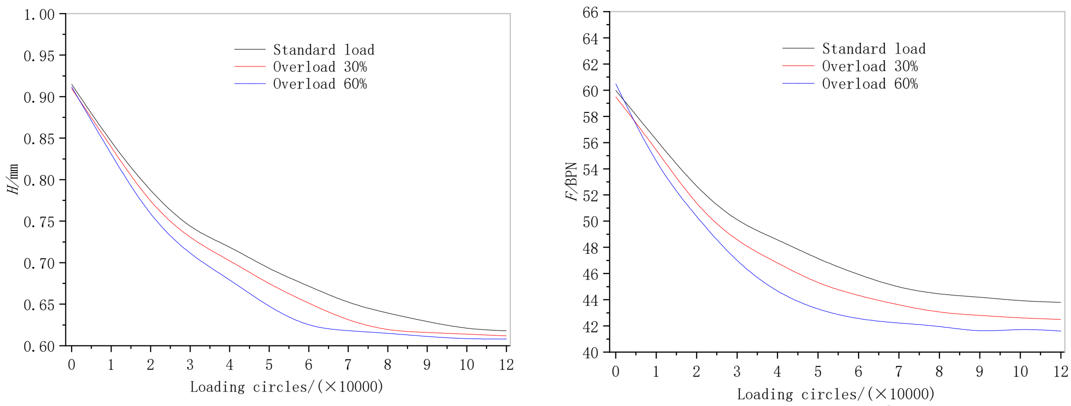


Fig.9 Decay of skid-resistance for SMA-13 mixture with SBS modified asphalt under different loading

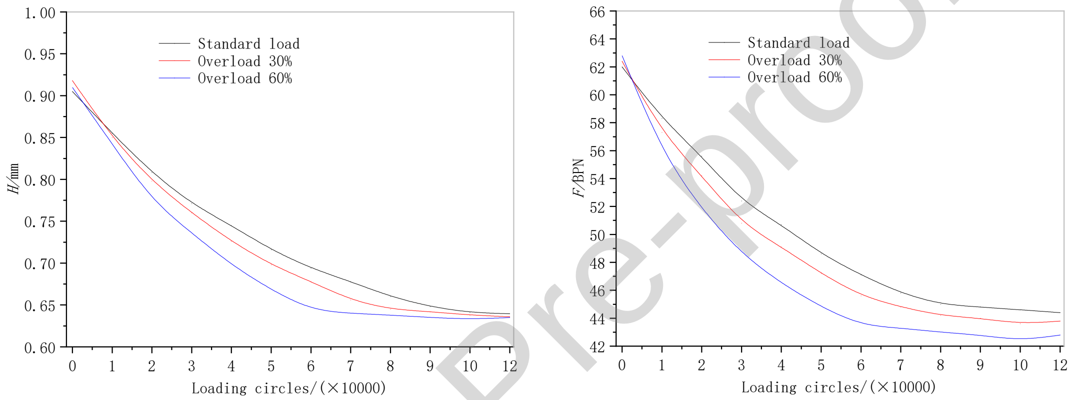


Fig.10 Decay of skid-resistance of SMA-13 mixture with HVMA under different loading

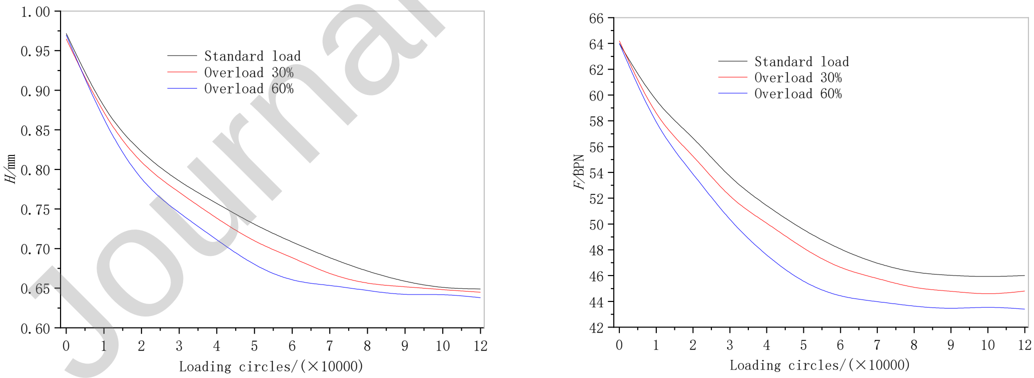


Fig.11 Decay of skid-resistance of PA-13 mixture with HVMA under different loading

The result presented in Fig.9, Fig.10, Fig.11 and Table 11 indicates that the skid resistance of SMA-13 and PA-13 mixture is speedily decayed with increasing of load. The skid-resistance durability of SMA-13 mixture is better than PA-13 mixture under different loads. That is because that abrasion between two touching bodies is mainly caused by adhesive wear and abrasive wear, and the adhesive wear and abrasive wear are positive correlated with load. The larger the vertical load is, the greater the abrasion of pavement texture is. Another explanation is that the void rate of asphalt mixture is reduced with increasing of loading, and the asphalt is migrated to surface. The asphalt film in unstable state is quickly worn out, so the pavement texture will be accelerated to decay. The aggregate is rotated with increasing of loading, which causes the structure asphalt mixture to be destroyed, and the asphalt mixture is most easily to produce compaction deformation.

The skid resistance of asphalt mixture is more decayed by the load variation according to texture depth. The simulated load is increased from standard load to overload 60%, the number of loading repetition is decreased by 40000 circles when texture depth is tending towards stability, but the number of loading repetition is decreased by 20000 circles for british pendulum number. It shows that the compaction deformation and migration deformation of asphalt mixture are accelerated with increasing of load, and the decay of pavement macrotexture is affected, which leads to that the skid resistance of asphalt mixture is worse.

When the skid resistance is tending towards stability, the decay and stability value of skid resistance for same asphalt mixture under different load are similar. That is because that the pavement texture is mainly depended on mixture structure and component material, and decay rate of skid resistance for asphalt mixture is also affected by external factor.

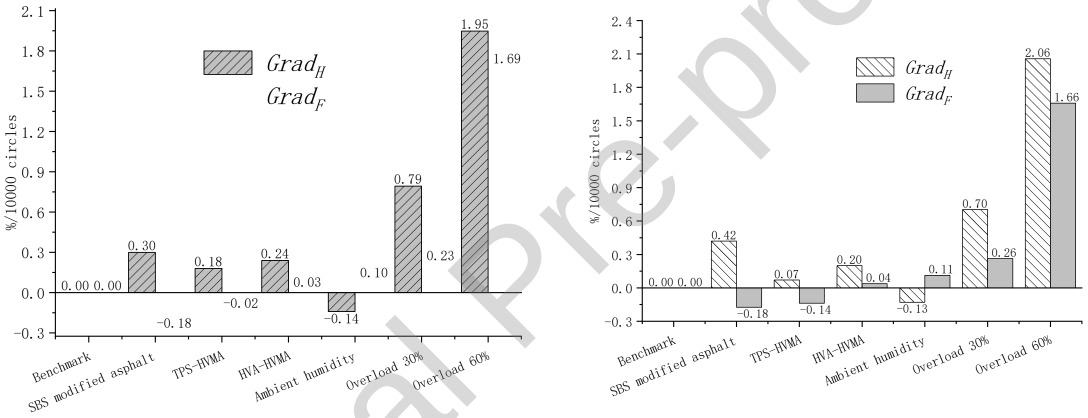
3.4 Significant influence of different factors on the skid-resistance durability of asphalt mixture

The number of loading repetition is decreased when evaluation index of skid resistance is tending towards stability under overload, so the skid-resistance durability of asphalt mixture is not evaluated by the attenuation rate. The attenuation rate at one circle of skid resistance is introduced to quantitatively evaluate the influence of different factors on the skid-resistance durability of asphalt mixture. The different attenuation rate at one circle of skid resistance is calculated as by the Eq.(3) and Eq.(4). The attenuation rate at one circle of skid resistance for SMA-13 mixture and PA-13 mixture with SINOTPS-high viscosity modified asphalt under dry condition is used as a benchmark, and the differences between reference value and indicator value is evaluated the influence of selected factors on the skid-resistance durability of asphalt mixture. The calculation result is shown in Fig.12.

$$Grad_H = \frac{H_0 - H_n}{H_0 \bullet n} \times 100 \tag{3}$$

$$Grad_F = \frac{F_0 - F_n}{F_0 \bullet n} \times 100 \tag{4}$$

Here, the $Grad_H$ is attenuation rate of texture depth at one circle, %/10000 circles; the $Grad_F$ is attenuation rate of british pendulum number at one circle, %/10000 circles; specific meaning of other indexes are referred to Eq.(3) and Eq.(4).



(a) SMA-13 (b)PA-13

Fig.12 Difference of attenuation rate at one circle

As shown in Fig.12, the significant influence of different factors on the skid-resistance durability of asphalt mixture is overload, SBS modified asphalt, ambient humidity, TPS-high viscosity modified asphalt and HVA-high viscosity modified asphalt. It shows that the wear amount of pavement texture and deformability of asphalt mixture are increased by the overload, which is positive correlated with loading. So the decay of skid resistance for asphalt mixture is accelerated by the overload.

The texture depth of asphalt mixture is more easily decay than british pendulum number. The reason is that the decay of texture depth for asphalt mixture is not only related to compaction deformation and migration deformation, but also the abrasion of mineral aggregate. The different asphalt mixture with the same mineral aggregate is used in this paper, and british pendulum number of asphalt mixture is affected by the surface feature of mineral aggregate. Meanwhile, the abrasion of different asphalt mixture with the same mineral aggregate has little difference, which leads to that the decay of texture depth for asphalt mixture happened mostly in the stage of compaction deformation and migration deformation. It shows that the skid-resistance durability of asphalt mixture for texture depth is determined by the mechanical property of asphalt mixture.

To sum up, the influence of composition materials and external conditions on skid-resistance durability of asphalt mixture with high viscosity modified asphalt is analyzed by the accelerated abrasion test, and the important degree of various factors is clarified. The feasible method based on image processing technique is used to evaluate skid resistance of asphalt mixture. The attenuation rate of skid resistance for asphalt mixture is affected by mixture and asphalt binder type, and attenuation rate of british pendulum number for asphalt mixture with the same mineral aggregate is only significantly affected by the asphalt binder. The skid-resistance durability of SMA mixture is better than OGFC and PA mixture under different conditions, and the mechanical property and conventional road performance of SMA mixture are more excellent. So the SMA mixture can be used in the pavement of intersection and large longitudinal slope sections. Research confirms that the skid-resistance durability and mechanical properties of asphalt mixture with SINOTPS additive are improved. The SINOTPS additive is developed by the China Enterprise to reduce dependence of Japanese products. But the economic cost and construction temperature of asphalt mixture with SINOTPS additive are also increased, which consumes even more energy. Life cycle cost of different asphalt mixture will be analyzed. In the full life cycle, service life of asphalt mixture with SINOTPS additive will be longer, which reduces maintenance cost. The surface function of asphalt mixture with high viscosity modified asphalt can be better understood in this paper.

4 Conclusions

The skid resistance of OGFC and PA mixture is better than SMA mixture, but SMA mixture has the good skid-resistance durability. The attenuation rate of different indexes for SMA-13 mixture is 1.6~2.2% and 0.8~2.1% lower than compared with OGFC-13 and PA-13 mixture. The mixture and asphalt type have significant influence on the attenuation rate of texture depth for asphalt mixture, but the attenuation rate of british pendulum number for asphalt mixture with the same mineral aggregate is only significantly affected by the asphalt type.

The skid resistance of SMA-13 and PA-13 mixture is improved by the addition of high viscosity modified asphalt, and skid-resistance durability of SMA-13 mixture with different asphalt is better than PA-13 mixture. The evaluation index of skid-resistance durability of asphalt mixture is affected by the asphalt.

The skid-resistance durability of asphalt mixture with SINOTPS additive is better. The attenuation rate of texture depth for asphalt mixture with SINOTPS additive modified asphalt is lower than TPS additive and HVA. The attenuation rate of british pendulum number for asphalt mixture with SINOTPS additive is in the middle of selected high viscosity modified asphalt.

The skid-resistance durability of SMA-13 mixture is better than PA-13 mixture under different condition. The evaluation index of skid-resistance durability of asphalt mixture is affected by the humidity conditions. The attenuation rate of texture depth and british pendulum number for asphalt mixture is respectively reduced and increased under wet condition.

The skid resistance of asphalt mixture is rapidly decreased under overload. The attenuation rate of skid resistance of asphalt mixture is increased with the increasing of the load. The attenuation of texture depth for asphalt mixture is affected obviously by the overload.

The influence of overload and SBS modified asphalt on the skid-resistance durability of asphalt mixture is more than ambient humidity, TPS-high viscosity modified asphalt and HVA-high viscosity modified asphalt. The skid-resistance durability of SMA-13 mixture is better than PA-13 mixture under different external conditions.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

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Conflict of Interest

The authors declare they have no conflicts of interest.