Evaluation of Three Warm Mix Asphalt Technologies

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ABSTRACT: Recently, warm mix asphalt (WMA)has become a focus of research and application because it has many potential benefits such as lower fuel costs, lower emissions, wider cold-weather paving window and better working environment. Three potential warm mix asphalt processes, namely, chemical surfactant additive technology, two kinds of organic viscosity-decreasing additives technology, were evaluated in this study. A laboratory study was conducted to evaluate the asphalt and mix performance of these processes. These laboratory tests included the penetration, softening point, ductility and viscosity of the asphalts and compaction characteristic, high and low temperature properties, moisture damage properties and fatigue properties of the mixes. The results showed that the three WMA technologies can all reach the performance requirements of HMA in China. It's worth noting that, for the chemical surfactant additive WMA, fatigue tests in MTS indicated it has better anti-fatigue performance than HMA. For the mixes containing organic viscosity-decreasing additives, wheel-tracking tests indicated they have better rutting resistance performance than HMA. Two chemical surfactant additive WMA field trials have been constructed in Henan province, China. The field test suggests that each performance index is ideal.

KEY WORDS: Warm-mix asphalt; hot-mix asphalt; performance evaluation; chemical surfactant additive WMA; organic viscosity-decreasing additives WMA

1 INTRODUCTION

Warm mix asphalt is a general designation of the new asphalt mixes whose construction temperature resides between that of hot mix asphalt and that of cold mix asphalt, but whose performance can satisfy the requirement of hot mix asphalt technology. Compared with hot mix asphalt, its service temperature can be reduced by 25~60℃; besides, it is energy efficient and environment friendly, and also can relieve asphalt aging effect, extend the period proper for construction, improve the working conditions of workers, and put the road into operation timely(Graham C,2007). Therefore, the warm mix asphalt technology, since its birth, has attracted road practitioners all over the world and turned a popular subject for research and application in this field. At present, many WMA technologies or products have sprung up, but the representatives among them are WAM-Foam technology, chemical surfactant additive warm mix technology(here, in SFA), Aspha-Min additives, and such organic warm mix additives as Sasobit, Asphaltan B (Graham C,2007 and Kristj nsd ttir et al. 2007)and SAK. Different warm mix technologies feature different warm mix mechanisms and different warm mix processes, so the subsequent results must be different. This contribution largely investigates the SFA warm mix technology, and the warm mix technologies of the two organic viscosity-reducing additives - Sasobit and SAK(here, in SA1 and SA2). Systematic experiments have been run to test the performance of the three kinds of asphalt and mix and to compare them with similar hot asphalt and similarly-graded hot mix asphalt so as to conduct a comprehensive evaluation on the three warm mix technologies. Moreover, this contribution will also make an introduction to the trial section of SFA warm mix technology constructed in Zhubi Expressway of Henan, China in September 2007.

2 TECHNICAL TARGET TEST AND EVALUATION OF WMA

Directed at SBS modified asphalt and (or) common asphalt, the above three warm mix technologies were employed to fabricate warm mix asphalt. Then tests were conducted to test the penetration and softening point, as well as ductility and viscosity at different temperatures and to compare their performance with the performance of similar hot asphalt so as to accomplish a better knowledge of and a comprehensive evaluation on the characteristics of warm mix asphalt.

2.1 SFA WMA

SFA warm mix additive is a product of MeadWestvaco. SFA warm mix technology is based on the surfactant principle, that is, adding DAT additive (products of 2nd-generation) and hot asphalt simultaneously, and this additive can form water film lubrication structure within the binder during blending the asphalt mixes, thus achieving the performance of working at low temperatures. This contribution is targeting the 2nd-Generation dispersed asphalt technology of SFA.

The concentrated DAT solution was added to SBS modified asphalt at 130~140℃ to make warm mix asphalt; then tests were conducted to test the penetration, softening point, ductility and viscosity and also compare it with the hot asphalt. See Table 1 and Figure 1 for the testing and comparison results.

As we can see, after adding the warm mix additive, the softening point and 10℃ ductility of the binders decreased, but the penetration and viscosity did not change much. It suggests that SFA warm mix technology does not reduce the viscosity of the binders to achieve mix at lower temperatures, which matches the above principle.

Table 1: Indexes of SFA warm mix asphalt and hot asphalt

Type of asphalt	Softening Point(℃)	Penetration ,25℃ (0.1mm)	Ductility,10℃ (cm)	Ductility,15(cm)
SBS	83.5	47.0	49.5	>100
SBS+DAT	67.2	44.2	29.2	>100

2.2 SA1 WMA

SA1 is a universal modified additive of polyolefin bitumen produced by a German company – Sasol Wax based on F-T process; it melts at about 100℃and is completely soluble in asphalt mixes above 115℃(Graham C,2007). During our research, based on the existing experiences, first, 3.5% SA1 modified additives were added to SBS modified asphalt and shell 70# asphalt respectively, and the mixture were mixed manually at 140~150℃ for 30 min.

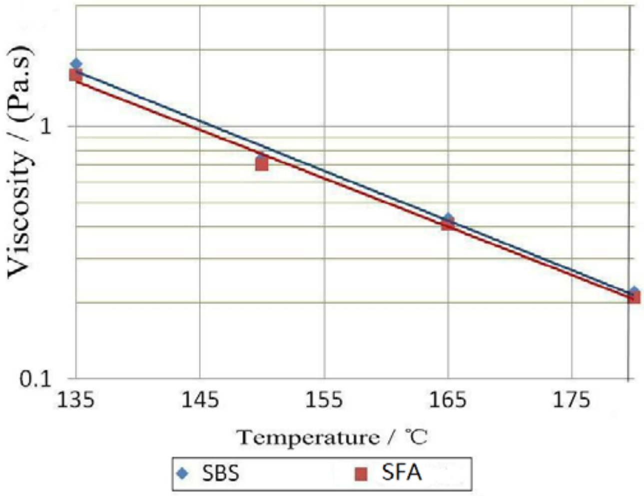


Figure1: Viscosity-temperature curves of SFA warm mix asphalt and hot asphalt

Then tests were conducted to test the penetration, softening point, ductility and viscosity and compare them with the hot asphalt. See Table 2 and Figure 2 for the testing and comparing results.

As we can see in Table 2, after SA1 was added, whether SBS modified asphalt or Shell 70# asphalt, their softening point was elevated markedly but the penetration and ductility decreased to different extent, which suggests that their high-temperature properties may be improved and their low-temperature properties may be negatively affected. Figure 2 shows the comparing results of the viscosity-temperature curves of two HMA and two WMA. As we can see from Fig. 2, after SA1 was added, compared with the HMA, the viscosity of WMA at the same temperature decreased slightly; with the rise of temperature, the viscosity-reducing effect of common asphalt and modified asphalt develops conversely.

Table 2: Indexes of SA1 WMA and hot Asphalt

Type of asphalt	SBS	SBS+SA1	Shell70#	Shell70#+SA1
Penetration ,25℃(0.1mm)	54.4	34.7	64.4	33.1
Softening Point(℃)	74.3	90.7	52.7	77.3
Ductility,5℃(cm)	41.5	brittle-broken	——	——
Ductility,10℃(cm)	148	38	90.8	brittle-broken
Ductility,15℃(cm)	>100	——	>100	>100

2.3 SA2 WMA

SA2 is a kind of WMA additive produced by Shanghai Chenghong Road New Material Co., Ltd.; it improves the workability of asphalt binders by adding low-melting point organic materials to the binders, which is similar to SA1. 2.5% SA2 additives were added to SBS modified asphalt and shell 70# asphalt respectively, and the mixture were mixed manually at 140~150℃ for 30 min. Then tests were conducted to test the penetration, softening point, ductility and viscosity and compare them with the hot asphalt. See Table 3 and Figure 3 for the testing and comparing results.

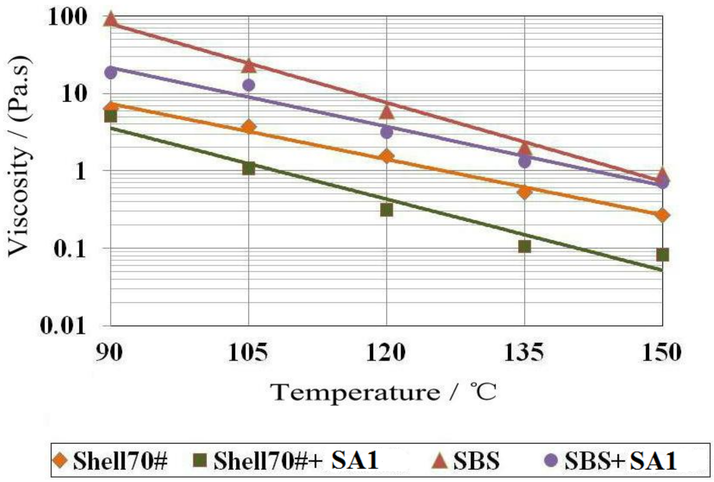


Figure2: Viscosity-temperature curves of SA1 WMA

Table 3:Indexes of SA2 WMA and hot asphalt

Type of asphalt	SBS	SBS+SA2	Shell70#	Shell70#+SA2
Penetration ,25℃(0.1mm)	54.4	46.6	66.4	45.0
Softening Point(℃)	74.3	89.9	52.7	91.9
Ductility,5℃(cm)	41.5	25.2	——	——
Ductility,10℃(cm)	74.5	51.0	57.5	30.0
Ductility,15℃(cm)	>100	76.4	>100	61.8

As we can see from Table 3, after SA2 was added, whether SBS modified asphalt or Shell 70# asphalt, both their softening point was elevated prominently, especially that of common asphalt with a greater increase magnitude, but both penetration and ductility decreased to different extent, which suggests that the high-temperature properties may be improved and the low-temperature properties may be negatively affected. Fig. 3 shows the comparing results of the viscosity-temperature curves of two HMA and two WMA. As we can see from Fig. 3, after SA2 was added, compared with the HMA, the viscosity of WMA at the same temperature decreased slightly; with the rise of temperature, the viscosity-reducing effect declined. Therefore, SA2 is similar to SA1; both technologies achieve low-temperature mix by reducing the viscosity of binders.

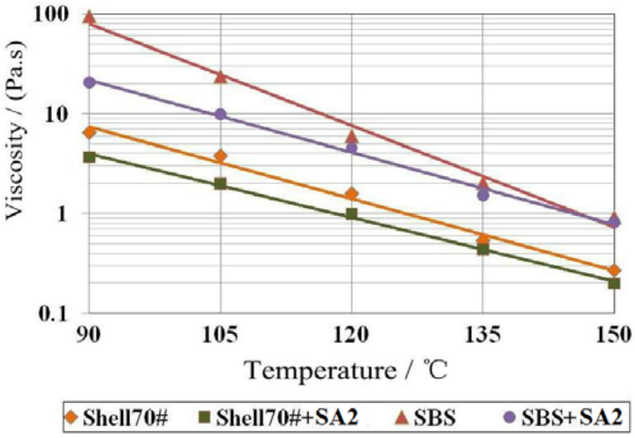


Figure3: Viscosity-Temperature Curves of SA2 WMA

3 PERFORMANCE EVALUATION OF WMA

This contribution will make an evaluation on the three WMA in respect of compaction characteristic, high-temperature stability, low-temperature crack resistance, water stability and anti-fatigue property and will make comparison about the performance of the three WMA and similarly-graded HMA. With SBS modified asphalt as the binders, diabase as the coarse aggregates, limestone as fine aggregates, mixture grade at AC-13C, and target air void at 4%, the optimal asphalt content of SFA, SA1 and SA2 WMA design through Marshall method is 4.6%, 4.5%, and 4.5% respectively, mix temperature in the neighborhood of 140℃, and shaping temperature at about 130℃. The optimal asphalt content of similarly-graded HMA designed in the same method is 4.3%.

3.1 Compaction characteristic of WMA

This contribution takes SFA and SA2 warm mix technologies as example to investigate the compaction characteristics of WMA from different perspectives.

3.1.1 Compaction characteristic of SFA WMA

Marshall compaction method and SGC method were employed to test and analyze the air void of AC-20 E-WMA at different compaction temperatures. Marshall compaction method adopted the heavy compaction standard, that is, 75 blows per face of the specimen, while the SGC revolved 75 revolutions, with compaction work at 600kPa, mixing temperature at 150℃, and compaction temperatures at 90℃, 110℃, 130℃ and 150℃ respectively. See Fig. 4 for the changes of air void at different shaping temperatures.

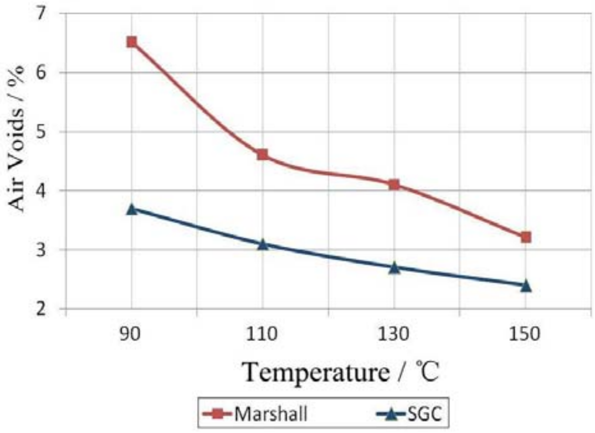


Figure4: Impact of different shaping methods on air void of SFA WMA

As we can see from Fig.4, shaping method has great impact on the compaction characteristics of WMA. At the same temperature, the air void of the mixes shaped by SGC method is much lower than that by Marshall method. Especially when the temperature is low (e.g. 90℃), the overall temperature sensitivity of SGC method is obviously lower than Marshall method. Moreover, with the rise of temperature, the air void of mixes decreases, which suggests that higher temperature facilitates the compaction, even for warm mix asphalt. Therefore, reasonable compaction process and sound temperature control are essential for a successful warm mix.

3.1.2 Compaction characteristic of SA2 WMA

This contribution has considered 2.5% and 3% SA2 additives, using the specimen (AC13C) shaped by Marshall compaction method, adopting the optimal asphalt content of similarly-graded HMA, with shaping temperature at 130, 140, 150 and 160℃ respectively. See Fig. 5 for the changes in the air void of mixes at different shaping temperatures.

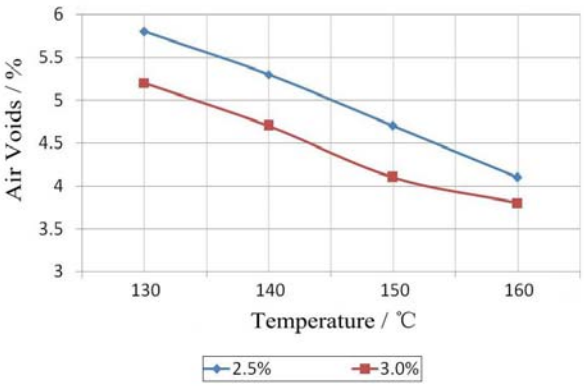


Figure5: Impact of different shaping temperatures on air void of SA2 WMA

As we can see from Fig.5, with the increase of SA2 additives and the rise of temperature, the air void of mixes decreases. At the same amount of asphalt content with HMA, temperature reduction has great impact on the compaction of WMA. In order to reach the target air void of 4%, the shaping temperature of WMA with 2.5% SA2 additives should be at about 160℃, and the shaping temperature of WMA with 3% SA2 additives at about 150℃. Compared with the shaping temperature of HMA, it is just reduced by about 10~25℃, so the temperature-reducing extent is limited. In order to further reduce the shaping temperature, we can increase the asphalt content or the additive content, which has been proved by the indoor tests. For instance ,the asphalt content is further elevated by 0.2%, the shaping temperature for accomplishing the target air void can be further reduced by about 20℃.

3.2 High- and Low-temperature Properties of WMA

This contribution employs wheel-tracking tests and low-temperature bending failure tests(JTJ 052-2000)to evaluate the high- and low -temperature properties of WMA, and compares them with similarly-graded HMA. See Table 4 for the testing results.

Table 4: Comparison of WMA and HMA in high- and low-temperature properties

Type of WMA	Dynamic Stability (times/mm)		Maximum damage strain (με)	
	WMA	HMA	WMA	HMA
SFA	7693	10443	5632	5652
SA1	10974	7199	4792	5912
SA2	9796	7199	5154	5912
HMA requirement (JTJ F40-2004)	＞3000		＞2500	

As we can see from Table 4, while reducing the mixing and shaping temperature, the high-temperature stability of both SA1 and SA2 WMA is markedly elevated as compared with HMA, and the low-temperature property declines slightly but still can meet the prevailing code requirements on HMA. The low-temperature property of SFA WMA is nearly the same as that of HMA, while the dynamic stability is poorer than that of the similarly-graded HMA but can easily satisfy the prevailing code requirements on HMA. Therefore, while achieving energy efficiency and emission reduction, WMA still feature sound high-temperature stability and low-temperature crack resistance.

3.3 Moisture stability of WMA

During our research, freeze-thaw split test and immersion Marshall test(JTJ 052-2000) were employed to evaluate the moisture stability of WMA and comparison was made between WMA and HMA. See Table 5 for the results.

Table 5 :Comparison of WMA and HMA in moisture stability

Type of WMA	TSR (%)		MS_0(%)	
	WMA	HMA	WMA	HMA
SFA	81.2	85.6	——	——
SA1	——	--	95	96
SA2	84.6	85.2	93	96
HMA requirements (JTJ F40-2004)	＞80%		＞85%	

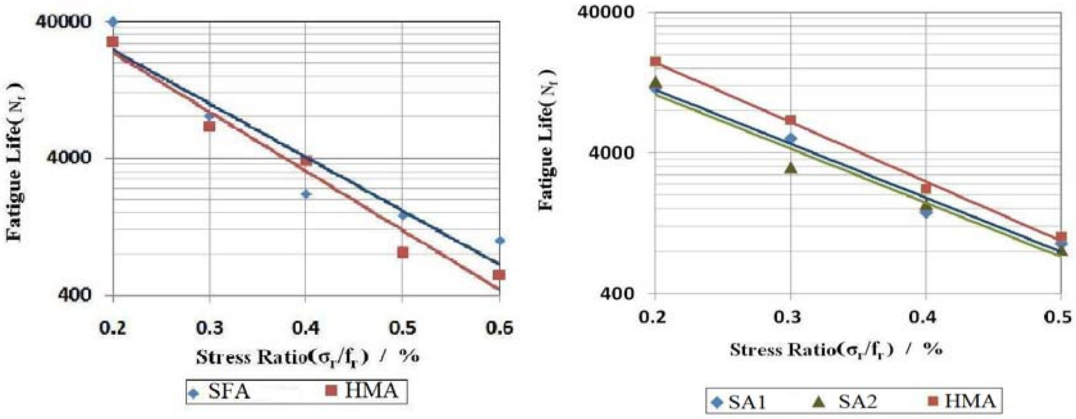
As we can see from Table 5, the reduction of mixing temperature will have certain impact on the moisture stability, especially SFA WMA technology. For all such impacts, the WMA still can satisfy the prevailing code requirements on HMA. When the mixes are applied in humid and rainy districts, the water content of aggregates should be strictly controlled, and proper measures should be taken against moisture damage.

3.4 Anti-fatigue Property of WMA

During our research, MTS stress control method was utilized to test the anti-fatigue property of the specimen. In order to compare the anti-fatigue property of WMA and HMA, beam bending tests were conducted at the constant temperature of 20℃ to measure the respective fatigue frequency of HMA and WMA under different stress ratios. The fatigue tests were conducted on MTS-810 test machine, with the beam size at 50 mm×50 mm×240 mm, with half-Sine wave of 10Hz as the loading wave form, and stress ratios at 0.2, 0.3, 0.4, 0.5 and 0.6 respectively. See Fig. 6 for the test results.

As we can see from Fig. 6(a), compared with HMA, SFA WMA features better anti-fatigue performance, and with the rise of stress ratio, the amplitude of fatigue life also increases. This may be related to the relief of aging magnitude. However, as suggested by Fig. 6(b) with the application of SA1 and SA2 additives, the anti-fatigue property of the mix declines apparently; with the same stress ratio, the fatigue life under both conditions decreases by about 20~30%, which is just opposite to the changing tendency of high-temperature stability.

Therefore, the shaping methods have big impact on the compactness of WMA. Moreover, the temperature sensitivity of different methods is also different. An appropriate compaction method plays a significant role in compaction of WMA. In addition, even for WMA, the higher the temperature is, the better compaction the mix has.



SFA WMA and HMA SA1 & SA2 WMA and HMA

(a) (b)

Figure6: Comparsion of WMA and HMA in anti-fatigue property

Different warm mix technologies have different influence on performance of the mixture, so we should select the proper technology based on the specific conditions. SFA WMA has a quite sound anti-fatigue property, so it can be mainly applied in the place which has a high demand on anti-fatigue performance. SA1 and SA2 organic viscosity-reducing technologies boast their high-temperature stability, so they can be largely applied in the place which has a high demand on high-temperature stability. Certainly, we also should incorporate such factors as operation convenience and economy.

4 SFA Warm Mix Asphalt Test Section

Since SFA warm mix technology was introduced to China in 2006, it has had great influence and developed rapidly, and was applied in many projects. This study applied SFA second generation warm mix technology on two ramps of Zhubi Expressway in Henan in September, 2007. This was the first application of the technology in China. Here it is briefed. The warm mix trial section is totally 543m long. SFA warm mix asphalt was adopted at both the upper and lower layers: Gradation AC-13C was adopted at the upper layer, optimal asphalt content 4.6%; Gradation AC-20C was adopted at the lower layer, optimal asphalt content 4.3%.

During construction, it was a fine day and the temperature was 30℃ or so. Temperature of warm mix asphalt was controlled at 130℃ or so when it was discharged, 120℃ or so when it was initially compacted, and 70~80℃ when roller compaction was over. Roller compaction mode was the same as that for hot mix. However, roller compaction was added for 1~2 more times. Figure 7 was the laying site then. One did not have a feeling of being blazed when he/she stood beside it. Table 6 is the after construction site test results.

It can be seen from Table 6 that various testing indices meet requirements on hot mix asphalt. Figure 8 is the photo of observation in 1 year. Overall conditions are good. However, the long-term performance is pending for further observation.

Figure 7: Paving site

Figure 8: Road conditions after 1 year in service

Table 6: After construction site test result of warm mix test section

Testing Index		Structure depth (mm)	Friction coefficient (BPN)	Permeability coefficient (ml/min)	Degree of compaction (%) (Marshall Density)	Degree of compaction (%) (Maximum theoretical density)
The upper layer	Ramp G	0.73	80	Non-permeable	98.2	95.3
	Ramp I	0.70	67	Non-permeable	98.5	95.6
The lower layer	Ramp G	/	/	40	100	94.7
	Ramp I	/	/	Non-permeable	99.2	94.9
Requirements of Code on HMA		≮0.6	＞45	≯100	≮97	≮92

5 CONCLUSIONS

(1) After SFA warm mix agent is added in asphalt binder, softening point and ductility at 10℃ of binder drop to some extent. Penetration and viscosity don’t vary much. After SA1 and SA2 of certain dose are added, the softening points rise significantly, while penetration, ductility and viscosity drop to different extent. The inflence varies slightly with different asphalt.

(2) Shaping method has great influence on compaction of WMA. Under the same temperature, air void of gyratory shaping is much lower than that of Marshall shaping. The temperature sensitivity is significantly lower than that of Marshall compaction method. As shaping temperature rises, air void of mixture drops, indicating that even for warm mix, the higher the temperature is, the easier compaction is. Therefore, it is the key to successful implementation of warm mix to adopt reasonable roller compaction process and good temperature control.

(3) When WMA is designed with the same optimal asphalt content as HMA, in order to reach the same air void, then the temperature drop is limited; if shaping temperature needs to be further reduced, then it can be realized by increasing asphalt consumption or warm mix additive consumption.

(4)The three warm mix asphalt technologies have their respective advantages and disadvantages. However, all of them can meet the requirements on performance of hot mix asphalt. Fatigue performance of SFA warm mix technology is prominent. It can be used where requirements on fatigue performance are high as an emphasis. High temperature stability performance of SA1 and SA2 warm mix technologies is prominent. They can be used where requirements on high temperature stability are high as an emphasis.

(5) The successful laying in warm mix test section indicates that provided that all construction links are controlled properly, WMA can achieve the same compaction effect as HMA.

At present energy efficiency and environment protection have become a focus of concerns of the whole society. It is of important realistic significance and significant social and environmental benefit to study and popularize warm mix asphalt technology. It is worthy of further study and application. Especially it has significant advantages and a broad development prospect in construction in long tunnels and urban roads where requirements on environment protection are high and construction in low temperature seasons.

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