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EFFECT OF TYPE AND CONTENT OF WARM-MIX ADDITIVES ON HIGH-VISCOSITY ASPHALT

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Abstract

High viscosity asphalt (HVA) is a kind of asphalt modified with styrene-butadiene-styrene, plasticizer, and crosslinker. HVA is widely used in porous asphalt pavements around the world, especially in China and Japan. Most previous studies have focused on improving the performance of in-service HVA pavements at high and low temperatures. There is a need to ensure that HVA can also perform well at high temperature during construction to improve the workability of the mixture. The purpose of this study was to use warm-mix additives (WMA) to reduce viscosity during construction and keep acceptable performance at high and low temperatures. To accomplish this objective, three types of warm-mix additives (RH, EC-120, and Sasobit) with three different contents (2%, 3%, and, 4%) were mixed with HVA. An HVA without any WMA was used as a control sample. Physical tests conducted for each sample included viscosity (135℃), motive viscosity (60℃), penetration (25℃), softening point, ductility (5℃), tenacity (25℃), and toughness (25℃) before and after short-term ageing (thin film oven test). The test results show that the WMA additives have a significant effect on reducing viscosity 135℃) of HVA during construction, while substantially improving motive viscosity (60℃) with the addition of EC-120 and Sasobit. In addition, EC-120 improved toughness and tenacity. However, WMA had an adverse effect on low-temperature performance due to the reduction on ductility. The results show that EC-120 is considered as the optimal type among the three WMA and 3% is suggested as the best content of EC-120 for HVA.

INTRODUCTION

Porous asphalt pavement, an alternative to traditional asphalt, is produced by removing fine aggregates from the asphalt mixture, whose void space generally ranges from 18% to 22% (Barrett and Shaw 2007). Porous asphalt pavement is very popular in many countries, especially in Japan and China, due to the acknowledged benefits of permeability, noise reduction, skid resistance, runoff pollution decrease, and splash and spray reduction (Takahashi 2013). However, it is recognized that the stripping of asphalt and the lack of durability are important challenges for porous asphalt pavements (Takahashi 2013).

Based on practical experiences for many years in Japan, a unique concept "high viscosity asphalt (HVA)" was proposed to improve long-term performance and durability of porous asphalt pavements. The concept was accepted by East and Southeast Asian countries and other countries, such as Japan, China, and Netherlands (Xu 2011). HVA is defined as an asphalt with motive viscosity (60℃)that is higher than 20 000Pa·s, which has better high-temperature performance, strong holding power, and deformation resistance (Zhang and Hu 2015a). The motive viscosity is a key parameter that plays a vital role in resisting fluidity and stripping of porous asphalt pavements (Zhongxi and Chi 2002). The higher motive viscosity, the longer service life and the better stability of porous asphalt pavements (Zhongxi and Chi 2002). However, with the increase in viscosity, the poor workability is a challenge that makes it difficult in producing and compacting asphalt mixtures during construction and hinders the further development of HVA. To improve the application of HVA, it is necessary to reduce viscosity at 135℃ which is used to evaluate the workability of asphalt mixture during construction.

Warm-mix additives (WMA) is considered to be an effective method to reduce viscosity of HVA during construction with similar temperature to those of hot-mix asphalt (HMA)(Elsa et al. 2011). The WMA technology was originally developed to reduce the temperatures during construction in order to promote energy savings and reduce environmental emissions compared with HMA. To evaluate the performance of asphalt after adding WMA, several studies were conducted. Hassan and Amir (2016) investigated the performance of adding WMA (Sasobit) into four types of modified asphalt, including crumb rubber (CR), anti-stripping agent, polyphosphoric acid, and styrene-butadiene-styrene (SBS). The results indicated that Sasobit had a significant decrease in stiffness at low temperatures for anti-stripping agent modified asphalt, while viscosity is reduced. In addition, the CR-Sasobit modified asphalt performed best among the four types of asphalts, especially at low and intermediate temperatures. María et al. (2013) presented a study on the effect of four types of WMA (Sasobit, Asphaltan A, Asphaltan B and Licomont BS 100) on crumb rubber modified asphalt (CRMA). The results showed that these WMA successfully reduced viscosity, improved softening point, and reduced penetration. However, they did not have a clear effect on the elastic recovery and ductility at 25℃. A number of studies were presented including different types of WMA(e.g., organic and chemical WMA) and different types of modified asphalt (Yu and Wang 2013, Silva and Oliveira 2010, Hakseo et al. 2012, Xie et al. 2014, Liu et al. 2011, Wang et al. 2012, Hamzah et al. 2015, Omari et al. 2016). Previous studies focused more on the properties of rubberized WMA asphalt, but there are very limited work done on the performance of the combination of WMA and HVA to reduce viscosity during construction. In addition, it is necessary to investigate and analyze some parameters that are required for HVA, such as motive viscosity, toughness, and tenacity.

In this study, the proposed HVA based on SBS modifier was designed to obtain high motive viscosity, which is usually used for porous asphalt pavements with high air void (Zhang and Hu 2015a, 2015b).Three kinds of organic WMA with three contents were incorporated into the proposed HVA to reduce viscosity during construction while keeping reasonable high and low-temperature performance during the use phase. The physical properties were investigated to evaluate the performance of HVA with different types and contents of WMA, including viscosity (135℃), motive viscosity (60℃), softening point, ductility, penetration, toughness, tenacity. Based on the physical properties, an optimal type and content of WMA was suggested for future work.

MATERIALS AND EXPERIMENTAL DESIGN

The experimental design of this study is shown in Figure 1. One control HVA sample is made for comparing the effect of adding WMA, which included SBS, plasticizer and crosslinker. Three types of WMA (RH, EC-120, and Sasobit) were added into HVA with different contents (2%, 3%, and 4%). Then, nine types of samples were prepared. For each sample, physical tests were conducted including viscosity measure and other traditional physical tests. Details of the experimental design are presented in Figure 1.

2.1 Materials

The proposed HVA is made with four types of materials, including Fuzhou-70 paving asphalt, SBS1301, furfural extract oil and sulfur (Zhang and Hu, 2015a). Fuzhou-70 paving asphalt was obtained from the

Fuzhou Petroleum Asphalt Factory, China. The physical properties are listed in Table 1. SBS1301 with 30 wt% styrene is a linear polymer and the average molecule weight is 110,000 g/mol. Furfural extract oil is acted as plasticizer and sulfur is considered as crosslinker, which are chemically pure reagents.

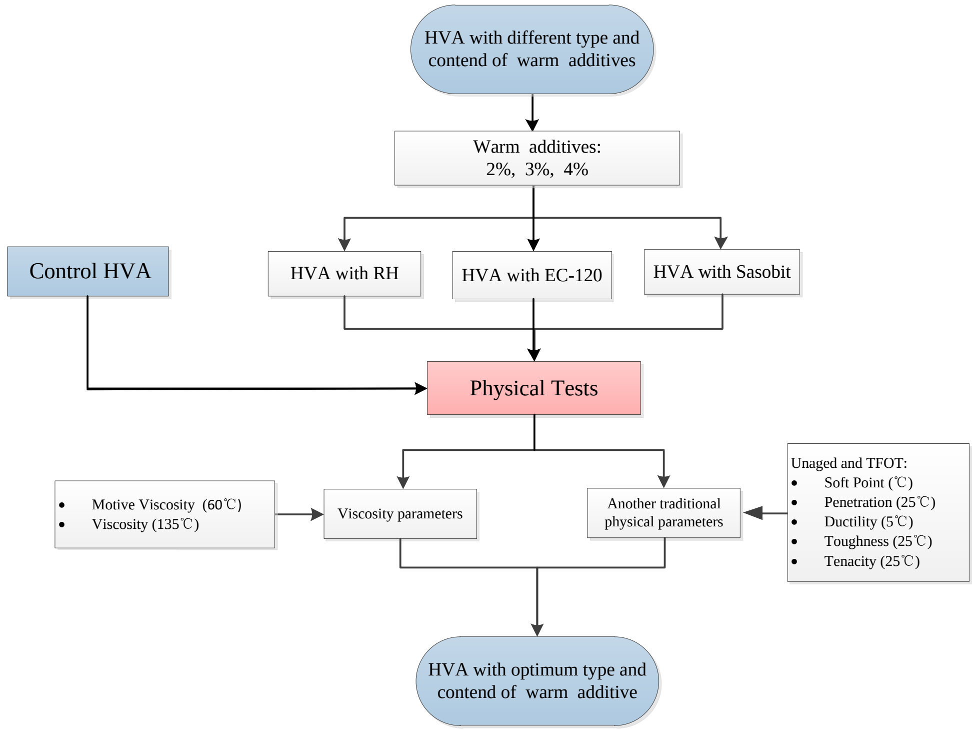

Figure 1: Details of the experiment design

Table 1: Physical properties of AH-70 asphalt

Properties	Unaged	After TFOT ageing
Softening Point (℃)	49.8	54.3
Penetration (25℃, dmm)	61	34
Motive Viscosity (60℃, pa•s)	448	865.8
Viscosity (135℃, pa•s)	0.77	-

The organic WMA used in this study are RH, EC-120 and Sasobit, which belong to wax-based additives. This organic WMA is designed to improve the flow properties of the asphalt by lowering its viscosity above the wax melting point, and also increasing the stiffness of asphalt at a temperature below the melting point (Silva and Oliveira 2010). RH was developed by the Research Institute of Highway Ministry of Transport, China. EC-120 was developed by Shenzhen Oceanpower New Materials Technology Co., China and Sasobit is used widely and developed by Sasol Wax Co., Germany.

2.2 Preparation of samples

The preparation of samples included two steps:

Step1: The preparation of HVA was used a high shear mixer (made by Qishuang Machine, China). First, Fuzhou-70 paving asphalt (500 g) was heated until it became fluid in an iron container, then upon reaching about 180℃, 9% SBS and 6 % furfural extract oil (based on 100 parts asphalt) were added. The shearing time was 1 h-15min at the shearing speed of 4500 r/min, and then 0.25% sulfur (based on 100 parts asphalt) was added. Subsequently, the blend was stirred for 1 h-50min by a mechanical stirrer at 180℃~190℃.

Step 2: WMA was added and stirred in the iron container for 40 min to ensure full swelling of the additives in the asphalt.

2.3 Ageing of modified asphalt

The short-term aging of asphalt was performed using the thin-film oven test (TFOT, ASTM D 2872) which simulates manufacturing and placement ageing for the physical properties testing. In this study, the softening point, ductility, penetration, toughness, tenacity were conducted to evaluate the performance after short-term ageing.

2.3 Physical properties test

To evaluate the physical properties of HVA after adding WMA, the following tests were conducted: viscosity (135℃), motive viscosity (60℃), softening point, ductility(5℃),penetration(25℃), toughness(25℃), tenacity(25℃), based on ASTM D2171, D2196, D36, D5, D113,D5801, respectively.

RESULTS AND DISCUSSION

3.1 Viscosity (135℃)

The workability of asphalt is represented by the viscosity at 135℃, which was tested using Brookfield viscometer. Figure 2 shows the effect of type and content of WMA on viscosity (135℃). It can be seen that the three types of WMA produced a significant decrease on viscosity (135℃), where the greatest reduction was more than 26% when the addition of EC-120 was 4%. The results show that the workability of samples was improved apparently by the addition of RH, EC-120, and Sasobit. Comparing the three types of WMA, EC-120 performed best, followed by Sasobit and RH, which have similar reductions. In addition, as the three types of WMA increase, the viscosity at 135℃ uniformly continued to decrease by different extents. The viscosity reduction in this study is due to the organic WMA melted at the test temperature (135℃) and promoted to the flow properties of modified asphalt which showed a decrease in viscosity.

3.2 Motive viscosity (60℃)

The motive viscosity at 60℃is a key parameter for evaluating high-temperature performance of HVA. The results for the sample are shown in Figure 3. As noted, RH warm additive produced a significant decrease in motive viscosity, which was reduced by nearly 30% compared to control HVA. For the samples involving EC-120 and Sasobit, motive viscosity was improved compared to control HVA. The reason is that the test temperature for the motive viscosity, which did not reach the melt temperature of these two wax-based additives ranged from 90℃ to110℃ (Silva and Oliveira 2010).The higher motive viscosity resulted from the interaction of HVA and WMA which improved the structure characterization of this modified asphalt. In addition, with the increase in WMA content (from 2% to 3%), the motive viscosity improved. However, the viscosity is reduced greatly when the content of EC-120 and Sasobit changed from 3% to 4%. This result shows that the excessive and unreacted WMA might have an adverse effect on motive viscosity. When comparing different types and contents of WMA, it can be found that Sasobit with 3% content has optimal effect on motive viscosity for HVA.

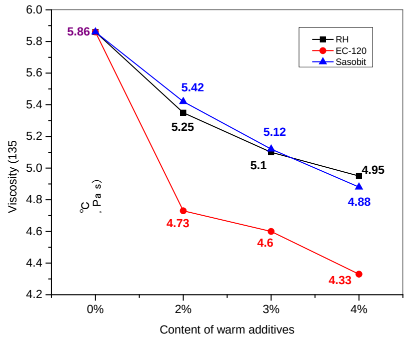

Figure 2: Effect of WMA on dynamic viscosity

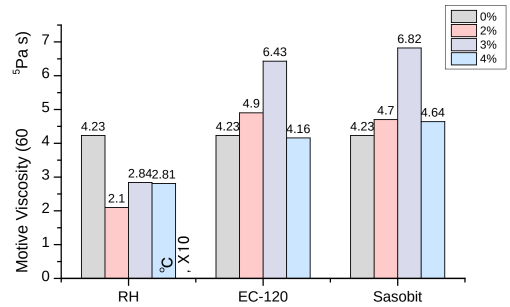

Figure 3: Effect of WMA on motive viscosity

3.3Softening point

The softening point test establishes the temperature at which the asphalt softens, which is a parameter that represents high-temperature performance for asphalt. The softening points of the samples were as follows: 98.8℃, 98.2℃, 99.2℃, 100℃, 99.1℃, 100℃, 100℃, 100℃, and 100℃, respectively for 2%, 3%, and 4% of RH, EC-120 and Sasobit, respectively, where the control HVA is 97.75 ℃. It is observed that the softening points increased slightly after adding WMA and changed little by different contents. The high softening points occurred due to the presence of SBS and organic WMA which acted as stabilisers.

To evaluate the ageing performance, the softening point difference was calculated as follows,

[1] $\Delta S = SP_b - SP_a$

where

ΔS = softening point difference
SP_b = softening point before aging
SP_a = softening point after aging.

The results of the softening point difference are shown in Figure 4. A lower ΔS means a better ageing resistance. It can be seen from the figure that the ageing resistance was improved for all the samples with WMA compared to control HVA. In addition, by varying the content of WMA from 2% to 3%, ΔS substantially declined, while the values increased for contents of 3% and 4%. It indicates that 3% is the optimal content of WMA for ageing resistance on high-temperature performance due to the complete reaction of WMA and HVA with this content after short-term ageing.

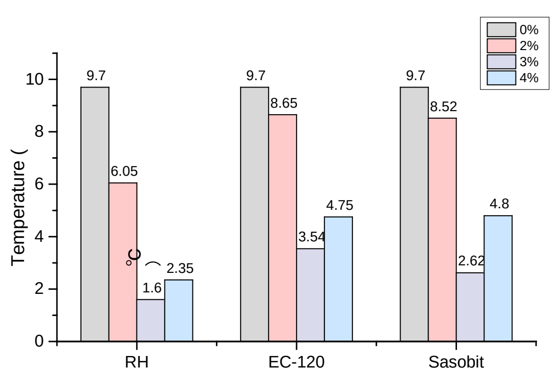

Figure 4: Softeningpoint difference before and after ageing

3.4 Penetration

Penetration is a parameter that represents the stiffness of asphalt. It is observed in Figure 5 that the penetration was improved for the RH samples and was reduced by the addition of EC-120 and Sasobit which made HVA stiffer. Compared to EC-120 and Sasobit, the physiochemical reactions occurred between HVA and WMA, and the structural properties were formed by the reaction. It has a stable structure since EC-120 and Sasobit did not fuse, a phenomenon that occurs at temperatures greater than 90℃ (Silva and Oliveira 2010), while the penetration test was performed at 25℃. When comparing different types of WMA, the sample with Sasobit was the stiffest and the combination of RH and HVA was the softest.

The penetration ageing index was used to compare the penetration variation before and after short-term ageing in this study. The index was calculated as follows,

[2] $PAI = 100\,\frac{P_a}{P_b}$

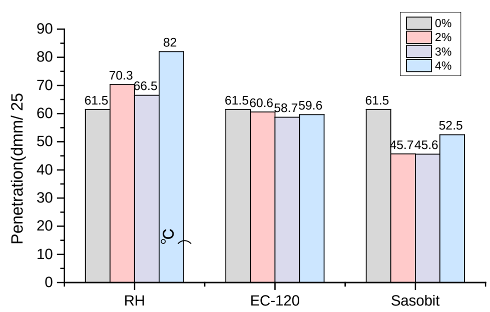

Figure 5: Effect of WMA on penetration of HVA

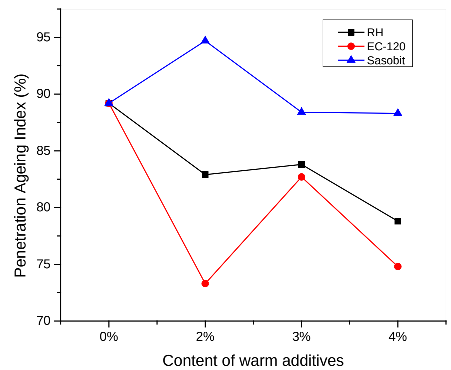

Figure 6: Effect of WMA on penetration ageing index

where

PAI = penetration ageing index (%)
P_a= penetration after aging
P_b = penetration before aging.

The results of the penetration aging index are shown in Figure 6. It is noted that *PAI* decreased by the addition of the WMA compared to the control HVA and reached the lowest value for the 2% content of EC-120.

3.5 Ductility

Ductility is a traditional parameter for evaluating low-temperature performance for asphalt, which represents the crack resistance for pavement at low temperature. The higher value of ductility means the better crack resistance. The results of ductility are shown in Figure 7. It is noted that ductility was reduced greatly for most of the samples after adding WMA. Comparing the effect of different types of WMA, Sasobit had the greatest decrease of ductility, followed by EC-120, while RH had lowest effect on low-temperature performance among the three types of additives. In addition, with the higher contents of WMA, ductility did not show a significant difference.

To evaluate the low performance after ageing, the ductility decrease rate was calculated, based on the reduction in ductility before and after ageing, as follows

[3] $DDR = 100\left(1 - \frac{D_a}{D_b}\right)$

where

DDR = ductility decrease rate (%)
D_a = ductility after aging
D_b = ductility before aging

Figure 7 shows that the ductility of each sample was reduced after short-term ageing, especially for Sasobit where the biggest *DDR* was nearly 50%. With the increase in WMA content, the effect of ageing on ductility was increased continuously. It is noted in Figures 6 and 7 that the addition of RH, EC-120, and Sasobit had an adverse effect on low-temperature performance of HVA since organic WMA made HVA more brittle at low temperature.

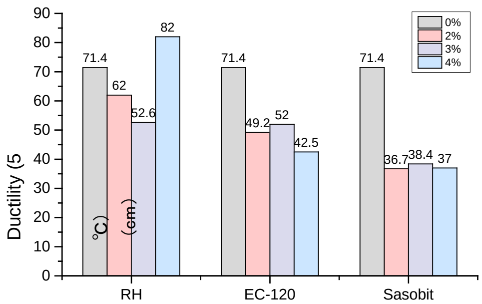

Figure 7: Effect of WMA on ductility of HVA

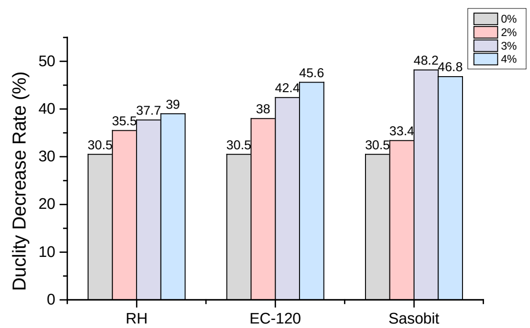

Figure 8: Ductility decrease rate before and after ageing

3.6Toughness and tenacity

Toughness and tenacity represent the holding power of asphalt to aggregate, which are important parameters for porous asphalt pavements with high-air void. The test was designed to investigate the effect of WMA on toughness and tenacity of HVA. Table 2 shows that toughness and tenacity of HVA was reduced with the addition of RH. Both toughness and tenacity increased by the additives of EC-120, and the values did not substantially change when the content changed from 2% to 4%. For the samples of HVA with Sasobit, both toughness and tenacity declined compared to control HVA. In addition, the higher values of toughness and tenacity occurred with the higher content of Sasobit.

After short-term ageing, toughness and tenacity of each sample contained WMA considerably improved compared to homologous un-aged sample. However, this result did not occur in control HVA sample where toughness and tenacity were reduced slightly after short-term ageing. The results show that the addition of RH, EC-120, and Sasobit is beneficial for toughness and tenacity and improve the cohesive force of asphalt and aggregates after short-term ageing.

Table 2: Effect of WMA on toughness and tenacity of HVA

Sample	Toughness (25℃)		Tenacity (25℃)	
	Before Aging (N·m)	After TFOT Ageing (N·m)	Before Aging (N·m)	After TFOT Ageing (N·m)
HVA	22.75	21.85	15.48	15.42
HVA+2%RH	14.81	21.45	11.37	16.02
HVA+3%RH	19.45	20.89	13.14	13.27
HVA+4%RH	17.47	20.92	12.51	13.71
HVA+2%EC-120	23.28	33.05	17.20	27.11
HVA+3%EC-120	23.78	27.26	16.83	17.84
HVA+4%EC-120	23.03	26.65	16.36	22.02
HVA+2%Sasobit	18.98	32.29	11.25	24.41
HVA+3%Sasobit	20.41	29.94	11.47	18.66
HVA+4%Sasobit	21.21	29.71	11.94	13.41

CONCLUSIONS

The objective of this study was to use WMA to reduce viscosity during construction and keep acceptable performance at high and low temperatures. Three types of organic WMA (RH, EC-120, and Sasobit) with three different contents (2%, 3%, and, 4%) were mixed with HVA. Based on this study, the following conclusions are offered:

1. This study has shown that the addition of the three organic WMA has a significant effect on reducing viscosity (135℃) of HVA during construction. The greatest reduction in viscosity occurred with 4% EC-120.
2. To evaluate the high-temperature performance of HVA after adding WMA, motive viscosity and softening point were conducted. The results show that RH has an adverse effect on motive viscosity, which was improved by the other two WMA (EC-120 and Sasobit). The 3% Sasobit produced the highest value of motive viscosity, followed closely by 3% EC-120. The softening point of each sample after adding WMA was slightly improved. Penetration was reduced for most of the samples by the addition of WMA which made HVA stiffer. Ductility, performed to evaluate the low-temperature performance, showed a significant decrease after adding the three types of additives, especially for EC-120 and Sasobit. The results show that EC-120 improve toughness and tenacity which did not substantially change for different contents of EC-120. However, these parameters declined by the addition of RH and Sasobit.
3. The softening point, penetration, ductility, toughness, and tenacity were tested after short-term ageing. The results show that softening point, penetration, ductility were reduced by different extents, whereas tenacity and toughness were substantially improved after short-term ageing.
4. According to the preceding physical properties, EC-120 is considered as the optimal type among the three WMA and 3% is suggested as the best content of EC-120 for HVA. Further research will be conducted to analyze the rheological properties and structural characteristics using the optimal WMA.

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