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Research Article

Characterization of Warm Mix Agent and Its Influence on Properties of SBS-Modified Asphalt

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Warm mix agent is the key factor to restrict the performance of warm mix asphalt. In this paper, methods of X-ray diffraction, thermal stability test, and laser particle size analysis were used to test and analyze the internal structure, composition, and properties of three kinds of warm mix agents. In order to study the performance impact of the warm mix agent on SBS-modified asphalt, the warm mix agents of Advera®, LTA synthetic zeolite, and 13X synthetic zeolite were added to SBS-modified asphalt in different contents. The three kinds of warm mix asphalt were tested by the experiments of softening point, penetration, and ductility to analyze their physical properties. The testing results showed that the softening point of three kinds of warm mix SBS-modified asphalt is greater than the softening point of SBS-modified asphalt without adding warm agents, which indicate the warm mix additives can improve the high-temperature stability of SBS-modified asphalt. The three kinds of the warm mix agent make SBS-modified asphalt hard, and the consistency and the ability of resisting deformation increase. The low temperature performance of SBS-modified asphalt decreased in different degrees with mixing different zeolite warm mix agents.

1. Introduction

Compared with hot-mix asphalt, warm-mix asphalt technology can wrap asphalt in aggregate at low temperature by some technical measures, which has good adhesion and lubricity and increases the construction operation of asphalt mixture. After mixing, these technical measures shall not adversely affect pavement performance so as to ensure that the road performance of the mixture is not less than that of the hot mix asphalt.

In recent years, many scholars have studied and applied warm mix technology, mainly focusing on asphalt performance and road performance of warm mix-recycled asphalt mixture [1–9]. Many scholars have made meaningful results on the influence of warm mix additives on the properties of asphalt [10–13]. In current studies, it has been proven that the amount of zeolite additive depends on the type of the zeolite structure. Also, the water content of zeolite varies, depending on the type of the zeolite structure [14, 15]. WMA with the addition of zeolites and mesoporated silica materials impregnated with water has been researched by Woszuk et al. [10, 15, 16]. The investigation of zeolite as a WMA additive and its comparison with different types of WMA additives were studied [17–22]. The viscosity reduction effect factors of asphalt mixture are closely related to the warm mix agents and asphalt properties. The reason is that the compatibility and compatibleness between asphalt type and warm mix additives are very different.

The raw materials for the production of artificial zeolite include chemical raw materials, bentonite, kaolin, quartz sand, bauxite, and so on. Sodium aluminate solution was prepared first, and then zeolite was produced by hydrothermal synthesis with a low-speed turbulent mixer. In this paper, the synthesis of zeolite Advera®, LTA, and 13X was analyzed by the methods of ignition loss, X-ray diffraction, SEM electron microscope analysis, differential thermal analysis, and laser particle size analysis. The three kinds of warm mix agent type, molecular phase, cell size, cell structure, cell morphology, grain size, grain size distribution, the structure stability of the internal structure, and composition characterization were studied and compared the similarities and differences between the compositions of node three warm mix asphalt admixture. This will provide a basis for better selection of zeolite temperature mixture. In order to study the effect of the three kinds of warm mix additives on the properties of SBS-modified asphalt, the three kinds of warm mix asphalt were tested using the experiments of softening point, penetration, and ductility.

2. Test and Analysis of Warm Mix Agents

2.1. X-Ray Diffraction Analysis. X-ray diffraction test is based on the X-ray diffraction pattern of the sample or the value of $2\theta{\sim}d$ to analyze the oxide type and content of the sample, which can be used to judge the molecular formula of the sample. The phase determination of the sample was determined using an X-ray diffractometer. The atlases were analyzed by software of Jade, Eva, and Search Match to test the microcomposition of the sample whether there were impurities or not and calculate the crystallinity of the sample.

The test procedure is as follows: 1 gram of sample is taken to be placed in an oven with a constant temperature of 105°C, dried for 3 hours, and then put in a humidifier with saturated ammonium chloride solution, and fully moisture is absorbed over 18 hours. The X-ray diffraction pattern or the value of $2\theta{\sim}d$ of the sample was obtained according to the operating rules of the X-ray diffractometer and the selected test conditions.

Compositional mass fraction (WL%) of LTA zeolite, Advera®, and 13X zeolites is shown in Table 1. X-ray diffraction of 13X zeolite shows typical characteristic peaks of zeolite. The main materials of LTA zeolite and Advera® phase were sodium aluminosilicate hydrate ($Na_{12}Al_{12}Si_{12}O_{48}\cdot 27H_2O$). The main phase of 13X zeolite is sodium aluminosilicate hydrate ($Na_2Al_2Si_{2.5}O_{9.0}\cdot 6.2H_2O$), and the main phase of the samples is sodium silicate hydrate.

2.2. SEM Electron Microscope Analysis. SEM electron microscope was used to observe the micromorphology of Advera®, LTA, and 13X zeolite warm mix additives. The result is shown in Figure 1. As can be seen from Figure 1, LTA and 13X synthetic zeolites have the same particle shape as Advera®, and most particles are regular hexahedron. The crystal grows well. The crystal boundary is clear. The crystal is even and regular, and the dispersion is good.

2.3. Thermal Stability Analysis. In the process of heating or cooling, when the material reaches a certain temperature, melting, solidification, crystal transformation, decomposition, chemical absorption, desorption, and other physical or chemical changes are often occurred. Synchronous thermal analysis is a technique for continuously measuring the mass and heat of a sample varying with temperature or time under program temperature control. Thermal gravimetric analysis and differential scanning calorimetry are combined to obtain thermal and differential thermal information in one measurement.

Synchronous thermal analysis of Advera®, LTA zeolite, and 13X zeolite warm mix was carried out using a synchronous thermal analyzer, and the test results are shown in Figure 2. As can be seen from Figure 2, when the temperature is between 60 and 300°C, the amount of crystalline water releases rapidly increases to a stable state (after the temperature is over 300°C). Thus, the thermal stability of the three kinds of warm mix agents is consistent. When the temperature is between 30 and 60°C, the amount of crystalline water is less. At 60°C, the amount of crystalline water released by LTA zeolite, 13X zeolite, and Advera® was 0.76%, 0.85%, and 0.64%, respectively. At 120°C, the amount of crystalline water released by LTA zeolite, 13X zeolite, and Advera® was 5.1%, 6.4%, and 4.6%, respectively, and could last for some time. Therefore, the three kinds of warm mix samples meet the requirements of crystallization water release.

2.4. Laser Particle Size Analysis. The particle-size distribution of the warm mix agents was measured by laser particle-size distribution analyzer. The results of three kinds of warm mix agents are shown in Figure 3. The size of LTA zeolite and 13X zeolite is 0.8~3 μm. The size of the Advera® warm mix is 0.8~6.4 μm. As shown in Figure 3, the size distribution of the Advera® sample is wide, and the particle size content is relatively average. However, the size distribution range of LTA zeolite and 13X zeolite sample is narrow, and the content of fine particle size is more.

3. Influence Analysis of Warm Mix Agent on Properties of SBS-Modified Asphalt

3.1. Preparation of Warm Mix SBS-Modified Asphalt. Because of the difference of compatibility between asphalt and warm mix agents, in order to study the influence of warm mix agents on asphalt performance, Advera®, LTA zeolite, and 13X zeolite were added into SBS-modified asphalt. The softening point, ductility, and penetration of warm mix SBS-modified asphalt were analyzed. These will be analyzed in Sections 3.2–3.4. The test results of warm mix SBS-modified asphalt are shown in Table 2.

As can be seen from Table 2, the conventional performance indexes of the warm mix SBS-modified asphalt meet the technical requirements of the technical specification for highway asphalt pavement (JTG F40-2004).

The preparation process of three kinds of warm mix asphalt is as follows. SBS-modified asphalt is heated to 135°C and stirred at low speed. Individually added Advera®, LTA zeolite, or 13X zeolite to the heated SBS-modified asphalt is kept at a temperature of 135°C. Stir at low speed for 10–15 min until the Advera®, LTA zeolite, or 13X zeolite is completely and uniformly melted into the SBS-modified asphalt. At this point, the preparation of warm mix SBS-modified asphalt is completed. Finally, put the warm mix SBS-modified asphalt in a small container for further testing.

Table 1: Composition analysis results of three kinds of warm mix agents.

Advera®		13X zeolite		LTA zeolite	
Composition	Mass fraction	Composition	Mass fraction	Composition	Mass fraction
SiO_2	31.47	SiO_2	33.85	SiO_2	31.47
Al_2O_3	28.85	Al_2O_3	25.34	Al_2O_3	28.49
Ignition loss	21.34	Ignition loss	25.30	Ignition loss	21.64
Na_2O	18.26	Na_2O	14.92	Na_2O	18.30
CaO	0.02	CaO	0.20	K_2O	0.05
SO_2	0.01	MgO	0.13	Fe_2O_3	0.01
Fe_2O_3	0.01	K_2O	0.12	Cl	0.01
Cl	0.01	SO_2	0.05	SO_2	0.01
P_2O_3	0.01	Cl	0.04	CaO	0.01
ZrO_2	0.01	Fe_2O_3	0.03	P_2O_3	0.01
Trace amounts of TiO_2, K_2O, ZnO, Ga_2O_3, and CuO		Trace amounts of TiO_2, ZrO_2, CuO, NiO, Ga_2O_3, and SrO		Trace amounts of TiO_2, ZrO_2, and Ga_2O_3	

3.2. Effect of Warm Mix Agents on Softening Point of SBS-Modified Asphalt. The softening point of asphalt can be defined as the temperature at which the bitumen is changed from solid or viscous to a state with a certain flow capacity under certain external forces and heating. The softening point of asphalt is associated with the degree of soft deformation of the asphalt pavement surface. The high temperature stability of asphalt is evaluated by the degree of the softening point. The higher the softening point, the better the stability of asphalt at high temperature.

The softening point test results of three kinds of warm mix SBS-modified asphalt are shown in Table 3. As can be seen from Table 3, the softening point of three kinds of warm mix SBS-modified asphalt is larger than that of the no added warm additives of SBS-modified asphalt. Among them, the softening point of SBS-modified asphalt with Advera® and LTA zeolite is little different. The test results show that the three kinds of warm additives can improve the high temperature stability of SBS-modified asphalt.

3.3. Effect of Warm Mix Agents on Penetration of SBS-Modified Asphalt. Penetration can reflect the rheological properties of asphalt, in essence, the consistency of asphalt at test temperature. The penetration test condition of warm mix SBS-modified asphalt is that the temperature is 15, 25, and 30°C, the load is 100 ± 0.1 g, and the time is 5 s. The penetration test results of warm mix SBS-modified asphalt are shown in Table 3.

The penetration test results of three kinds of warm mix SBS-modified asphalt are shown in Table 4. At the temperatures of 15, 25, and 30°C, the penetration value of SBS-modified asphalt mixed with Advera®, LTA zeolite, or 13X zeolite is lower than that of the no added warm additives of SBS-modified asphalt. The penetration of LTA zeolite and 13X zeolite SBS-modified asphalt are close to that of Advera® SBS-modified asphalt. It indicates that the warm mix agents make the SBS-modified asphalt harden and thicken. This also means that the antideformation ability of SBS-modified asphalt mixed with the three kinds of warm mix agents has increased.

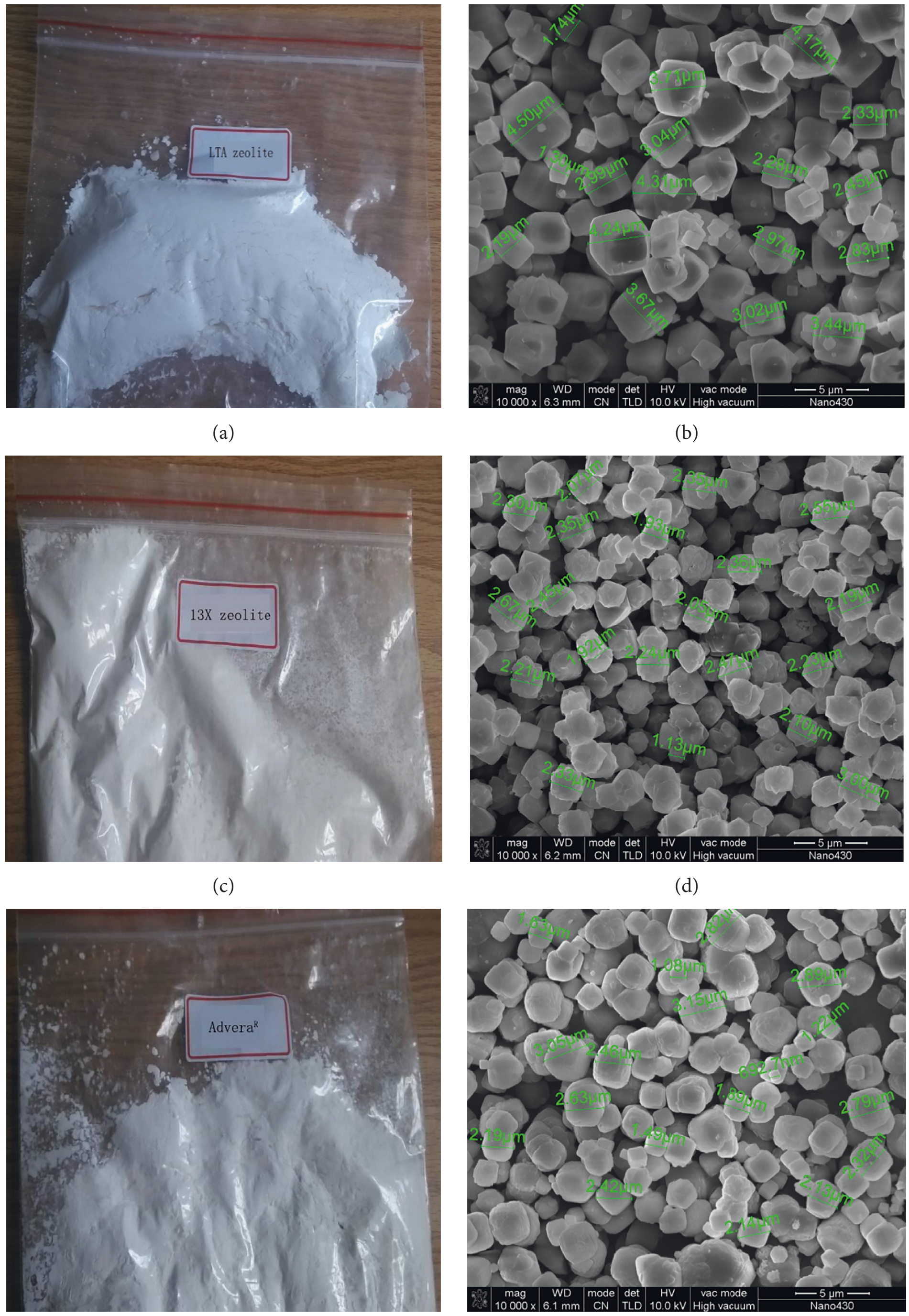
3.4. Effect of Warm Mix Agents on Ductility of SBS-Modified Asphalt. At present, scholars have different views on the significance of the asphalt ductility index and have not put forward more reasonable alternative test. Generally speaking, the ductility of asphalt is related to the performance of asphalt pavement, especially the ductility test at lower temperature. The test condition of the temperature ductility of SBS-modified asphalt is the temperature of 10°C and 5°C, and the tensile speed is 5 cm/min.

The test results of the ductility of the SBS-modified asphalt are shown in Table 5. As can be seen from Table 5, the ductility of the SBS-modified asphalt decreases in different degrees than that without the warm mix additives. Among them, the ductility of 13X zeolite SBS-modified asphalt decreases the most. This shows that the warm mix agents have some influence on the low temperature performance of the SBS-modified asphalt. Generally speaking, when the ductility value is large, the warm mix SBS-modified asphalt has low temperature deformation ability, that is to say, asphalt pavement is difficult to crack at low temperature. Therefore, it is especially important to choose the proper amount of the warm mix agent.

4. Conclusions

(1) The principle of synthesizing zeolite as additive of warm mix asphalt is that it contains a certain amount of crystallization water, and the crystallization water is continuously evaporated in hot asphalt to produce microfoaming to enhance the covering ability of asphalt at lower temperature. The thermogravimetric and differential thermal feature of zeolite characterize the release temperature of crystalline water. The three kinds of warm mix all accord with the release requirement of the crystalline water of the warm mix asphalt mixture. At the same amount of release, Advera® requires the highest temperature, followed by LTA zeolite and the lowest 13X zeolite. Different synthetic zeolites should be chosen according to different viscosity classes of asphalt so as to achieve evaporation boiling of crystalline water at a given temperature.

(2) The main phases of LTA, 13X, and Advera® are sodium aluminum silicate hydrate. Most of the



(a) (b)

(c) (d)

(e) (f)

Figure 1: Three kinds of warm mix asphalt agents and its microstructure: (a) original sample of LTA zeolite; (b) LTA zeolite seen under magnification of 10000 times; (c) original sample of 13X zeolite; (d) 13X zeolite seen under magnification of 10000 times; (e) original sample of Advera®; (f) Advera® seen under magnification of 10000 times.

particles of LTA, 13X, and Advera® are regular hexahedron. The crystal of three kinds of warm mix agent grows well, crystal shape boundary is clear, crystal is even and neat, and dispersive property is good. This results in the homogeneous release of zeolite water in bituminous mixtures, and no significant difference is seen.

(3) The particle size analysis of the zeolite can be used to evaluate the duration of the additive action. If the particle size range is wide, the effect time is longer, which is more conducive to enhance the uniformity of hot asphalt coating. If the range of particle size is narrow, the action time is relatively short. The results show that the size distribution of Advera® is wide

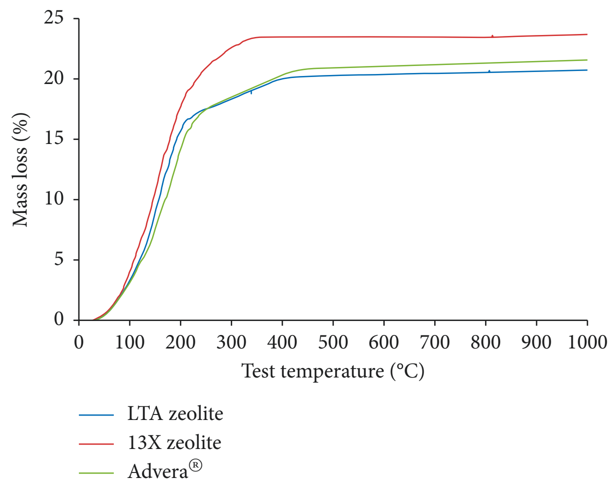


Figure 2: Thermogravimetric and differential thermal analysis of three kinds of warm agents.

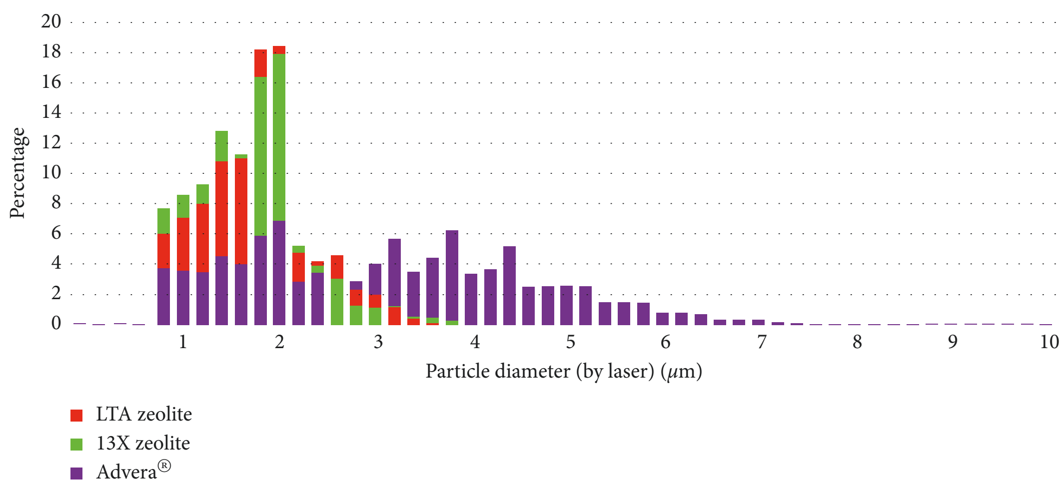


Figure 3: Particle-size distributions of three kinds of warm mix agents.

Table 2: Properties of SBS-modified asphalt.

Test items		Unit	Test result
Penetration (25°C, 100 g, 5 s)		0.1 mm	46
Penetration index (PI)			0.51
Ductility (5°C, 5 cm/min)		cm	40
Softening point		°C	80.5
Flash point		°C	318
Solubility		%	99.8
Storage stability		°C	1.5
Elastic recovery (25°C)		%	98
Dynamic viscosity		Pa·s	2.62
TFOT	Mass change	%	−0.11
	Ductility (5°C, 5 cm/min)	cm	26.7
	Penetration ratio	%	86.3

Table 3: Effect of warm mix additives on softening point of SBS-modified asphalt.

SBS-modified asphalt	No added warm additive	Advera®	LTA zeolite	13X zeolite
Softening point (°C)	80.5	81.3	81	80.7

Table 4: Effect of warm mix additives on the penetration of SBS-modified asphalt.

	Penetration			
	No additive	Advera®	LTA zeolite	13X zeolite
15°C (0.1 mm)	21	19	20	18
25°C (0.1 mm)	47	46	44	43
30°C (0.1 mm)	75	72	72	70

Table 5: Effect of warm mix additives on ductility of SBS-modified asphalt.

	Ductility			
	No additive	Advera®	LTA zeolite	13X zeolite
5°C (cm)	40	34	33	31

and the particle size is relatively average. The size distribution range of LTA and 13X zeolite sample is narrow, and the content of fine particle size is much. It can be improved by the production process.

(4) The softening point of SBS-modified asphalt with Advera®, LTA, and 13X zeolite is greater than the softening point of no added warm mixture. At the same time, the influence of these three kinds of warm agents on softening point of modified asphalt is not very different.

(5) At 5°C, the degree of ductility of warm mix SBS-modified asphalt decreased with different temperature, and the degree of decline of 13X zeolite was the greatest.

(6) The penetration of modified SBS asphalt with three kinds of the warm mix agent shows that the addition of warm admixture makes the bitumen hardened and the consistency increased.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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