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Effect of chemical warm asphalt additive on the rheological properties of bituminous binders

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Abstract – In recent years, warm mix asphalt (WMA) mixtures started to be widely used to achieve energy savings, reduce emissions, and lower overall costs by decreasing production temperatures during mixing. The present study investigates the effects of the use of a chemical warm asphalt additive, PAV110 additive, at different ratios (1% and 1.5%) on the high-temperature rheological properties of both pure and SBS-modified (3%) binders by using the frequency sweep test. The frequency sweep test was conducted at temperatures of 40 °C, 50 °C, 60 °C, and 70 °C within the frequency range of 0.1-10 Hz. Given the results achieved, it was determined that the warm asphalt additive reduced the complex modulus values, increased the phase angle values of both pure and SBS-modified binders, and caused a more viscous behavior. Moreover, it is also believed that this might have reduced rutting resistance.

Keywords – Asphalt Binders, M*odification, Warm Mix Asphalt, Additives, Frequency Sweep Test*

I. Introduction

Nowadays, various additives (SBS, CR, HDPE, LDPE, etc.) used as asphalt additives increase the viscosity of the asphalt binder, which reduces workability and necessitates higher mixing-compaction temperatures. In recent years, warm mix asphalt (WMA) mixtures, which were designed to provide energy savings without compromising usability and to reduce emissions from the construction process and which also reduce overall costs by lowering production temperatures during mixing, have been widely used [1][2]. This is primarily because warm asphalt additives allow for asphalt mixture production at lower temperatures by reducing the viscosity of the binder. It also provides environmental benefits thanks to energy savings and emission reduction. Warm Mix Asphalt (WMA) has been reported to be a valuable and effective technology for achieving energy savings and reducing carbon dioxide (CO_2) emissions [3]. Many researchers reported that WMA additives could reduce mixing and compaction temperatures by 20-50 °C [4][5][6]. Warm mix additives are classified into three different categories: organic, chemical, and water-based. According to the 2021 data from the National Asphalt Pavement Association (NAPA) and as seen in Figure 1, the use of additives increased from approx. 5% in 2011 to 62% in 2021. It was determined that the highest contribution to this increase was that of chemical warm asphalt additives (60%) [7]. Warm Mix Asphalt (WMA) additives are used in order to reduce the mixing-compaction temperatures of Styrene-Butadiene-Styrene modified (SBS) binders. Thus, sustainable pavements offering higher performance and lower energy consumption can be achieved with this method. It is emphasized that this modification can alter the physicochemical structure of SBS-modified binders and affect their rheological properties [8]. In the present study, three different warm asphalt additives (organic, chemical, and water-based) were used together with SBS.

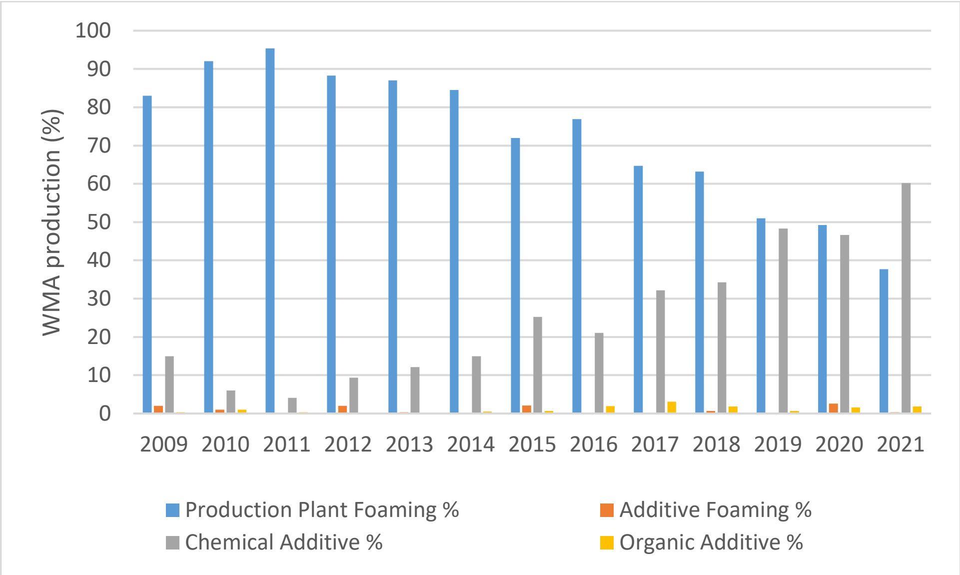

Figure 1. WMA technologies used of WMA production in USA [7].

The results achieved here indicated that short-term aging adversely affected the high-temperature performance of SBS-modified binders, suggesting potential degradation of the SBS binder.

Furthermore, the type and dosage of WMA additives had a significant effect on SBS-modified binder, both in unaged and short-term aged conditions. Considering the combined effect of WMA additives and short-term aging, it was determined that organic and water-based warm asphalt additives improved rutting resistance and reduced aging susceptibility of SBS-modified binders. On the other hand, chemical warm asphalt additive was found to reduce aging resistance but also decreased the high-temperature performance of SBS-modified binders [8].

In this study, it was aimed to examine the rheological properties of WMA additives (Sasobit, Cecabase, Evotherm, and Rediset) at high-performance temperatures in a laboratory setting. Traditional test procedures such as viscosity, performance grade, creep and creep recovery, amplitude sweep, and frequency sweep were conducted to determine the effects of WMA additives on asphalt binders. Given the test results achieved, it was determined that WMA additives might reduce the viscosity of asphalt binders and, therefore, lower the mixing and compaction temperatures of the mixture. WMA-modified binders provided higher rutting resistance when compared to the control binder. In addition, the results of creep recovery, amplitude, and frequency sweep tests revealed that binders containing Sasobit had a higher complex modulus, lower penetration compatibility, and phase angle values compared to other warm asphalt additives, whereas warm asphalt additives other than Sasobit exhibited similar complex modulus and phase angle values to the pure binder [9].

Asphalt rheology can be examined by measuring two viscoelastic parameters, including complex modulus (G*, rigidity) and phase angle (δ, a viscous or elastic indicator), across various test temperatures and frequencies. This allows the prediction of asphalt pavement behavior under different conditions. A temperature ramp test is conducted within the temperature range that may be encountered throughout the lifespan of an asphalt pavement, and a frequency sweep test is used in order to expand the DSR's oscillation speed range from very slow to very fast [10]. In this study, it was aimed to determine the viscoelastic behavior of asphalt binders at high temperatures (40 °C, 50 °C, 60 °C, and 70 °C) and within a specific frequency range (0.1-10 Hz). The effect of using the chemical warm asphalt additive MasterLife PAV110, both solely and in combination with SBS, on the rheological properties of the asphalt binder was evaluated by using a frequency sweep test.

II. MATERIALS AND METHOD

A. *Materials*

B50/70 pure binder obtained from the Batman TÜPRAŞ refinery was used in this study. The SBS additive material was obtained from the Kraton company, whereas the MasterLife PAV110 chemical warm asphalt additive was obtained from the BASF company. Modified binders were prepared by adding the additive material to the pure binder in the specified concentrations and mixing them at a constant temperature of 170°C for 1 hour by using a four-blade mixer rotating at a speed of 1000 rpm. The physical properties of the pure binder used in this study are presented in Table 1, whereas the binder combinations are given in Table 2.

Table 1. Binder properties

Properties	**Standard**	**B50/70**
Penetration (1/100cm)	ASTM D5	60.00
Softening point (°C)	ASTM D36	52.0
Penetration index (PI)		-0.26
Specific gravity		1.030
Viscosity (cP, 135 °C)	ASTM D4402	750
Viscosity (cP, 165 °C)	ASTM D4402	212.5

Table 2. Binder combinations

	Proportion of binder by weight (%)					
PAV110	0	1	1.5	0	1	1.5
SBS	0	0	0	3	3	3
Representation	Neat Binder	WMA-1	WMA-2	SBS	SWMA-1	SWMA-2

B. *Metod*

Frequency sweep generally serve the purpose of characterizing the time-dependent behavior of a sample within the nondestructive deformation range (linear viscoelastic region - LVE). High frequencies are used in order to simulate rapid motion at short time scales, whereas low frequencies simulate slow motion at long time scales or in case of stationarity. In practice, frequency sweeps are proven methods used in order to gather information about the behavior and internal structure of polymers and the long-term stability of dispersions [11].

Frequency sweep tests were conducted by using a Bohlin DSR device at temperature ranges of 40-70 °C with a temperature increment of 10 °C at four different temperatures and a frequency range of 0.1-10 Hz. A 2mm parallel plate and 1mm gap geometry were used. The master curves of complex modulus were drawn using the Bohlin DSR software based on the time-temperature superposition principle.

III. TEST RESULTS

Figure 1 illustrates the master curves of complex modulus values at a reference temperature of 40°C. According to the results obtained, it was determined that SBS-modified binders exhibited the highest complex modulus values at all frequencies. The use of only the warm asphalt additive resulted in a decrease in complex modulus values, with the lowest complex modulus values observed for 1% PAV110-modified binders. The addition of warm asphalt additive into SBS modification was found to yield a decrease in complex modulus values and exhibit a performance similar to pure binders, particularly at high frequencies.

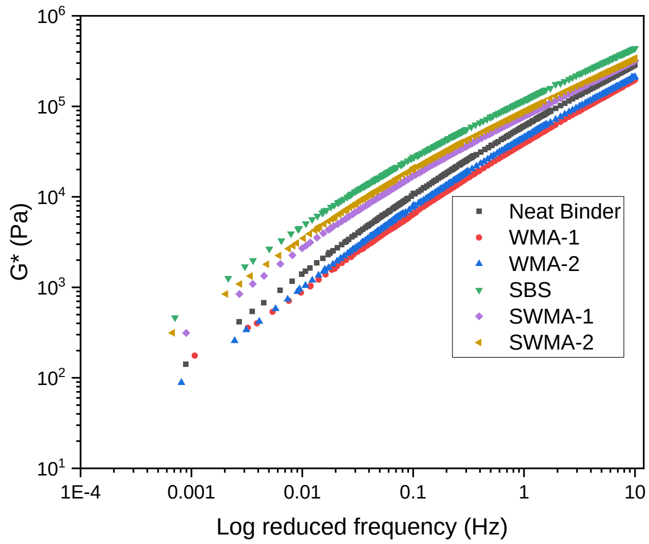

Fig. 1 Master curve of complex modulus values at 40 °C reference temperature

Figure 2 illustrates the master curves of phase angle values at a reference temperature of 40°C. As seen in Figure 2, SBS-modified binders exhibited the lowest phase angle values, indicating a more flexible behavior. The addition of warm asphalt additive to the pure binder yielded a decrease in phase angles, resulting in a more viscous behavior, which might have a negative effect on rutting resistance. The addition of PAV110 to SBS modification also exhibited a negative effect on complex modulus, as indicated by an increase in phase angle values.

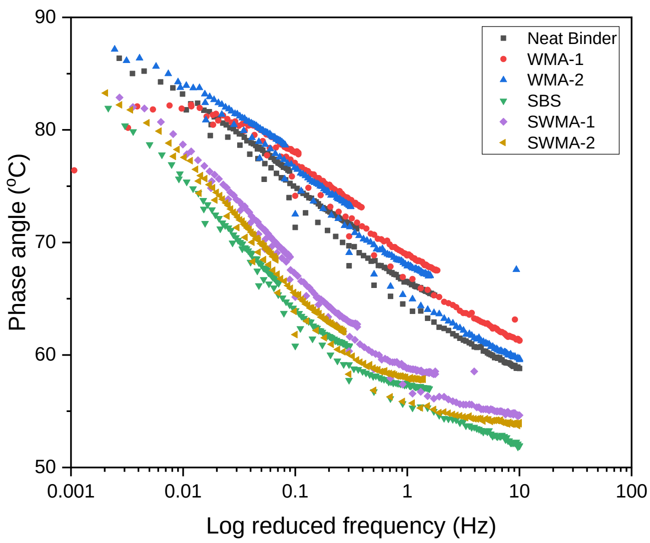

Fig. 2 Phase angels master curve at 40 °C reference temperature

The complex modulus against phase angle change for pure and modified binders (black diagram) is presented in Figure 3. A low phase angle against high complex modulus suggests more flexible behavior and better resistance to rutting. As seen in the black diagram in Figure 3, considering high complex moduli, SBS, SWMA1, and SWMA2 binders exhibited lower phase angle values and more flexible behavior, whereas Neat binder, WMA1, and WMA2 binders showed a more viscous behavior. However, at low complex modulus values, the binders started to exhibit similar performance. Here, WMA1 binder returned to lower phase angles and showed decreasing trend at low complex moduli, indicating a flexible behavior.

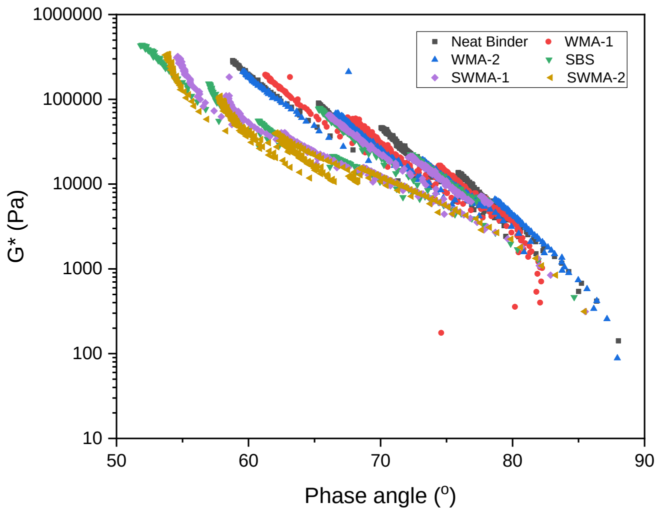

Fig. 3 Black diagram

Figure 4 shows the graph of elastic modulus versus viscous modulus (Cole-Cole diagram). As seen in Figure 3, at low frequencies, binders exhibited viscous behavior, while they shifted to elastic behavior towards high frequencies.

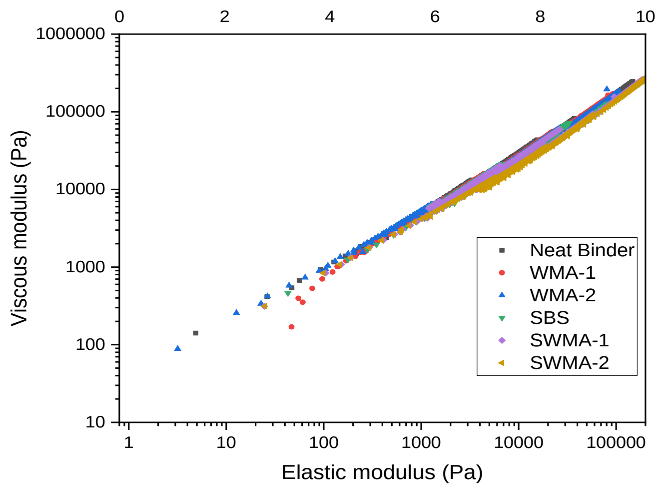

Fig. 4 Cole-Cole diagram

IV. CONCLUSION

In the present study, the effects of the chemical warm asphalt additive PAV110 on the rheological properties of the binder when used solely and in combination with SBS were determined by using frequency sweep testing. According to the results obtained:

- It was determined that the warm asphalt additive caused to a decrease in the complex modulus values of both pure and SBS-modified binders.
- The warm asphalt additive yielded an increase in the phase angle values of both pure and SBS-modified binders, resulting in a more viscous behavior.
- Binders modified with SBS exhibited the highest complex modulus and the lowest phase angle values, indicating a more flexible behavior and higher rutting resistance.
- It is suggested that the behavior of the PAV110 chemical warm asphalt additive within the mixture should be further investigated and that it might be used as an age rejuvenator in stiffer blends.

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