Enhancing Bitumen Properties through Worm Mix Asphalt Additives: a Study on Physical and Rheological Characteristics

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Abstract. This study aimed to determine how various concentrations of warm mix asphalt (WMA) additives can affect the rheological and physical characteristics of asphalt cement. Bitumen was modified by the chemical additive PAWMA® with an addition ratio of (0.2, 0.4, and 0.6), while the organic additives, Sasobit® and Kaowax®, were added at concentrations of (2, 4, and 6%) by the weight of bitumen. Bitumen hardness, softness, temperature susceptibility, viscosity, and elastic behavior have all been measured using a variety of physical and rheological tests, such as the penetration degree, softening point, penetration index, rotational viscosity, and dynamic shear rheology. This study showed that bitumen physical and rheological properties were affected differently according to the type and percentage of the WMA additive employed. The PAWMA additive, for instance, raised the bitumen penetration while Sasobit® and Kaowax® decreased the bitumen penetration degree. The inverse occurred for the softening point values. All WMA additives lowered bitumen viscosity values. Results from a dynamic shear rheometer (DSR) showed that the rutting index value (G*/Sin) rose, indicating improved rutting resistance.

Keywords: Warm mix asphalt; WMA additives; temperature susceptibility; viscosity; rheological properties.

1. INTRODUCTION

Road engineers and contractors have been using modifiers such as polymers [1-4], WMA additives [5-7], anti-stripping additives [8, 9], and bio-oils [10,11], to enhance the rheological and physical properties of asphalt mixtures due to the impact of environmental and traffic conditions on pavement construction. Researchers and contractors in the asphalt sector are increasingly interested in Warm Mix Asphalt (WMA) technology due to its ability to lower production temperatures, fuel consumption, and environmental emissions. This technology helps ensure that bitumen is appropriately mixed with aggregate materials by lowering viscosity and friction. Because WMA technology allows asphalt plants to reduce the temperatures at which it is produced and the amounts of natural pollutants, it releases, the asphalt plants can be located closer to urban and populated areas. This will lead to a shorter transporting distance, increases worker safety, and lessens aging [5,7,12-17]. Using RAP (reclaimed asphalt pavement) in asphalt mixtures can be increased using WMA technology [10,18–20]. There are three broad categories into which WMA additives fall: Natural additive enhancers like Sasobit and Kaowax. Second, chemical supplements can be used, like Evotherm. Thirdly, zeolite and other bituminous foam additives. The impact of additives on bitumen physical and rheological characteristics has been the subject of extensive research. Bitumen physical and rheological performance has been found to be significantly influenced by factors such as bitumen type, additives, components, and chemical structure [6,7, and 21].

Bitumens modified with organic and chemical additives such as (Zycotherm, PAWMA, and Sasobit) were studied by Mansoori and Modarres in 2020. The results showed that chemical additives did not affect bitumen's physical and microstructural properties. At the same time, the organic additive (Sasobit) did not only alter the microstructural properties of the bitumen but also caused an ionic exchange [22]. In a different work, modified bitumen rheological and physical characteristics were investigated. Overall, the additives utilized in this study lowered the mixing and compaction temperature by around 40℃ [23], and the results also showed that, with the exception of the organic additives, the rest of the additives do not have such an influence on the qualities of the modified bitumen. Bitumen's softening point and penetration index were improved as Sasobit's content increased, according to a study that compared the physical and rheological performance of the modified bitumens with varying concentrations of the additive. Sasobit, on the other hand, increased viscosity at low temperatures and decreased viscosity at high temperatures [24,25].

Bitumens modified with various additives (Sasobit, Kaowax, Zeolite, and PAWMA) were also studied for their effects on mechanical qualities. It was found that the mechanical properties of asphalt mixtures varied widely depending on the type of additive utilized. Consequently, unlike other additives, the PAWMA ingredient had a beneficial effect on the asphalt mixture's resistance to moisture sensitivity. Furthermore, it was shown that using all additives enhanced the resistance to cracking. However, this study demonstrated that, except zeolite, the WMA additives improved rutting resistance [12,26]. The reviewed literature revealed that the physical and rheological performance of asphalt mixtures can vary depending on the type of additive, the percentage of addition utilized, and the source and type of bitumen. Since the production temperature of asphalt mixtures incorporating additives has dropped, the stone components may still have some moisture, which can cause problems like rutting and susceptibility to water [8-10].

It is no secret to all those working in the field of asphalt mixtures the negative impact of high temperatures during mixing and compaction of asphalt mixture. It leads to a large pollution of the environment with its harmful gases during the service period, in addition to the aging process that affects the asphalt binder during heating to these high temperatures, which could lead to many types of distresses like fatigue cracking and low-temperature cracking. This study works on using additives that help reduce temperatures during mixing to minimize aging and high pollution of the environment, which in turn reduces global warming. Consequently, testing the rutting resistance and maximum performance grade of bitumen treated with these additives is crucial. One of the other significant issues for asphalt researchers is to find the optimal amount to use WMA additives. The authors found that not enough attention has been paid to the performance characteristics of asphalt mixtures changed with additives like Kaowax as an organic additive and PAWMA as a chemical additive. This study aims to evaluate the effectiveness of adding Kaowax and PAWMA to bitumen and compare them with the performance of asphalt modified with Sasobit, a common additive for warm mix asphalt.

2. MATERIALS AND EXPERIMENTAL TESTING

2.1 Neat Asphalt Binder

A performance grade (PG64-22) asphalt binder with a penetration grade of 60/70 has been utilized in this study. Table 1 lists the neat asphalt binder characteristics.

Table 1: The physical properties of the neat asphalt binder.

Type of experiment	Test standards	Standard limit		Results
		Min	Max	
Penetration at 25℃ (0.1)	ASTM D5	60	70	62
Softening point (℃)	ASTM D36	46	---	48.5
Ductility at 25℃ (cm)	ASTM D113	100	---	130
Flashpoint, ℃	ASTM D 92	232	---	290
Specific gravity	ASTM D90	1010	1060	1.018

2.2 WMA Additives

This research uses three types of WMA additives to modify pure bitumen: Organic additives (Sasobit®, Kaowax®) and (PAWMA®) as chemical additives. The basic properties of these WMA additives with their used percentages are presented in Table 2.

Table 2: Sasobit®, PAWMA®, Kaowax® characteristics.

Additive	Dosage (%)	Physical Properties
PAWMA®	0.2, 0.4, and 0.6	Physical state: liquid
		Color: Pale yellow
		Viscosity (25℃): 150 (mPa.s)
		Density (g/cm^3 at 20℃): 0.93 ± 0.2
		Flashpoint (℃): <150
Kaowax®	2, 4, and 6	Physical state: Granulated solid
		Color: White
		Melting point (℃): 111–117
		value (mg KOH/g): <10
		Total amine value (mg KOH/g): <10
		Volatile matter (180℃): <0.5%
Sasobit®	2, 4, and 6	Physical state: Granulated solid
		Color: White
		Viscosity (135℃): 12 (mPa.s)
		Density (gr/cm3at 20℃): 0.62
		Flashpoint (℃): 290

In this study, the asphalt binders were prepared by adding the WMA additives to a plain binder preheated to 125 degrees Celsius, and then the blending continued for 18 minutes [27]. This research used pure bitumen modified with 2, 4, and 6% of organic additives (Sasobit and Kaowax) and (0.2, 0.4, and 0.6%) of the chemical additive (PAWMA). As shown in Figure 1, several tests were conducted to evaluate the physical and rheological properties of modified bitumen.

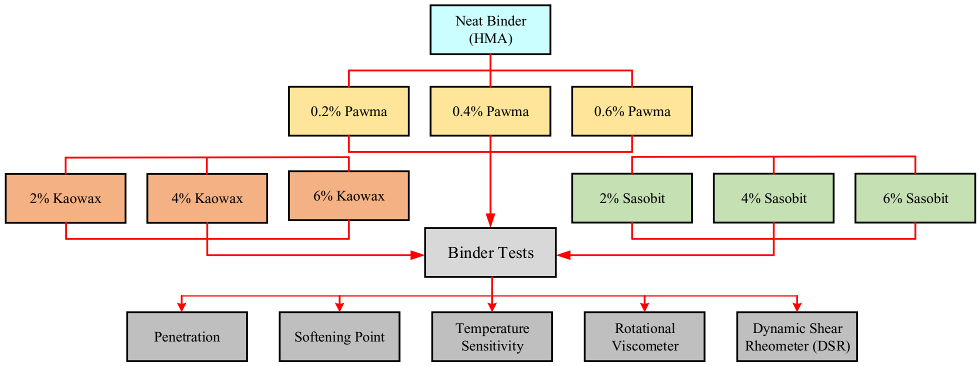

Figure 1: Laboratory program to study the modified binder.

Experiments were conducted to determine how WMA additives alter the physical and rheological characteristics of warm-mix asphalt binders, and the results are presented in the next section.

2.3 Penetration and Softening Point Test

Penetration test was performed at 25°C following ASTM D5 standard on samples modified with WMA additives (PAWMA, Sasobit, and Kaowax) [28]. At the same time, the liquefaction inspection is carried out as per the standard ASTM D36 [29].

2.4 Temperature Sensitivity Test (PI)

An index called the Penetration Index is used to check the temperature sensitivity of bitumen, predict the behavior of bitumen in different weather conditions, and describe the flexibility of bitumen. PI can be obtained from Equation 1 [28,30].

$$\mathrm{PI} = \frac{(1952 - 500 * \log^{\mathrm{Pentration}} - 20 * \mathrm{softeninig\ point})}{(50 * \log^{\mathrm{penetration}} - \mathrm{softeninig\ point} - 120)} \quad (1)$$

The lower value of PI indicates that bitumen is convenient for cold climate regions, while the higher value provides conditions for hot climate regions.

2.5 Viscosity Test

To ensure that both modified and unmodified bitumen have sufficient pumping ability throughout production and construction, their viscosity at 135℃ should be less than 3 Pa.s, as measured by the rotational viscosity test used in the asphalt mixing and compaction stages. This study measured the viscosity of modified bitumen with WMA additives at 135 and 165 degrees Celsius.

2.6 Dynamic Shear Rheometer (DSR)

A dynamic shear rheometer test evaluates bitumen's rheological properties at high and medium temperatures. This measurement of the complex shear modulus (G*) and the phase angle (δ) provides information on the material's elastic and viscous properties. G* is a measure of the resistance of the material as a whole to deformation under repeated shear stress application. It has elements of both elasticity (reversible) and viscosity (irreversible). Different phase angles represent reversible and irreversible deformation. At elevated service temperatures, the mixture's shear modulus is divided by the sine of the phase angle (G*/sinδ) to determine the rutting parameter representing its strength and resistance against permanent deformation. The greater the value of this parameter, the higher the mixture's resistance against rutting.

3. RESULTS AND DISCUSSION

3.1 Effect of WMA Additives on Penetration Value

Figure 2 shows the penetration test results for bitumen modified with different WMA additives. The results indicate that the PAWMA additive has increased the penetration degree while Kaowax and Sasobit additives have decreased the penetration degree. The decrease in penetration degree with Kaowax and Sasobit could be attributed to the creation a network structure and increased stiffness of modified bitumen. This reduction is more significant with the increase in WMA additives. The comparison between different additives shows that Sasobit was the most effective in reducing the degree of penetration. By adding 2, 4, and 6% Sasobit additive, the penetration was decreased by 11, 27, and 41%, respectively, while the addition of 2, 4, and 6% of Kaowax additive reduced the penetration degree by 8, 22, and 32%, respectively. The degree of penetration increased with 0.4% PAWMA additive but decreased as the amount of PAWMA additive increased.

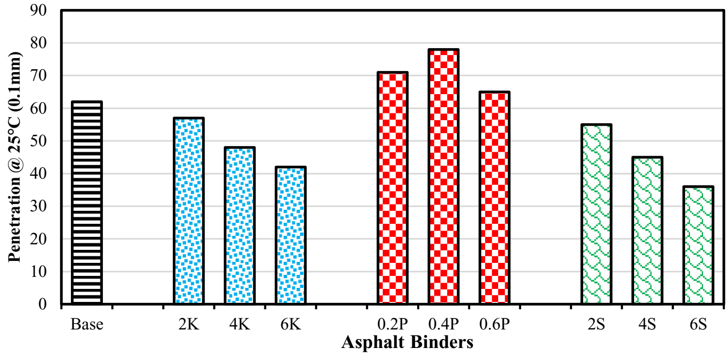

Figure 2: Penetration results of different asphalt binders.

3.2 Effect of WMA Additives on Softening Point

The results of the softening point test for bitumen modified with different percentages of WMA additives (Sasobit, Kaowax, and PAWMA) are shown in Figure 3. The results illustrated that using other WMA additives could have various results on the softening point, so the Sasobit and Kaowax additives increased the softening point values. Using 2, 4, and 6% of Kaowax and Sasobit has increased the softening point by 10, 61, and 120%, and 16, 71, and 126%, respectively. However, the PAWMA additive has decreased the softening point value; the most significant decrease in softening point was at 0.4% of PAWMA content.

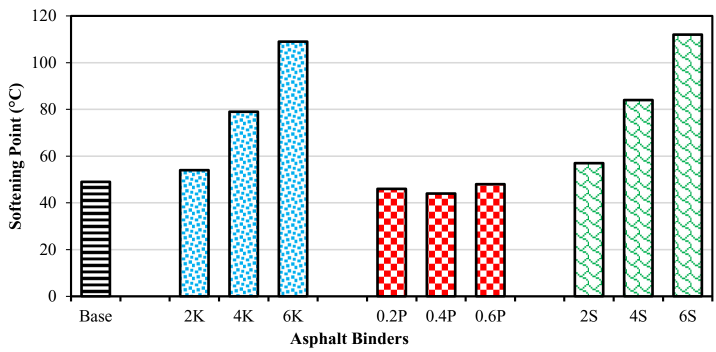

Figure 3: Softening point results on different asphalt binders.

3.3 Effect of WMA Additives Penetration Index (PI)

The penetration index for different bitumen is shown in Figure 4. The results of the PI illustrated that the use of Kaowax and Sasobit additives increased the PI of bitumen, which was more significant with the increase in their usage percentages. Therefore, it can be said that the use of high percentages of Kaowax and Sasobit makes the bitumin more convenient for hot environmental conditions. However, the results of the PI of PAWMA-modified binders show a reduction in PI's value, allowing this type of bitumen to be more suitable to cold climate regions. The use of 0.4% PAWMA has decreased the value of the PI to -1.8.

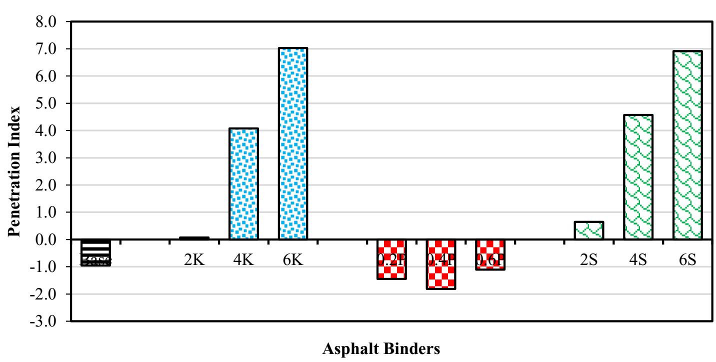

Figure 4: The penetration index of different asphalt binders.

3.4 Effect of WMA Additives on Viscosity

The test results of the rotational viscosity of bitumen modified with different WMA additives at two temperatures of 135 and 165˚C are shown in Figure 5. The results showed that using WMA additives reduced the viscosity of the bitumen, and this reduction was more significant when adding Kaowax and Sasobit additives. Moreover, the results showed that PAWMA as a chemical additive did not significantly affect the viscosity of the asphalt binders. The range of compaction and mixing temperature for different bituminous compounds are shown in Table 3. As a result, bitumen modified with WMA additives has lower viscosity values than the base binder. Comparing the mixing and compaction temperatures for the bitumen modified with Kaowax and Sasobit additives, these two additives had the same effect. They reduced the asphalt mixing production temperature almost to the same extent.

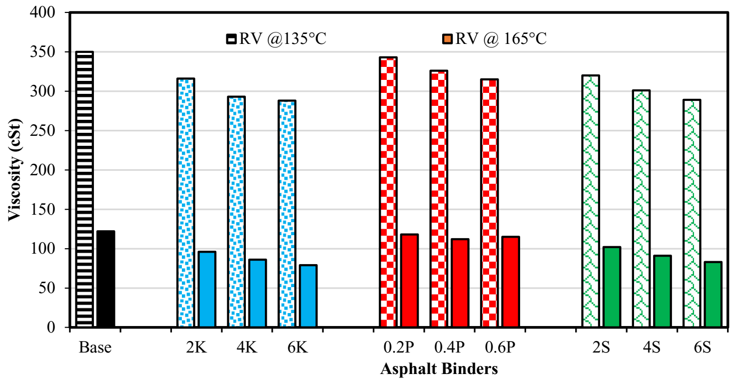

Figure 5: The fracture energy of different asphalt mixtures.

Table 3: Mixing and compaction temperature of asphalt binders.

Asphalt binders	Compaction Temperature (°C)	Mixing temperature (°C)
Base	156-161	140-148
2K	152-158	136-144
4K	150-156	133-141
6K	149-155	132-140
0.2P	157-163	140-148
0.4P	153-158	137-145
0.6P	154-160	140-148
2S	153-158	136-145
4S	151-157	132-142
6S	149-155	132-141

3.5 Effect of WMA Additives on the Rutting Parameter

To evaluate the resistance to rutting for the modified samples, DSR test was conducted at a frequency of 10 radians/s and temperatures of 58, 64, 70, and 76 ˚. The results are shown in Figures (6-8). According to Superpave criteria, the higher operating temperature is the temperature at which the value of the G*/Sinδ parameter should be at least 1 kPa for unaged bitumen and 2.2 kPa for bitumen aged by the RTFO method for the asphalt sample to be considered able to bear the loads that cause permanent deformation (rutting). The results showed that the G*/Sinδ index values have increased with the percentage of each WMA additive (Kavox, Sasobit, and PAWMA). Therefore, it can be said that using WMA additives in this research has increased rutting resistance.

The increased rutting parameters for Sasobit and Kaowax-modified samples could be attributed to the network structure created by bitumen modified with these additives. On the other hand, the increase in G*/Sinδ can be seen as an increase in the adhesion energy between bitumen and stone materials. Figure 9 shows the upper limit of temperature and its direct proportion with the performance of different percentages of WMA additives. So that with the increase in the percentage of use of each of these additives, the increase in the failure temperature has become more significant. For example, using 6% of Sasobit and Kaowax increased the asphalt performance grade from PG64 to PG70. However, the use of 0.6% of PAWMA didn't significantly increase pure bitumen's failure temperature, so there is no notable improvement in performance grade.

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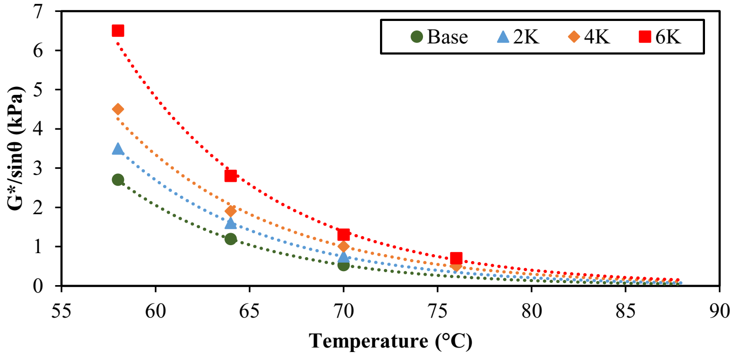

Figure 6: Rutting parameter of Kaowax-modified asphalt binders.

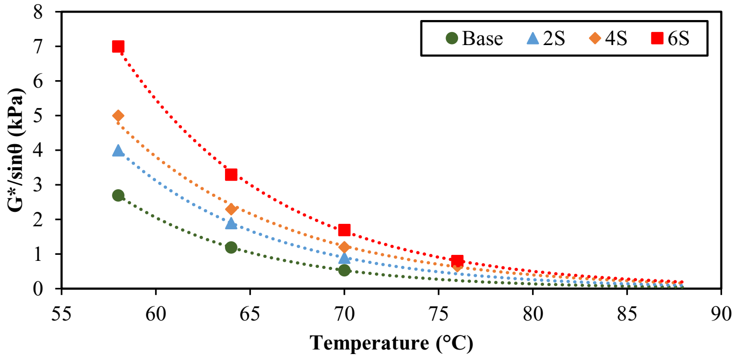

Figure 7: Rutting parameter of Sasobit-modified asphalt binders.

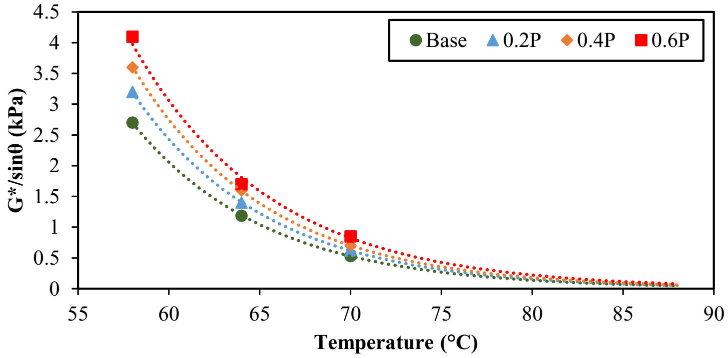

Figure 8: Rutting parameter of PAWMA-modified asphalt binders.

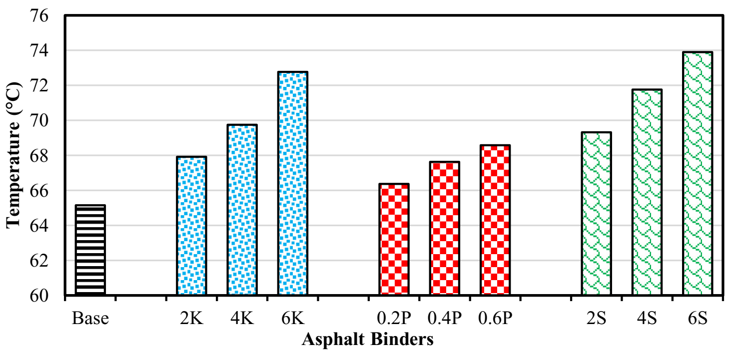

Figure 9: Relationship of temperature with the percentage of WMA additives.

4. CONCLUSIONS

This study aimed to assess the impact of different percentages of WMA additives on bitumen's physical and rheological properties. Two organic additives were used, Sasobit® and Kaowax®, and one chemical additive, PAWMA®. According to the tests, the following conclusions can be drawn:

- The test results of penetration degree and softening point showed that using Kaowax and Sasobit additives decreased the penetration degree and increased the softening point of the modified bitumen. On the contrary, using PAWMA has increased the penetration value and reduced the softening point of bitumen.
- The results of the penetration index to check the sensitivity of bitumen to temperature changes showed that the use of Sasobit and Kaowax increased the value of this index. In contrast, the use of PAWMA reduced the value of this index. These results imply that Sasobit and Kaowax are more suitable for hot regions, while PAWAN is more suitable for cold regions.
- The results of the rotational viscosity test showed that using WMA additives has reduced the viscosity of bitumen at 135 and 165℃, and consequently, the compaction and mixing temperature has decreased.
- The results of the dynamic shear rheometer test showed that the use of Sasobit, Kaowax, and PAWMA as WMA additives has increased the value of the rutting parameter values (G*/Sinδ), which indicated an increase in the rutting resistance. This increase has been significant for bitumen modified with Sasobit and Kaowax compared to PAWMA.

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