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Predicting Mixing and Compaction Temperatures of Polymer Modified Bitumen

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Abstract

Despite many advantages of using polymer additives in bitumen, there are several challenges bordering on standards and specifications with regards to their utilization. One of these challenges is related with specifying the required heating or mixing and compaction temperatures of the polymer modified bitumen. The standard method (ASTM D 2493) aims to determine mixing and compaction temperatures of the base or unmodified bitumen. Nevertheless, the application of this method in the case of polymer modified bitumen led to very high temperatures which may not be appropriate for PMB. In this paper, some alternative methods named as the high shear rate and steady shear flow method suggested in the literature have been examined and tested for 50/70 and 160/220 penetration grade bitumen samples involving an elastomeric type of additive. A suggested method has also been proposed to overcome the complexities in the implementation of the alternative methods.

Keywords: Mixing, Compaction, Polymer Modified bitumen, High Shear Rate, Steady Shear Flow.

1. Introduction

Over the years, base bitumen has been used in the construction of the asphalt pavement. The rapid growth rate in the traffic volumes showed a limitation in the performance of the conventional bitumen which may be clearly noticed in the earlier failures of the pavement than what is expected. This led to a decrease in service life and an increase in maintenance costs [1]. To overcome such problems and to enhance the performance of the asphalt pavement, in the last few decades modified bitumen with polymers has been adopted [2]. Polymer additives that will provide the desired properties for asphalt materials are applied in the wearing layers in many parts of the world. The polymer additive belonging to the elastomer class called Styrene-Butadiene-Styrene (SBS) was started to be used in the wear layers to produce the polymer modified bitumen PMB. However, selecting suitable temperatures to handle this modified bitumen has become an issue since a suitable method has not been regulated. The traditional method (ASTM D 3493), which has been described and used for the calculation of mixing and compaction temperatures of the base bitumen, yields high temperature when it is applied for the polymer modified bitumen. This is because the ASTM D 2493 method is established for the base bitumen (unmodified) which exhibits Newtonian behavior at high temperatures. In such behavior, viscosity is the shear rate dependent. while modified bitumen exhibits a Non-Newtonian behavior where the viscosity values dependent on shear rate [3-4]. Such high temperatures, especially due to oxidation, cause hardening in bitumen. In most oxidation reactions, the hardening of the bitumen doubles as the temperature increases by 10 ºC. High temperatures also cause emission and odor problems [3-10]. In the absence of a reliable method for the selection of mixing and compaction temperatures for polymer modified bitumen, many agencies have designed their own standards to estimates the appropriate temperatures of each modified bitumen. Obviously, there is a need for a formal method to determine the mixing and compaction temperatures of the modified bitumen and must consider its behavior [3-15].

In this study, two alternative methods named as High Shear Rate Method (HSR) and Steady Shear Flow (SSF) have been applied on using two penetration bitumen grades (50/70 and 160/220) samples involving elastomeric polymer called Styrene-Butadiene-Styrene (SBS) to determine mixing and compaction temperatures. Also, the alternative methods have been correlated with the ASTM D 3493 method to find more simple approach to determine the required mixing and compaction temperatures of PMB.

2. Materials and Methods

In this study 50/70 and 160/220 penetration grades base bitumen supplied by DERE Group were used.

Some of the conventional tests have been conducted on the base bitumen such as penetration test, softening point test, and rolling thin film oven test to measure the bitumen characteristics. Table 1 shows the test results according to the ASTM specification.

Table 1. Properties of the base bitumen.

Test	Specification	Results		Specification limits	
		50/70	160/220	50/70	160/220
Penetration (25 ºC; 0.1 mm)	ASTM D5 EN 1426	65	190	50-70	160-220
Softening point (ºC)	ASTM D36 EN 1427	51	41	46-54	35-43
Penetration index (PI)	-	0.35	0.123	-	-
Rolling thin film oven test (RTFOT)	ASTM D2872-12				
Change of mass (%)	-	0.160	0.94	0.5 (max.)	0.5 (max.)
Penetration (25 ºC; 0.1 mm)	ASTM D5 EN 1426	53	97	50 (min.)	50 (min.)
Retained penetration (%)	ASTM D36 EN 1427	82	51	50 (min.)	50 (min.)
Softening point after RTFOT (ºC)	ASTM D36 EN 1427	58	50	48 (min.)	48 (min.)

2.1. Preparation of Polymer Modified Bitumen

The SBS polymer used was Kraton D-1101 supplied by the Shell Chemicals Company. The SBS concentration was selected as 5% as an optimum content based on the past researches [16-18]. High shear laboratory mixer was used to prepare the polymer modified bitumen as shown in Fig. 1. The bitumen was heated to (180-185 º C) and poured into glass beaker. The SBS in powder form was added gradually to the base bitumen and the rotating speed was maintained at 2000 rpm for 1 hour.

Figure 1. High shear laboratory mixer.

The utilization of the shear mixer rate is made based on past researches. The mixing speed of 2000 rpm has seen to be suitable compare to the higher shear rate since the viscosity of the polymer modified bitumen sample remains almost the same regardless of the duration used compared to the higher shear rates [18,19].

2.2. Determination of Mixing and Compaction Temperatures

Mixing and compaction temperatures are determined through the standard method (ASTM D2493). Several alternative methods have been suggested in the literatures to implement for the polymer modified bitumen such as high shear rate, steady shear flow. The summarized procedure for each method is presented below

2.2.1. ASTM D 2493 Method

The device used for this method is the Brookfield viscometer. Based on ASTM D 2493, the viscosity of bitumen sample at two different temperatures (135 ° C and 165 ° C) is determined at a constant shear rate of 6.8 1 / s.

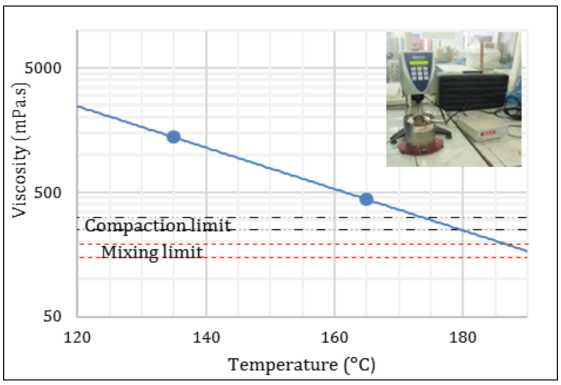

Figure 2. Determination of mixing and compaction temperatures.

The obtained viscosity values are plotted on a semi-logarithmic graph as shown in Figure 2. Mixing and compaction temperatures are corresponding to 170 ± 20 mPa. s and 280 ± 30 mPa. s, respectively [20].

2.2.2. High Shear Rate method (HSR)

Solaimanian et al. found the shear rate during the Superpave compactor is higher than the one used in ASTM D2493 method (6.8 1/s). They found the shear rate value is around 500 1/s. The viscosity at this shear rate must be calculated and used for mixing and compaction temperatures determination. In this method, Brookfield viscometer is used to determine the viscosity of the bitumen at different shear rates and then drawn and extrapolated to 500 1/s shear rate as shown in Fig. 3. Mixing and compaction temperatures are found by using the same viscosity limits used in the traditional method 0.17±0.02 Pa. s and 0.28±0.03 Pa. s, respectively (High Shear Rate original (HSR-O)). In attempt trying to get lower temperatures in 2006 , the authors suggested a higher viscosity range to be used which are 0.275±0.03 Pa. s and 0.550±0.06 Pa.s. (High Shear Rate Evolution (HSR-E)) [21-22].

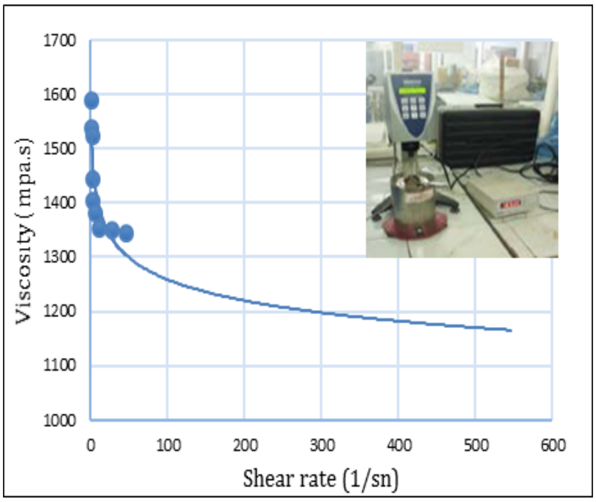

Figure 3. High shear rate method.

2.2.3. Steady Shear Flow Method (SSF)

This method is based on the shear dependency behavior of the polymer modified bitumen. Using Dynamic Shear Rheometer (DSR) and the procedure recommended by Reink, the mixing and compaction temperatures of the bitumen can be determined. It is proposed that the viscosity values are measured at different shear stresses and the suggested stress levels are from 0.3 to 500 Pa at different temperatures 76 ºC, 82 ºC and 88 ºC as shown in Fig. 4. The measured viscosity values at 500 Pa or 1000 Pa are then plotted using a log viscosity versus log temperature chart and extrapolated to obtain the mixing and compaction temperatures through using the suggested viscosity limits 0.17 ± 0.02 Pa s and 0.35 ± 0.03 Pa s, respectively [23].

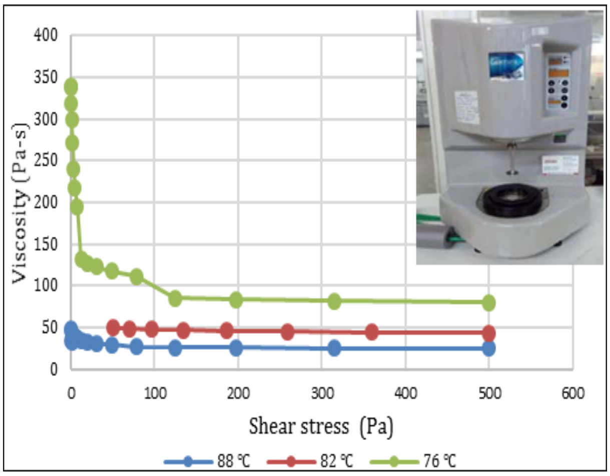

Figure 4. Steady shear flow method.

3. Results and Discussion

3.1. Mixing and compaction determination results

The determined mixing and compaction temperatures for each of the alternative methods are presented in Fig. 5. As depicted in Figure 5, the mixing and compaction temperatures obtained from the ASTM method were the highest compared to the other alternative methods for both bitumen grades. Also, 50/70 PMB samples yielded higher mixing and compaction temperatures than 160/220 PMB samples regardless of the implemented approach. This is attributed to the higher consistency of the 50/70 penetration grade compared to the 160/220 penetration grade which is less viscous. So, the required handling temperature for 50/70 would be higher to reach the desired workability during construction of the asphalt mixtures.

For the mixing and compaction temperatures determined by the High shear rate method, the results for bitumen polymers modified samples involving SBS have shown a noticeable reduction in mixing and compaction temperatures compared to the ASTM method for both bitumen grade types. The reduction in the obtained mixing and compaction temperatures is attributed to the lower viscosity value used in this method compared to the ASTM method. The HSR method proposes the utilization of viscosity value for PMB at a high shear rate (around 500 1/s). The reason behind obtaining a lower viscosity value at a high shear rate is associated with the behavior of the polymer modified bitumen. The PMB generally tends to exhibit a non-Newtonian behavior in which the viscosity is sensitive to the change in the shear rate and any increase in the shear rate will result in a decrease in the viscosity value. Also, mixing and compaction temperatures results for 50/70 PMB samples are higher than the 160/220 samples. As expected, as the penetration value of the bitumen increases the more fluid it becomes, and this explains the variation in the mixing and compaction temperatures between 50/70 PMB and 160/20 PMB.

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For a steady shear flow method, the determined mixing and compaction temperature results demonstrated a discernible reduction in mixing and compaction temperatures compared to the ASTM method. Also, it can be noticed that the obtained mixing and compaction temperatures through this method is lesser than the temperatures determined through the HSR method. The substantial reduction in the obtained mixing and compaction temperatures for PMB samples by implementing the SSF method is associated with the sensitivity of the PMB samples while being tested at Dynamic Shear Rheometer (DSR). PMB samples are more susceptible to the variation in both temperature and the applied stress and this attributed to the Non-Newtonian behavior of the PMB. Also, in this method, the proposed limits to determine the required mixing and compaction temperatures for PMB are different from both ASTM and HSR methods and this is generating lower temperatures. As mentioned earlier, the variation in mixing and compaction temperatures for 50/70 PMB and 160/220 PMB is due to the difference in the bitumen stiffness.

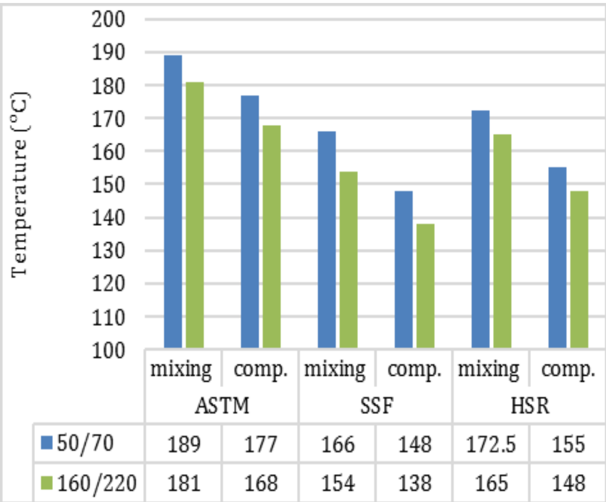

Figure 5. Mixing and compaction temperatures.

3.2. Simplification of the HSR and SSF approaches

The above-mentioned methods are relatively difficult to apply and they have not standardized yet. The HSR method requires the use of the rotational viscometer at the maximum range of shear rates at which data can be collected (0.1 1/s to 100 1/s). While the SSF method requires the utilization of the Dynamic Shear Rheometer (DSR) and the test duration is higher compared to the ASTM method. In order to overcome these complexities, an empirical equation has been developed to determine the mixing and compaction temperatures of the PMB samples.

Based on the obtained mixing and compaction temperatures, it has been noticed that the reduction amount in the temperatures for both PMB samples, when compared to the ASTM method, is almost constant. The mixing temperatures using the SSF method is almost less by 25 ºC compared to the ASTM results. Also, the compaction temperatures have a constant reduction amount which is about 29.5 ºC. The same conclusion applies to the HSR method and the reduction in mixing and compaction temperatures is 16.25 ºC and 21 ºC, respectively.
Thus, the following eq. (3.1) and eq. (3.2) can be proposed to simplify the determination of mixing and compaction temperatures of SBS polymer modified bitumen for SSF method.

$$T\,mix.\ SSF = Tmix.\ ASTM - 25 \quad \textbf{(3.1)}$$
$$T\,comp.\ SSF = T\,comp.\ ASTM - 29.5 \quad \textbf{(3.2)}$$

The same approach has also been made for the high shear rate method as explained in eq. (3.3) eq. (3.4).

$$T\,mix.\ HSR = Tmix.\ ASTM - 16.25 \quad \textbf{(3.3)}$$
$$T\,comp.\ HSR = T\,comp.\ ASTM - 21 \quad \textbf{(3.4)}$$

The results of the application of the above mentioned equations are presented in Table 2. The determined temperatures by the alternative methods (SSF and HSR) are almost similar to the temperatures obtained by the application of the proposed equations. Also, it should be noted that the equations above are valid for the PMB used in this study.

Table 2. Comparison of temperatures results with the new proposed equations.

	Method	50/70	160/220
Mixing (ºC)	SSF	166	154
	Proposed SSF	164	156
	HSR	172.5	165
	Proposed HSR	172.75	164.75
Compaction (ºC)	SSF	148	138
	Proposed SSF	147.5	138.5
	HSR	155	148
	Proposed HSR	156	147

4. Conclusion

The selection of the mixing and compaction temperatures of PMB has no specific standards and the application of the ASTM method is not practical. In this study, two penetration grade bitumen 50/70 and 160/220 samples involving styrene butadiene styrene (SBS) at 5% have been used. The proposed methods, HSR and SSF, have been implemented and the results were compared with the ASTM method. Also, an empirical equation has been developed to simplify the determination of the mixing and compaction temperatures for PMB. The obtained results showed the following

1. The implementation of the ASTM method resulted in high mixing and compaction temperatures for both PMB grades. The ASTM method is designed based on the base (unmodified) bitumen behavior by considering the viscosity value at a constant shear rate (6.8 1/s). The viscosity of the PMB at a low shear rate is generally high and the utilization of such high viscosity value would generate an excessive temperature for PMB.
2. 50/70 modified bitumen samples depicted the highest mixing and compaction temperatures for all methods compared with 160/220 penetration grade bitumen. This is because 50/70 is harder and more viscous than the 160/220 penetration grade. Moreover, adding the SBS polymer to the 50/70 bitumen grade considerably increases its stiffness compared to the 160/220 bitumen grade, and this results in a higher required handling temperature for 50/70 PMB.
3. The application of the SSF method resulted in the lowest mixing and compaction temperatures for both bitumen grades compared to other methods.
4. Based on the output of this study, the empirical equations that proposed to simplify the determination of the mixing and compaction temperatures for PMB resulted in very close mixing and compaction temperatures results compared to the alternative methods (HSR and SSF). This is may exclusively valid for bitumen samples with 5% SBS polymer utilized in this study.

The conclusion of this study covers the utilization of two SBS polymer additive. More research should be carried out by using different penetration grade bitumen involving different kinds of polymers and WMA additives in order to perform more validation.

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Author's Contributions

Ali Almusawi: Drafted and wrote the manuscript, performed the experiment and result analysis.
Burak Şengöz, Derya Kaya Özdemir, Ali Topal: Assisted in analytical analysis on the structure, supervised the experiment's progress, result interpretation and helped in manuscript preparation.

Ethics

There are no ethical issues after the publication of this manuscript.

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