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Effects of Preparation Conditions on the Properties of Crumb Rubber Modified Binder

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***Abstract*—**Various types of additives are used frequently in order to improve the rheological and mechanical properties of bituminous mixtures. Small devices instead of full scale machines are used for bitumen modification in the laboratory. These laboratory scale devices vary in terms of their properties such as mixing rate, mixing blade and the amount of binder. In this study, the effect of mixing rate and time during the bitumen modification processes on conventional and rheological properties of pure and crumb rubber modified binder were investigated. Penetration, softening point, rotational viscosity (RV) and dynamic shear rheometer (DSR) tests were applied to pure and CR modified bitumen. It was concluded that the penetration and softening point test did not show the efficiency of CR obtained by different mixing conditions. Besides, oxidation that occurred during the preparation processes plays a great part in the improvement effects of the modified binder.

***Keywords*—**Bitumen, crumb rubber, modification, rheological properties.

I. Introduction

HOT mix asphalt (HMA) needs to be developed to resist particular permanent deformations like rutting and thermal cracking due to increased traffic volumes and vehicle loads [1]. As the properties of bitumen used in HMA largely determines the performance of the mixture; generally, efforts are made to improve the bitumen. For this reason, polymer origin additives are used frequently [2]-[4]. However, the escalating cost of polymer modifiers and the lack of available resources have lead researchers to use waste materials for the construction of new roads. Reclaimed rubber obtained from waste tires has been successfully used for modifying bitumen.

Hamzah et al. [5] concluded that addition of crumb rubber to bitumen induced an increase in the G*/sinδ value of original bitumen, and hence, presented a longer fatigue life. Besides, the crumb rubber modified binder is less affected by aging. Navarro et al. [6] determined that crumb rubber modification increased the linear viscoelasticity at high service temperature and also reduced the storage stability at low temperature. The gradation of the crumb rubber was reported as the most important factor affecting the properties of rubber-asphalt [7]. Kok et al. determined that CR modification at high additive content exhibited higher elastic response, i.e., recoverable strain, than the SBS-modified mixture; while, the resistance to crack initiation of CR-modified mixtures increased with increasing additive content, and the resistance to crack propagation decreased dramatically according to the fatigue and semicircular bending tests [8].

There are various types of equipment provided to mixing bitumen with different additives in the asphalt plants. With regard to the laboratory, small devices instead of full-scale machines are used for bitumen modification. Laboratory scale devices can be different in terms of mixing speed and type of blender. On the other hand, various alternatives can occur by the changing of mixing rate, time and temperature, by the user during the modification processes at the laboratory. It is important to determine the suitable parameters in the laboratory, in order to obtain a modified binder that shows the same properties with that prepared at a full-scale asphalt plant.

The polymer bitumen modifications have been carried out by considering different mixing conditions in the modification related studies. Lepe et al. [9] used 1200 rpm and 8200 rpm mixing rates in producing modified bitumen and concluded that it is important to use a high mixing rate in order to obtain a stabile mixing; however, this process induced changes in the rheological properties of bitumen due to aging. Giuliani et al. [10] applied a 4000 rpm mixing rate at 180 C to 250-260 gr bitumen in 500 ml aluminum container. Ouyang et al. [11], produced SBS modified bitumen by using 4000 rpm, 170 C and 25 min. mixing conditions. Mouillet et al. [12], produced SBS and EVA modified bitumen by using 300 rpm, 180ºC and 2 hour mixing conditions. Larsen et al. [13] used 4200 rpm and 5800 rpm in the modification of two pure binders with different asphalt content with SBS. It was concluded that the binders reached maximum viscosity values at 90 min and 120 min mixing time. Haddadi et al. [14] denoted that mixing rate and temperature had a great influence on the properties of a modified binder. They recommended 300 rpm and 180ºC for producing the EVA modified binder. It was reported that the penetration values decreased with the increase of mixing time and reached a constant value after 4 hours of mixing time.

In this study, original and crumb rubber modified binder were prepared under different mixing conditions. The effects of the mixing conditions were evaluated using conventional and rheological binder tests.

II. Materials and Method

Pure and modified binders were subjected to conventional tests such as penetration and softening point test and rheological analysis such as RV and DSR tests. Crumb rubber (Fig. 1) content was kept constant at 10% by weight, which was determined as the most productive rate according to

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previous studies [15], [8]. Asphalt cement, B 50/70, obtained from Turkish Petroleum Refineries was used as pure bitumen for binder preparation. The modified binders were produced with a laboratory-scale mixing device (Fig. 2) with a four-blade impeller at a constant temperature of 180 °C at 30 min, 60 min, 90 min and 120 min mixing time and 1000 rpm, 2000 rpm and 5000 rpm rotation speed.

Fig. 1 Crumb rubber

Fig. 2 Laboratory mixer

The base bitumen and crumb-rubber-modified bitumen were subjected to penetration and softening-point tests. Tests were performed on three replicates for each binder. The temperature susceptibility of the modified bitumen samples was calculated in terms of its penetration index (PI) using the results obtained from the penetration and softening-point tests. Temperature susceptibility is defined as the change in the consistency parameter as a function of temperature. A classical approach related to PI is provided in the Shell Bitumen Handbook [16], as given by the following equation:

$$PI = \frac{1952 - 500 * \log(Pen_{25}) - 20 * SP}{50 * \log(Pen_{25}) - SP - 120} \quad (1)$$

where Pen_{25} is the penetration at 25ºC and SP is the softening-point temperature of the bitumen. Lower PI values indicate higher temperature susceptibility. Asphalt mixtures containing bitumen with higher PI are more resistant to low temperature cracking and permanent deformation [17].

Asphalt binders must remain sufficiently fluid, or workable, at the high temperatures necessary during the plant mixing, field placement and compaction of hot-mix asphalt. The rotational viscometer measures the rheological properties of asphalt binders to evaluate their pumpability during delivery and plant operations. The Brookfield DV-III rotational viscometer was used in this study. The RV was determined by measuring the torque required to maintain a constant rotational speed (20 rpm) of a cylindrical spindle while submerged in bitumen maintained at a constant temperature.

III. Results and Discussion

A. Penetration Test Results

Penetration test were applied to pure and 10%CR modified bitumen according to ASTM D 5. The variation on penetration value vs. mixing time at different mixing rates is given in Fig. 3.

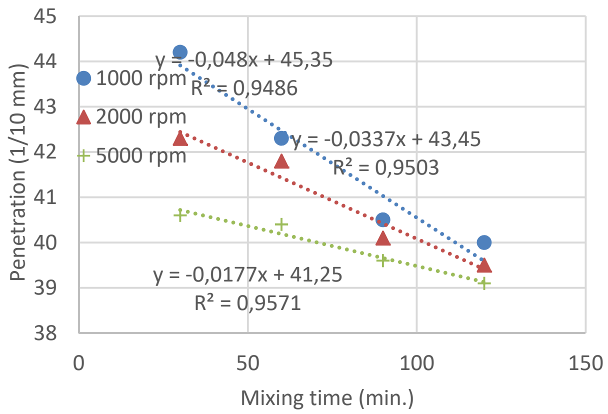

Fig. 3 The variation on penetration versus mixing time

Penetration values decreases with the increase of mixing time for all mixing rates. While this decrease rate is high at 1000 rpm, the abatement decreases with the increase of mixing rate. The penetration value of 10%CR modified binder reduces 8.1% and 2.2% at 1000 rpm and 5000 rpm mixing rate, respectively, with the increase of mixing time from 30 min to 120 min. Penetration values get closer to each other with the increase of mixing time. Therefore, the effect of mixing rate on penetration values lessens at high mixing time. The penetrations obtained at 1000 rpm and 5000 rpm for 120 min mixing time are 40 and 29.1, respectively.

The binder is subject to oxidation during the modification processes due to high temperatures and to having mating surfaces with the air. The penetration values of unmodified pure binder were determined at 120 min mixing time and 1000 rpm, 2000 rpm, and 5000 rpm mixing rates, in order to evaluate the oxidation effect. Furthermore, the penetration values of the pure binder, which is not subjected to any mixing processes, are also determined. The obtained results are given in Table I. It is seen from the table that the penetration value of pure bitumen without mixing processes reduces significantly after 120 min mixing time. The value reduces

36.1% and 38% after 120 min mixing time at 1000 rpm and 5000 rpm, respectively. This indicates that the most part of the diminishing of the penetration value of 10%CR modified binder results from the oxidation instead of additive effect. In Table II, it is seen that the difference between the penetration values of pure and CR modified binder under the same mixing conditions are very low.

TABLE I
PENETRATION VALUES OF PURE BITUMEN AT 120 MIN

Without mixing processes	@1000 rpm	@2000 rpm	@5000 rpm
65.8	42	41.6	40.8

TABLE II
PENETRATION VALUES OF BINDERS AT 120 MIN

	@1000 rpm	@2000 rpm	@5000 rpm
Pure bitumen	42	41.6	40.8
10%CR modified	40	39.5	39.1
Difference	+2	+2.1	+1.7

B. Softening Point Test Results

Softening point test was performed according to ASTM D36. The variations on softening point vs. mixing time at different mixing rates are given in Fig. 4.

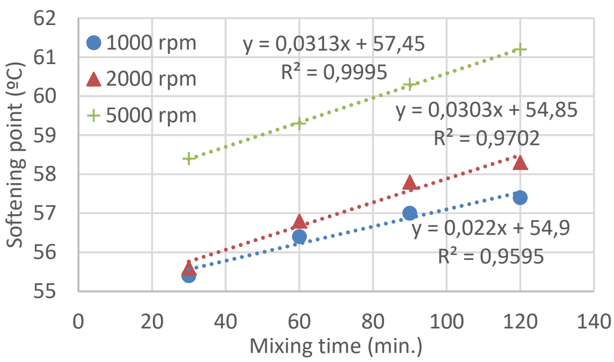

Fig. 4 The variation on softening point versus mixing time

Softening points increases with the increase of mixing time at all mixing rates. This increment is more efficient at 5000 rpm mixing rate. The increment rate begins to decrease with the increase of mixing time for 1000 rpm and 2000 rpm mixing rate. The softening point of 10%CR modified binder increase 1.9 ºC and 2.8 ºC after the increase of mixing time from 30 min to 120 min at 1000 rpm and 5000 rpm mixing rate respectively. The variation on softening points versus mixing rate under different mixing time is given in Fig. 5.

As seen in the figure showing the effect of mixing rate on softening point, the softening point values increase with the increase in the mixing rate; and this tendency to increase is similar throughout all mixing times. When the slopes of the lines in Figs. 4 and 5 are analyzed, it is seen that the slopes values in Fig. 4 are more than those in Fig. 5. This indicates that the increase in mixing time is effective on the increase in softening point more than the increase in mixing rate. According to the graphic, the softening point values obtained at 120-minute 2000 rpm mixing rate may be obtained at 5000 rpm and 30-minute conditions. Or, the softening point value obtained at 120-minute and 1000 rpm mixing rate may be obtained at 4000 rpm and 30-minute conditions. For this reason, it is possible that the mixing time is decreased 4-fold by increasing the mixing speed at a rate of 2.5-4 fold.

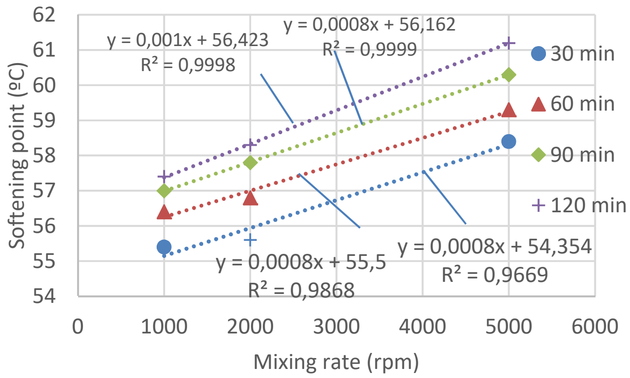

Fig. 5 The variation on softening points versus mixing rate

In order to assess the effect of oxidation on mixing process, the unmodified pure binder was mixed at 120-minute and 1000 rpm, 2000 rpm and 5000 rpm, and the softening point values were examined. In addition, the softening point values of the bitumen which was not subjected to any mixing processing were also determined. The results that were obtained are given in Table III.

TABLE III
SOFTENING POINT VALUES OF PURE BITUMEN AT 120 MIN

Without mixing processes	@1000 rpm	@2000 rpm	@5000 rpm
48.9	55.3	56.2	59.3

As it is seen in the table, the softening point of the unmodified pure binder increases at a significant level when it is subjected to 120-minute mixing process. The softening point of the pure bitumen increases at a rate of 13% and 21%, respectively when mixed at 120-minute and at 1000 rpm and 5000 rpm mixing speeds. For this reason, it has been concluded that the majority of the increase in the softening point that occur as a result of mixing process of the 10% CR-modified binder results from the oxidation not from the additive. As it is seen in Table IV, which shows the difference between the softening point values of the pure and 10% CR-Modified binders that are subjected to the same mixing conditions, the increasing effect of the additive on the softening point of the binder is very little.

TABLE IV
SOFTENING POINT VALUES OF BINDERS AT 120 MIN

	@1000 rpm	@2000 rpm	@5000 rpm
Pure bitumen	55.3	56.2	59.3
10%CR modified	57.2	58.3	61.4
Difference	+1.9	+2.1	+2.1

The PI values determined by using penetration and softening point are given in Fig. 6.

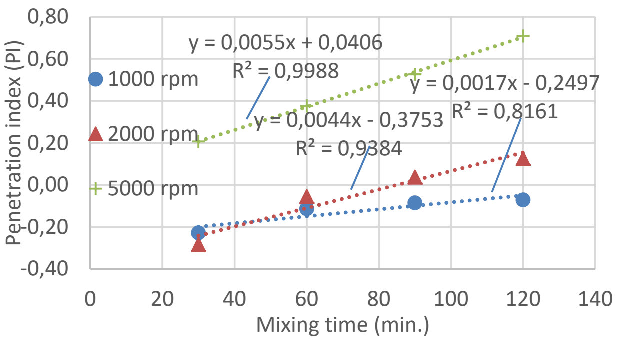

Fig. 6 The variation on PI versus mixing time

As it is seen in the figure, the PI values increase with the increase in mixing time. While this increase is not obvious at the 1000 rpm mixing rate, it is obvious at 2000 rpm and 5000 rpm mixing rates.

The PI values of the bitumen that is not subjected to any mixing process are given in Table V. The PI values of the unmodified binder increases with the mixing process. The PI values and the differences between these values of the 10% CR-modified binder and pure modifier obtained as a result of 120-minute mixing process are given in Table VI. In this respect, it has been concluded that most of the increase observed in the PI as a result of mixing process of the 10% CR-Modified binder stems from oxidation not from the additive.

TABLE V
PI VALUES OF PURE BITUMEN AT 120 MIN

Without mixing processes	@1000 rpm	@2000 rpm	@5000 rpm
-0.83	-0.37	-0.19	0.40

It is seen that the difference between the PI values of the pure and 10% CR-Modified binders subjected to the same mixing conditions are the same at different mixing rates; and therefore, the effects that would be brought by the additive at 120-minute mixing time are not affected by the mixing rate.

TABLE VI
SOFTENING POINT VALUES OF BINDERS AT 120 MIN

	@1000 rpm	@2000 rpm	@5000 rpm
Pure bitumen	-0.37	-0.19	0.40
10%CR modified	-0.07	0.12	0.71
Difference	+0.30	+0.31	+0.30

C. RV Test Results

RV tests were performed according to ASTM D4402. The variations on viscosity determined at 135ºC vs. mixing time at different mixing rates are given in Fig. 7.

As it is seen in the figure, the viscosity values increase with the increase at the mixing time. This increase is influential at 1000 rpm and 2000 rpm mixing rate; however, it is not so effective at 5000 rpm. The increase of mixing time from 30 minutes to 120 minutes at 1000 rpm causes a 22% increase in the viscosity; 24% increase in the viscosity at 2000 rpm.; and 3% increase in the viscosity at 5000 rpm. The increase that occurs in the viscosity with the increase of mixing time nearly loses its effect after 90-minute mixing time. The viscosity values obtained with 120-minute and 90-minute mixing were determined to be very close to each other at all mixing rates. The issue of how viscosity is affected by mixing rate is given in Fig. 8.

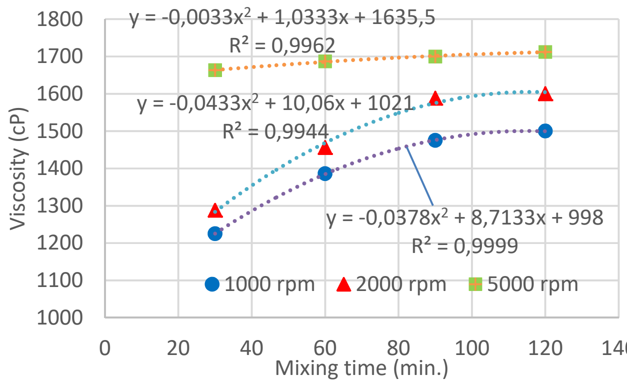

Fig. 7 The variation on viscosities versus mixing time

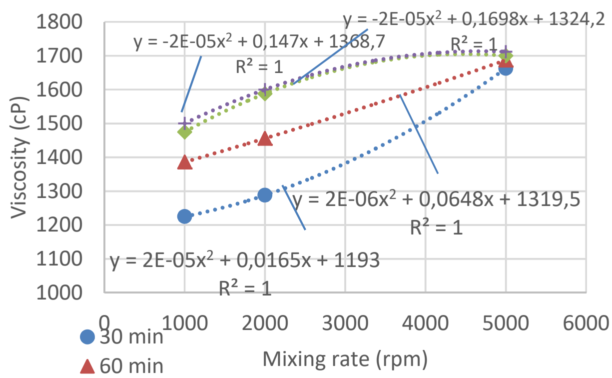

Fig. 8 Variation on viscosities versus mixing rate

The viscosity values increase with the increase in mixing rate. While mixing rate is effective on viscosity at 30-minute mixing time, it loses its effect as the mixing time increase. The fact that the effect of the mixing rate is nearly the same at 90-minute and 120-minute mixing time is clearly seen here. More viscosity value is obtained at 5000 rpm and 30-minute mixing conditions, than the viscosity value obtained at 2000 rpm mixing rate and at 90-minute or 120-minute mixing conditions.

The viscosity values of the bitumen that is not subjected to any mixing process are given in Table VII. The viscosity values of the bitumen that does not have additive increases with the mixing process. Mixing the pure bitumen at 5000 rpm for 120 minutes results in an 85% increase in viscosity. The viscosity values and the differences between them obtained as a result of 120-minute mixing of the pure binder and 10% CR-Modified binder are given in Table VIII.

TABLE VII
VISCOSITY VALUES OF PURE BITUMEN AT 120 MIN

Without mixing processes	@1000 rpm	@2000 rpm	@5000 rpm
425	557	625	787

It is seen that the difference between the viscosity values of the pure and 10% CR-Modified binders that are subjected to the same mixing conditions are the same at different mixing rates; and therefore, the effect that would be brought by the additive at 120-minute mixing time is not affected by the mixing rate. However, it is also seen here that the different values that occur in the viscosity with the additives are not insignificant, which was the case in penetration and softening points, but are high at a significant level when compared with the viscosity values of the pure binder. It has been determined that the experimental methods used in assessing the effects of the additives show significant differences.

TABLE VIII
VISCOSITY VALUES OF BINDERS AT 120 MIN

	@1000 rpm	@2000 rpm	@5000 rpm
Pure bitumen	557	625	787
10%CR modified	1500	1600	1712
Difference	+943	+975	+925

D.DSR Test Results

Dynamic sheer rheological tests were performed according to ASTM D7175. The variations on rutting parameters determined at 64ºC vs. mixing rate at different mixing times are given in Fig. 9.

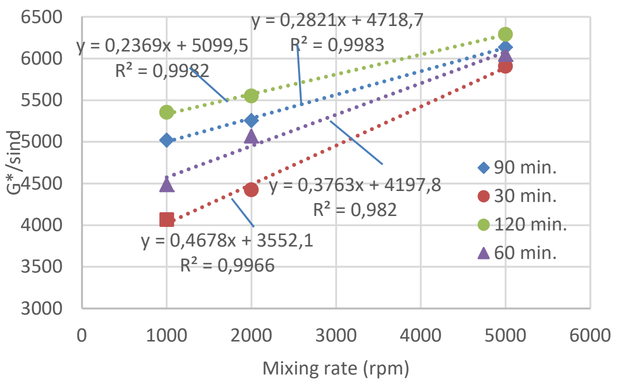

Fig. 9 The variation on rutting parameter with the mixing rate

Rutting parameters rise with the increase of mixing rate for all mixing times. The effects of mixing rate on the rutting parameter are more pronounced for low mixing time. Differences between the rutting parameter get closer at a high mixing rate. The improvement effects of additive become unimportant at a high mixing rate. The rutting parameter of binder prepared at 1000 rpm and 90 min mixing conditions can be obtained at 3000 rpm and 30 min mixing conditions. It is preferable to select low mixing time and high mixing rate in order to prevent excessive aging, and as well, it is less time consuming.

The rutting parameters of the bitumen that is not subjected to any mixing process are given in Table IX. It is seen that the rutting parameter of pure bitumen increases significantly by subjecting it to severe mixing condition; such that, a 120 min and 5000 rpm mixing process induces 4.39 times higher value compared to original bitumen.

TABLE IX
RUTTING PARAMETER OF PURE BITUMEN AT 120 MIN

Without mixing processes	@1000 rpm	@2000 rpm	@5000 rpm
1353	2840	3853	5943

The rutting parameters and the differences between them obtained as a result of 120-minute mixing of the pure binder and 10% CR-Modified binder are given in Table X.

TABLE X
RUTTING PARAMETER OF BINDERS AT 120 MIN

	@1000 rpm	@2000 rpm	@5000 rpm
Pure bitumen	2840	3853	5943
10%CR modified	5334	5550	6290
Difference	+2494	+1697	+347

It is seen from Table X that the differences between the rutting parameters of pure and modified binder decrease with the increase of mixing rate. This indicates that the rheological properties of aged bitumen exhibit similar properties with the modified binders.

IV. CONCLUSION

Penetration and softening point tests indicated that the improvement effect of CR were not distinct at the different mixing processes. The difference between the softening and penetration values of pure bitumen and that of the CR modified bitumen were very low at the same mixing conditions. The differences between the viscosity values of pure and CR modified binder were same at the different mixing rates at 120 minute mixing time. This indicates that the effects of additive are not affected by the mixing rate at a 120-minute mixing time. It was concluded that large parts of the improvement effects of the modified binder resulted from oxidation during the preparation processes. If this oxidation effects are not minimized, the modified binder prepared in the laboratory would not represent the binder prepared in full-scale devices; as a result of this, the designs based on the performance grade of bitumen would be too far from the realistic aspect.

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