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Effect of Blending Temperature and Blending Time on Physical Properties of NRL-Modified Bitumen

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Abstract

Bitumen is an important material that has been utilized as binder for aggregates in the construction of pavements for many years. In the past, unmodified bitumen was strong enough to resist deformation and deterioration from traffic loads. However, recent increase in traffic intensity and traffic volume has caused unmodified bitumen to be unable to attain the service life that they were designed for. Therefore, nowadays, polymer modified bitumen (PMB) technology has been widely applied by both researchers as well as manufacturers so that the performance of bitumen binder can be improved. This study aims to improve the physical properties of bitumen by the addition of natural rubber latex (NRL). Natural rubber latex was chosen as the modifier for this study because Malaysia is one of the largest producers and exporters of natural rubber latex worldwide and can be considered as one of the most important plants which help to contribute towards economic growth of the country. Therefore, the usage of natural rubber latex as a modifier in bitumen can give added value to local rubber products. The addition of natural rubber latex into bitumen was done in a mechanical mixer with three different variables: NRL content, blending temperature and blending time. The NRL content tested was varied between 1 – 12 percent in weight whereas the blending temperature and blending time were varied between 150 – 200ºC and 10 – 90 minutes respectively. The results of the study concluded that the usage of suitable NRL content, blending temperature and blending time can improve the physical properties NRL modified bitumen when compared to unmodified bitumen. The optimum NRL content to be added based on the results of this study was 9 percent whereas the optimum blending temperature and blending time were 150ºC and 10 minutes respectively.

Keywords: Natural rubber latex, Polymer modified bitumen, NRL content, Blending temperature, Blending time

INTRODUCTION

As Malaysia continues to grow towards becoming a developed country, an efficient transportation system is vital towards ensuring that there is good connectivity throughout the country. Among the different forms of transportation available, road transport is a very important one. In the road paving industry, bitumen has been utilized extensively as a binder for the construction of roads. In the past, usage of unmodified bitumen for road constructions was sufficient in supporting load from traffic flow. Nowadays however, high burden that is placed on the road system has reached a critical stage which can be seen in many developing and developed countries around the world. The reason for this is because of the increased volume of heavy vehicles together with a significant increase in the allowable axle weights of those vehicles. Because of this, the stress levels which are exerted on the pavement surface have increased dramatically as well. Due to the additional stresses exerted on the pavement surface, a majority of the road systems experience distress and deteriorate before being able to achieve the desired service life that they were designed for [1].

Engineers and researchers have therefore introduced polymer modified bitumen in order to counter this problem and so that the service life of roads can be improved. The modifier improves the characteristics of bitumen by dissolving into certain component fractions of the bitumen, thus spreading out its long chain polymer molecules and creating an inter-connecting matrix of the polymer. This inter-connecting matrix of long chain polymer molecules in bitumen is what improves the physical properties of bitumen. The polymer additives do not chemically alter the nature of the modified bitumen. They will only change or improve the physical properties of bitumen such as the softening point, brittleness, elastic recovery and ductility of the bitumen [2]. There are many types of polymers which can be utilized to improve the properties of bitumen. The examples of polymers are include styrene butadiene styrene (SBS), ethylene vinyl acetate (EVA), polyvinyl acetate (PVA), styrene butadiene rubber

(SBR) and natural rubber latex (NRL). In this study, natural rubber latex (NRL) was chosen as the modifier because of its wide availability in the country as well as its potential to boost the country's economy.

MATERIALS AND EXPERIMENT

Bitumen

The conventional bitumen that was used throughout this study was supplied by Atlas Setayesh Mehr (ASM) Co. The grade of the bitumen was 80/100 and it has the following physical properties: penetration, 86 PEN at 25ºC (ASTM D5-97), softening point, 47ºC (ASTM D36-95) and ductility of more than 150 cm at 25ºC (ASTM D113 – 99) [3-5].

Natural Rubber Latex (NRL)

Natural rubber latex is an elastomeric hydrocarbon polymer. It exists as a natural milky sap which is produced from a number of plant species. The 'sap' has a water-based colloidal structure. Natural rubber is produced through the process of coagulation from natural rubber latex in order to form a solid material [6].

Natural rubber latex was first applied in road construction in the year 1929 and that took place in Singapore. In United Kingdom, Europe and United States, the study of the use of natural rubber latex for modification of bitumen was carried out in the 1950's and 1960's. Since the introduction of natural rubber latex, the thermal stability of bitumen has been improved in two main ways [7]:

a) Bitumen's viscosity (thickening) is increased by NRL at high temperatures, thus increasing the resistance of road surfaces to deformation under heavy loads during hot weather

b) Thermal cracking at low temperatures is reduced by natural rubber

Because of this, the road surfaces exhibit better durability and have a greater resistance to defects and deformation. The improvement in the physical properties is due to the fact that natural rubber latex changes the rheological properties of bitumen. At low temperatures, bitumen freezes and stress causes it to crack due to the fact that it is so stiff. The natural rubber latex acts like an elastic band that holds bitumen together and dissipate stresses as they develop. On the other hand, at high temperatures, change in the rheology in bitumen causes it to flow. In this case, the natural rubber latex acts like a membrane which provides resistance to the flow of bitumen and thus, increases its shear resistance [7]. In this study, NRL was supplied by the LGM (Lembaga Getah Malaysia) in Sungai Buloh. The properties of the NRL are shown in **Table 1**.

Table 1: Properties of NRL

Property	Value	Unit
Total Solid Content	43.28	%
Dry Rubber Content	41.53	%
Total Alkalinity (NH_3)	0.52	%

Preparation of NRL-Modified Bitumen

In this study, modified bitumen was by prepared using a high shear mechanical mixer. Initially, bitumen was heated at a temperature of 160ºC for 30 to 40 minutes to ensure it melt enough to be mixed with NRL. The NRL was then added into bitumen at 1%, 2%, 3%, 5%, 7%, 9% and 12% of the total weight of bitumen content. The physical properties test of bitumen (softening point test and penetration test) has been conducted and penetration index (PI) has been calculated.

Figure 1: Mechanical mixer used to blend NRL with bitumen

Test on Bitumen

The three tests that have been conducted on bitumen to evaluate its physical properties are:

(1) Softening point test

(2) Ductility test

(3) Penetration test

(1) Softening point test (ASTM D36 – 95) [4]

All bitumen grades need to be fluid enough prior to being applied together with the aggregate mix and this is done by heating. The softening point of bitumen is defined as the temperature where the bitumen attains a particular degree of softening under specified conditions of the test. Two brass rings containing the bitumen to be tested are suspended in a liquid such as water at a specific temperature. A steel ball is placed on the surface of each bitumen sample. The liquid is heated at a specific rate and the temperature where the softened bitumen touches the metal plate located below the ring is recorded as the softening point [8]. The apparatus and test procedure for this test can be found in ASTM D36 – 95.

(2) Ductility test (ASTM D113 – 99) [5]

Ductility is an important strength in bitumen and it allows the bitumen to be subjected to notable deformation or elongation. In the construction of flexible pavements where bitumen films around the aggregates, it is required to have sufficient ductility or else the pavement surface would crack and be pervious [8]. The ductility of a bituminous material is measured as the distance, in centimeters, where it can elongate before breaking when two ends of a briquet specimen are pulled at a specified speed and temperature by the testing machine/ ductilometer. The apparatus and test procedure used can be found in ASTM D113 – 99.

(3) Penetration Test (ASTM D5 – 97) [3]

The penetration test determines the consistency of bitumen (or the hardness or softness of bitumen) by measuring the depth in deci-millimeters (or tenths of a millimeter) where a standard needle will penetrate vertically under specific conditions of loading, temperature and time. The penetration test values can be used to grade the bitumen by its hardness. Generally, lower grade bitumens are preferred in warmer regions to prevent excess softening from occurring.

RESULT AND DISCUSSION

Determination of Optimum NRL Content

At the initial stage of this study, the blending time of 10 minutes and blending velocity of 250 rpm were used to determine the optimum NRL content that could be added to prepare the polymer modified bitumen. Physical properties (softening point, penetration, ductility and penetration index (PI)) of the modified bitumen were considered to determine the best NRL content and the result are shown in **Table 2**. From the result, it can be seen that, the softening point decreases initially with the addition of NRL up to a percentage of 2%. This indicates that the addition of a small amount of NRL is not beneficial towards improving the bitumen's softening point. However, from 3% onwards, the softening point increases up to a maximum temperature of 50ºC at a percentage of 12%.

According to Chen et al. (2002), the softening point increases because the increase in polymer content results in an increase in polymer swelling [9]. Consequently, this causes an increase in the apparent asphaltene percentage which will form a harder matrix. A harder matrix will lead to more difficulties in softening the mixture, thus causing the softening point to be higher. Since the aim of this study is to improve the physical properties of bitumen by adding NRL, percentages of 7% or higher are considered in this case for the optimum content as the softening point at 7, 9 and 12% are all higher than unmodified bitumen (47ºC).

Table 2: Results of Physical Properties Test on Bitumen Modified with Different NRL Content

Run	% of NRL	Softening point (ºC)	Penetration (dmm / 1/10th mm)	Penetration Index (PI)
1	0	47	86	-0.648
2	1	46	72	-1.560
3	2	45	88	-1.125
4	3	47	81	-0.796
5	5	47	100	-0.179
6	7	47	91	-0.342
7	9	49	80	-0.399
8	12	50	107	0.943

For the penetration test, the penetration of unmodified bitumen is 86 dmm. When adding NRL, there are no specific upward or downward trends that are observed for the penetration results. However, the lowest penetration values of below 80 dmm were obtained at 1% and 9% respectively. Since 1% of NRL it too little to improve the bitumen's softening point, 9% of NRL is therefore considered for the optimum NRL content because the results indicate that 9% NRL modified bitumen has a higher softening point and lower penetration when compared to unmodified bitumen.

For ductility test, the results were not reported in Table 2 as all of the samples including unmodified bitumen did not rupture or break when they were pulled by the testing machine. The testing machine or ductilometer used had a maximum pulling capacity of 150 cm. From the result, it can be deduced that all samples have a ductility value greater than 150 cm and are very ductile. Based on the specifications stated by Jabatan Kerja Raya (JKR), the ductility requirement should not be less than 100 cm for Grade 80/100 bitumen [10]. Therefore, since all samples have a ductility value of more than 150 cm, the test results are acceptable and it can be used for pavement construction based on JKR requirements for ductility.

Penetration Index (PI) values obtained for all samples were calculated using the formula stated in equation (1) which applies both the softening point and penetration results [11]. The PI of bitumen should be between -1 and +1 so that it will be suitable for pavement construction.

$$PI = \frac{1952 - 500 \log P - 20 SP}{50 \log P - SP - 120} \qquad \text{Equation (1)}$$

Bitumen which has a higher PI value indicate lower temperature susceptibility as well as better resistance to permanent deformation and cracking [12]. Based on the results in Table 2, the PI of unmodified bitumen is -0.648. When NRL is added, the PI decreases to a minimum value of -1.560 at 1% NRL before increasing up to -0.179 at 5%. After that, the PI decreases slightly to -0.399 at 9% before increasing to a maximum value of 0.943 at 12%. All of the percentages of NRL modified bitumen with the exception of 1 and 2% can be used for pavement construction since they are in the range of -1 and +1. For the purpose of this study, the optimum NRL content chosen was 9% based on the softening point and penetration results.

Determination of Optimum Blending Temperature

Using 9 percent NRL content, the blending time and blending velocity of 10 minutes and 250 rpm respectively, was used to determine the optimum blending temperature. The mixing temperatures were varied at 150, 160, 170, 180, 190 and 200ºC respectively. Physical properties test were carried out on all samples and the results of the test are as shown in **Table 3**.

Table 3: Results of Physical Properties Test on Bitumen Modified with NRL at Different Blending Temperatures

Run	Temp (ºC)	Softening Point (ºC)	Penetration (dmm / 1/10th mm)	Penetration Index (PI)
1	150	52	78	0.427
2	160	49	80	-0.399
3	170	48	91	-0.103
4	180	48	82	-0.401
5	190	50	99	0.580
6	200	51	86	0.316

From the results, it can be seen that the highest softening point of 52ºC occurred when a blending temperature of 150ºC was used. Thereafter, the softening point decreased to a minimum of 48ºC at 170 and 180ºC blending temperature and subsequently increased back up to 51ºC at 200ºC blending temperature. For the penetration results, the lowest penetration value of 78 dmm was achieved at 150ºC blending temperature. After that, the penetration increases up to a maximum value of 99 dmm at 190ºC before decreasing to 86 dmm at 200ºC.

Similar to the first part of the study, the ductility results for all samples did not rupture or break when pulled to the maximum capacity of 150 cm by the ductility testing machine. Therefore, all samples have ductility value of more than 150 cm and are all suitable to be used as binder for pavement construction based on JKR requirements stated in **Table 4**.

For the plasticity index (PI), there are no specific upward or downward trends that are observed. However, the PI for all samples were between -1 and +1 which indicate that all are suitable to be used for pavement construction.

Table 4: JKR Specifications for Bitumen to be used as Binder Course [10]

Characteristics	ASTM Test Method	Penetration Grades	
		60-80	80-100
Penetration at 25ºC (1/100 cm)	D5	60-80	80-100
Ductility at 25ºC (cm)	D113	not less than 100	not less than 100
Softening point (ºC)	D36	not less than 48 & not more than 56	not less than 45 & not more than 52

From the results in Table 3, it can be suggested that 150ºC could be used as the optimum blending temperature as it produces the highest softening point and lowest penetration value. In addition to that, even though 190 and 200ºC blending temperatures produced relatively high softening points, it is not recommended to use because using blending temperatures above 180ºC, it may damage the structure of both the polymer and bitumen [13-14]. Moreover, Micaelo et al. (2012) stated that blending temperatures of higher than 180ºC can cause the polymers to undergo degradation [13]. Besides, Kumar (2010) in his study stated that a blending temperature of 180ºC can cause the bitumen to lose its rheological properties [14]. Therefore, based on the softening point and penetration results, 150ºC will be considered as the optimum blending temperature whereas temperatures above 180ºC are ruled out of consideration due to their negative effects on the bitumen and polymer structure.

Determination of Optimum Blending Time

In order to determine the optimum blending time, the optimum NRL content of 9 percent and optimum blending temperature of 150ºC was used and the blending time was varied from 10 to 90 minutes. Physical properties of the modified bitumen were considered to determine the best blending time and the results are shown in **Table 5**. For the softening point results, it can be seen that the highest softening point of 52ºC was attained at a blending time of 10 minutes. As the blending time increases, the softening point initially decreases to a minimum value of 49ºC at a blending time of 30 and 45 minutes. After that, the softening point increases again up to 52ºC at a blending time of 90 minutes.

While, for the penetration test, the lowest penetration of 78 dmm was also obtained for the blending time of 10 minutes. The penetration then increases to 88 dmm at 20 minutes of blending time before decrease to 81 dmm at 60 minutes blending time. Finally, at 90 minutes blending time, the penetration value increase up to 91 dmm.

Table 5: Results of Physical Properties Test on Bitumen Modified with NRL at Different Blending Time

Run	Mixing time (minutes)	Softening Point (ºC)	Penetration (dmm / 1/10th mm)	(PI)
1	10	52	78	0.427
2	20	50	88	0.153
3	30	49	87	-0.048
4	45	49	82	-0.356
5	60	51	81	0.201
6	90	52	91	0.808

For the plasticity index (PI), 10 minutes mixing time produces a PI of 0.427. After that, the PI decreases to a minimum value of -0.356 at 45 minutes before increasing to the maximum value of 0.808 at blending time of 90 minutes. Since the PI for all samples are between -1 and +1, they are all suitable to be used for pavement construction. Therefore, based on the results in Table 5, 10 minutes can be considered as the optimum blending times because it produce the highest softening points and lowest penetration value respectively.

When compared to previous researchers who have carried out similar studies on blending time of polymer modified bitumen, 10 minutes mixing time can be deduced as an acceptable result. Study carried out by Wegan (2001) found that a mixing time of 5 minutes was suitable to obtain a homogenous bituminous mixture [15]. Wegan used ethylene vinyl acetate (EVA) to modify bitumen and he found that 5 minutes of blending time was sufficient to produce a homogenous distribution of the polymer phase present in the bituminous mixture [15]. Therefore, the observation by Wegan (2001) also supports the suggestion that a short blending time of 10 minutes can be taken as the optimum blending time since 5 minutes can already produce the homogenous mix associated with polymer modified bitumen.

CONCLUSION

Based on the result, it can be concluded that natural rubber latex (NRL) can be utilized to modify bitumen and improve the physical properties (ductility, softening point, penetration and penetration index (PI)) of modified bitumen. 9 percent of NRL content was the maximum useful amount that could be added to the prepared modified bitumen. The results from the experiment show that, the addition of 9 percent NRL could increase the softening point and penetration index (PI) value and reduce the penetration value. These properties can indicate that the hot mix asphalt using NRL modified bitumen could have more strength and durability than using unmodified bitumen. The results also show that the blending temperature and blending time have a significant effect on the physical properties of modified bitumen. It is suggested that the blending temperature and blending time to prepare NRL modified bitumen should not be more that 150ºC and 10 minutes respectively.

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