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Research paper

Hot mix asphalt (HMA) properties using natural rubber latex (NRL)-modified bitumen

Mohd Amin Shafii [1] *, Sian Jiun Chia [1], Nuryantizpura Mohamad Rais [2]

[1] *Faculty of Engineering and Built Environment, SEGi University, Petaling Jaya, Selangor, Malaysia*
[2] *Malaysia Institute of Transport (MITRANS), University Technology MARA, Shah Alam, Selangor, Malaysia*
**Corresponding author E-mail: aminshafii@segi.edu.my*

Abstract

Hot mix asphalt (HMA) is one of the common flexible pavement used in Malaysia. Due to the increasing in the volume of traffic nowadays, unmodified HMA has begun to be insufficient in providing the strength to resist the increased traffic load. Therefore, many research have been done to improve HMA by modifying the bitumen. This study aims to investigate the properties of the HMA using natural rubber latex (NRL) modified bitumen. The optimum bitumen content (OBC) of the NRL-Modified HMA was determined by using Marshall mix design method and the properties of the NRL-Modified HMA was investigated based on the strength and volumetric properties. Besides that, a few tests were conducted in order to determine the properties of the bitumen and aggregates used. The properties of bitumen determined based on its softening point, ductility and penetration while the properties of the aggregated were determined based on its apparent specific gravity, aggregate impact value and shape (flakiness index and elongation index). From the result, it was found that the addition 9% of NRL by the total weight of modified bitumen had altered the volumetric properties and decrease the strength properties of the HMA.

Keywords: *Hot Mix Asphalt; Natural Rubber Latex; Polymer Modified Bitumen; Strength Properties; Volumetric Properties*.

1. Introduction

There are many forms of transportation in Malaysia. Among the different forms of transportation available, road is very important. Road is one of the important way on land that allows people to transport from one place to another place. Hot mix asphalt (HMA) is one of the common flexible pavement used to construct the road surface in Malaysia. HMA is combination of bitumen and graded mineral aggregates mixed together by heating the materials. Unmodified HMA has been used for centuries in providing the uniformly pathway. However, as Malaysia is developed to become an advance country, the volume of the traffic continues to increase, the unmodified HMA start to insufficient in supporting the heavy traffic load. Hence, the engineers are searching for new technology to modify the HMA in order to improve the strength and the service life of the pavement.

HMA normally modified by modifying the bitumen. Bitumen can be modified by using polymers, chemical modifiers, chemical extenders, fibers, antistripping, natural binders and fillers. Generally, bitumen is modified by using polymers. The polymers used to modify bitumen can be categorised into plastomer and elastomer. The common types of plastomer used to modify bitumen are ethylene vinyl acetate (EVA), polyethylene (PE), polypropylene (PP) and others while the common types of elastomer used to modify bitumen are crumb rubber and natural rubber latex (NRL). Plastomers increase the viscosity and stiffness of the bitumen, for example EVA can improves the resistance to heat and deformation at the same time decreasing the thermal susceptibility and penetrability [1]. While, elastomers improve the elastic behavior of the bitumen, for example NRL can acts like a membrane to resist the flow of bitumen and increase the shear strength [2]. NRL is chosen in this study because Malaysia is one of the largest producer of NRL worldwide.

2. Materials and experiments

The materials used in this study were bitumen, coarse aggregates, fine aggregates, filler, cement and NRL. Some experiments were conducted to determine the properties of the materials used.

2.1. Tests on aggregate

The aggregates used in this study were supplied by Hanson Heidelberg Cement Group, and the aggregates were provided from the quarry located at Cheras, Malaysia. The properties of the aggregate were determined based on impact value, apparent specific gravity and shape (flakiness and elongation).

a) Aggregate Impact Value Test (BS 812 Part 112-1990) [3]

The impact value of aggregate also known as a test of aggregate toughness. The aggregate used to make the bituminous mixture should has sufficient toughness to resist the load from the vehicles on the road.

b) Apparent Specific Gravity Test (ASTM D 7370) [4]

Apparent specific gravity is the weight-volume ratio for a unit of aggregate compared to the weight-volume ratio of an equal unit of water. Apparent specific gravity of an aggregate is also considered to be a measure of strength or quality of the material. Apparent specific gravity of aggregate is needed in Marshall mix design in order to make weight-volume conversions and calculate the voids content in a HMA sample.

The apparent specific gravity of aggregate was determined by using CoreLok machine and the coarse and fine aggregate were tested separately. Coarse aggregate is the aggregates that are retained on 4.75 mm sieve size and fine aggregate is the aggregates passing 4.75 mm sieve size.

c) Aggregate Shape Test (BS 812 Part 105-1989) [5]

The shape and size of aggregate may affect the suitability of aggregates to be used in bituminous mix. The shape and size of the aggregates are determined by the percentages of flaky and elongation particles, which are the flakiness index and elongation index of the aggregate.

2.2. Tests on bitumen

The bitumen act as a binder to bind the aggregates in the bituminous mixture. In this study, the bitumen was supplied by Atlas Setayesh Mehr (ASM) Co. The grade of the bitumen provided is grade PEN 80/100 bitumen. The properties of the bitumen and NRL-modified bitumen were determined based on softening point, ductility and penetration.

a) Softening Point (ASTM D 36 / D 36-09) [6]

The purpose of softening point test is to determine the softening point of bitumen in a temperature range by using the ring-and-ball apparatus immersed in water. The viscosity of bitumen decrease and become softer as the temperature rise. Therefore, the softening point of bitumen needed to be determined to find out the pavement design temperature.

b) Ductility Test (ASTM D 113-07) [7]

Ductility of the bitumen can be defined as its ability to be elongated under the traffic load without fracture. The ductility of bitumen is determined by the distance which the bitumen able to be elongated before it break.

c) Penetration Test (ASTM D 5-06) [8]

The purpose of penetration test is to determine the penetration value of the bitumen. Penetration can be defined as the consistency of bitumen indicated as the tenths of a millimetre that the needle penetrates vertically into the bitumen sample under known conditions of loading, time and temperature. Higher values of penetration represent softer consistency of bitumen, lower values of penetration represent harder consistency of bitumen.

2.3. Natural rubber latex (NRL)

In this study, the NRL was supplied by the Lembaga Getah Malaysia (LGM) in Sungai Buloh, Malaysia. The NRL provided is field latex. The properties of the NRL provided are as 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	%

2.4. Preparation of NRL-modified bitumen

In this study, the content of NRL used to prepare modified bitumen is 9%. This content was proposed by [9] in their study to investigate the properties of NRL-modified bitumen. There are some requirements needed to be followed when blending the NRL-Modified bitumen. The requirements in preparing NRL-Modified bitumen are as shown in Table 2.

Table 2: Requirements in Preparing NRL-Modified Bitumen

Requirement	Value	Unit
NRL content	9	%
Blending Time	10	minute
Blending Velocity	250	rpm
Blending Temperature	150	°C

2.5. Marshall Mix design

The gradation limit of the aggregate used in Marshall mix design was in accordance with JKR/SPJ/2008-S4 [11]. The gradation limit of the aggregate is as shown in Table 3.

Table 3: Gradation Limit of Aggregate

Mix Type	Wearing Course	Design Gradation (Percentage Passing by Weight)
Mix Designation	AC 14	
BS Sieve Size (mm)	Percentage Passing by Weight	
20.0	100	100
14.0	90 – 100	95
10.0	76 – 86	81
5.0	50 – 62	56
3.35	40 – 54	47
1.18	18 – 34	26
0.425	12 – 24	18
0.150	6 – 14	10
0.075	4 – 8	6

The design bitumen content of the HMA used in Marshall mix design was in accordance with JKR/SPJ/2008-S4 [11]. The design bitumen content is as shown in Table 4.

Table 4: Design Bitumen Content

Mix Type	Bitumen Content (%)
AC 14 – Wearing Course	4.0 – 6.0

By using the gradation limit of aggregate, Marshall samples were prepared for bitumen content within the range given in Table 4 at increments of 0.5 %, in accordance with the steps as follow:

1) Aggregate evaluation.
2) Preparation of Marshall samples.
3) Bulk and maximum specific gravity determination.
4) Marshall Stability and flow test.
5) Plotting test results and determination of optimum bitumen content (OBC).

Fig. 1: Marshall Samples.

The individual test values at the mean OBC were read from the plotted smooth curves and should comply with the design parameters given in Table 5.

Table 5: Test and Analysis Parameters

Parameter	Wearing Course
Stability (N)	>8000
Flow (mm)	2.0 – 4.0
Stiffness (N/mm)	>2000
VTM (%)	3.0 – 5.0
VFB (%)	70 – 80

3. Results and discussion

The results are compared to determine the differences of the HMA by using normal bitumen and NRL-modified bitumen.

3.1. Results of aggregate tests

The results obtained from the aggregate tests are as shown in Table 6.

Table 6: Results of Aggregate Tests

Property		Value	Specifications
Aggregate Impact Value (%)		40.70	< 30% [10]
Apparent Specific Gravity (g/cm^3)	Fine Aggregate	2.65	-
	Coarse Aggregate	2.64	-
Shape of Aggregate (%)	Flakiness Index	10.29	< 25% [11]
	Elongation Index	17.14	-

3.2. Results of bitumen tests

The results obtained from the bitumen tests are as shown in Table 7.

Table 7: Results of Bitumen Tests

Property	Normal Bitumen	NRL-Modified Bitumen
Softening Point (°C)	50.50	55.70
Ductility (cm)	>140.00	110.00
Penetration (d-mm)	81.30	93.10

The NRL-Modified bitumen has a higher average softening point than the normal bitumen which are 55.70 °C for NRL-Modified bitumen and 50.70 °C for normal bitumen. This mean the NRL-Modified bitumen has a higher resistance to high temperature compare to the normal bitumen. According to the research done by [12], the study found that the softening point of the NRL-Modified bitumen can be higher because of the increase in polymer content results in an increase in polymer swelling. This will make the apparent asphaltene percentage higher which will form a harder matrix and make the mixture harder to be softened [12]. Therefore, the addition of NRL has increase the softening point of the bitumen.

The NRL-Modified bitumen has a lower average ductility value than the normal bitumen which modified bitumen has an average ductility value of 110.00 cm and the normal bitumen does not rupture or break when it pulled to the maximum limitation of length by the ductility testing machine. The ductility testing machine used in this study only has a maximum test length of 140.00 cm. According to the specifications stated in JKR/SPJ/2008-S4, the requirement of the ductility in pavement and road construction should not be less than 100 cm for the bitumen grade PEN 80/100 [11]. Therefore, the normal bitumen and NRL-Modified bitumen fulfilled the requirement stated by Jabatan Kerja Raya (JKR).

The normal bitumen has a lower penetration value than the NRL-Modified bitumen where the normal bitumen has a penetration value of 81.30 d-mm and the NRL-Modified bitumen has a penetration value of 93.10 d-mm. The normal bitumen used has grade of PEN 80/100 which has a range of penetration value from 80 d-mm to 100 d-mm. Therefore, the normal bitumen has a relatively low penetration value among its grade. The lower the penetration value the harder the consistency of bitumen, the higher the penetration value the softer the consistency of bitumen. Therefore, the normal bitumen is harder than the NRL-Modified bitumen. Comparable to the results obtained from the research done by [13], the addition of NRL in the bitumen does results in a lower penetration value compare to the unmodified bitumen.

3.3. Results of marshall test

The results obtained from Marshall Test are as shown in Table 8.

Table 8: Results from Marshall Test

Property	Control Sample	NRL-Modified Sample
OBC (%)	5.15	4.99
Stability (N)	8091.00	6792.00
VFB (%)	73.64	75.66
VTM (%)	4.18	3.66
Flow (mm)	4.30	5.50
Stiffness (N/mm)	1881.60	1234.90

From the results above, the control sample and NRL-Modified sample have different OBC, where the OBC is 5.15 % for control sample while NRL-Modified sample has an OBC of 4.99 %.

The control sample has a higher stability value than the NRL-Modified sample at their OBC where the stability are 8091.00 N and 6792.00 N for the control sample and NRL-Modified sample respectively. Comparable to the results obtained from the research done by [13], the HMA modified by using NRL does reduce the stability of the HMA. The strength properties of the NRL-Modified sample does not fulfilled the requirement stated in JKR/SPJ/2008-S4 where the stability should not be less than 8000 N [9].

The control sample has a percentage of air voids in the compacted aggregate filled with bitumen (VFB) of 73.64 % while NRL-Modified sample has a VFB of 75.66 %. The NRL-Modified sample has a higher VFB value than that in the control sample. However, both of the VFB for control sample and NRL-Modified sample are fulfilled the requirement stated in JKR/SPJ/2008-S4 where the VFB should be in the range of 70 % to 80 % for wearing course asphaltic concrete [11].

The control sample has a percentage of air voids in the total compacted mix (VTM) of 4.18 % while NRL-Modified sample has a VTM of 3.66 %. The control sample has a higher VTM value than that in NRL-Modified sample. However, both of the VTM for control sample and NRL-Modified sample are fulfilled the requirement stated in JKR/SPJ/2008-S4 where the VTM should be in the range of 3 % to 5 % for wearing course asphaltic concrete [10].

The control sample has a lower flow value compared to NRL-Modified sample where the control sample has a flow of 4.30 mm while the NRL-Modified sample has a flow of 5.50 mm. Comparable to the results obtained from the research done by [13], the HMA modified by using NRL does increase the flow of the HMA.

The control sample has a higher stiffness value than the NRL-Modified sample where the control sample has a stiffness of 188.16 N/mm and the NRL-Modified sample has a stiffness of 123.49 N/mm. Therefore, the control sample is stiffer than the NRL-Modified sample.

From the results above, the HMA mixed by using NRL-Modified bitumen does not show a better properties than the HMA mixed by using normal bitumen. In the bitumen tests, the results show that the bitumen modified using the NRL has increase the penetration value and reduce the ductility of the bitumen. The properties of the NRL-Modified HMA may be related to the bitumen properties. A higher value in penetration and a lower value in ductility of the bitumen may decrease the strength properties of the mixture. Compare to the results obtained from the research done by [13], the NRL-Modified bitumen with higher penetration value also has a lower strength properties of the NRL-Modified HMA.

Besides, from the research done by [14], NRL-Modified bitumen should improve the strength properties of the mixture by increasing the stability value and decreasing the voids in the mixture. In this study, the results shows that NRL-Modified bitumen decrease the voids in the mixture as well as the stability. The possibility that cause the difference in results may be the difference source and properties of the NRL and aggregates. It might be also caused by the difference in percentage of NRL content added in the sample and the difference in grade of the bitumen used. Therefore, further researches are needed in order to study and improve the properties of HMA by using the NRL.

4. Conclusion

The summaries of the findings are as follow:

1) The NRL-Modified bitumen has increase the VFB and decrease the VTM of the HMA.
2) The NRL-Modified bitumen has reduce the Marshall stability and increase the flow of the HMA.

3) Aggregate impact value is more than 30% that might contribute to low stability value for modified sample.

From this study, it can be concluded that the properties of HMA with a mix type and designation of wearing course AC 14 cannot be improved by using the NRL-Modified bitumen with a NRL content of 9 % by the total weight of the modified bitumen. Further research are needed in order to improve the HMA by using NRL-Modified bitumen.

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