

Evaluation of Latex Modified Asphalt Mixture with Recycled Concrete Aggregate (RCA)

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Abstract

Natural rubber latex (NRL) is currently added into bitumen to improve the performance of asphalt concrete mixtures. However, the addition of NRL increased the cost of production and road authorities are generally reluctant to use a higher cost product albeit with better performance. The use of RCA such as from building demolitions can offset this increase in cost in the use of NRL modified bitumen. However, there is a need to ensure that the quality of the asphaltic concrete is not compromised by the addition of RCA. This paper details a study to evaluate the use of NRL modified asphalt bitumen together with 50 percent RCA on the performance of hot mix asphalt. Commercially produced bitumen modified with NRL was used for the asphalt mixes. Dense asphaltic concrete AC14 samples were then prepared using the modified bitumen together with the addition of 50 percent RCA by weight replacing the virgin aggregate. Performance tests were then carried out on the samples which include moisture susceptibility test, resilient modulus test, and dynamic creep test. The results revealed that the use of NRL together with 50 percent RCA to dense asphaltic concrete mixes gave comparable performance to conventional dense asphalt concrete mixes. It can be concluded that the use of NRL modified bitumen together with 50 percent RCA can provide a cost-effective solution to increase the performance of hot mix asphalt.

1. Introduction

Roads are essential for commerce and trade. They connect many locations and allow everyone easy access to goods and services. Road pavements, particularly flexible pavement, do not last permanently. After traffic has gone through the road for some time, signs of wear will occur. Some pavement layers may cause the early development of distress symptoms on the bituminous surface such as rutting, cracking, faulting, bleeding and potholes. This might be caused by the traffic as well as the seasonal changes in temperature. These issues can be resolved by applying a modified bituminous mix. Natural rubber latex is commonly used as a modifier in bitumen-based materials to enhance their properties and performance [1]. The addition of natural rubber latex improves the elasticity, durability, and resistance to cracking and aging of the modified bitumen [2]. Previous research found that natural rubber latex modified bitumen can increase the service life of road pavement and improve overall performance of asphalt mix used for road pavements [3,4]. Improved resistance to rutting and fatigue cracking of asphalt pavements are among the advantages discovered when utilizing natural rubber latex as a bitumen

modifier in asphalt mixtures. Although the improvement of rutting and fatigue resistance of asphalt pavements were among the benefits of adding natural rubber powder, but it also had certain limitations, such as high mixing temperatures and extended mixing times of up to two hours.

Construction is an industry that generates a wide range of waste due to the diverse range of materials that are utilised in the building process. Recycled concrete aggregate, emerges from the meticulous crushing and processing of aged or demolished concrete structures [5]. This process yields a diverse range of crushed concrete particles, each with its own unique size. These particles can serve as a suitable replacement for natural aggregate in the production of asphalt concrete mixture. By introducing recycled concrete into asphalt mixtures, the use of fresh aggregates is reduced, thus safeguarding the natural resources and diverting excessive concrete waste away from the landfills. Modifying asphalt mixes to accommodate waste materials, also reduce the requirement for naturally mined resources, decrease carbon emissions and the environmental effect of the pavement industry [6]. A number of researchers have proposed strategies for processing and incorporating recycled concrete aggregates into various types of asphalt mixtures.

As the addition of NRL increased the cost of production, road authorities are generally reluctant to use a higher cost product albeit with better performance. The use of RCA such as from building demolitions can offset this increase in cost in the use of NRL modified bitumen [7]. The purpose of this study is to investigate the performance of asphalt mix using natural rubber modified bitumen and the use of recycled construction aggregates to partially replaced the natural aggregates. The specific objectives of this study include the determination of the optimum bitumen content for asphaltic concrete AC14 gradation using a combination of new aggregates and 50% of recycled concrete aggregates and evaluation of the performance of the latex modified asphalt mixture with 50% RCA using moisture susceptibility test, resilient modulus test and dynamic creep test.

2. Methodology

2.1 Structure

The typical bitumen of 60/70 penetration grade utilized for this study was obtained from Petronas Berhad. Modified bitumen with 5% natural rubber latex was obtained from Kemaman Bitumen Sdn. Bhd. The bitumen properties were determined by the softening point test, penetration test and ductility test. The newly sourced aggregate was obtained from Kajang Rock Quarry in Selangor. The RCA was sourced from discarded concrete utilized in structural investigations at the concrete engineering laboratory of UiTM Shah Alam. This study conducted experiments on Los Angeles Abrasion Value, Aggregate Impact Value, Aggregate Crushing Value, and Flakiness Index Value. Portland cement was utilized as a filler ingredient in the mixture. The bitumen and aggregate utilized conformed to the specifications outlined in PWD Malaysia's Specification for Road Works [8]. The characteristics of the NRL modified bitumen, along with the gradation of fresh aggregates and RAP, are presented in Table 1 and Table 2.

Table 1 Properties of latex modified binder

No.	Test	Unit	Method	Specification		Results
				Min.	Max.	
1	Penetration at 25°C, load 100g, 5s		ASTM D5/D5M 13	50	70	55
2	Softening Point	°C	ASTM D36/D36M-14e1	50	-	53.6
3	Flash Point Cleveland Open Cup	°C	ASTM D92-16a	220	-	330
4	Elastic Recovery at 25°C	%	ASTM D6084	40	-	63
5	Dynamic Viscosity at 150°C	cP	ASTM D4402	200	600	590
6	Dynamic Shear, $G^*/\sin\delta$ at 70°C	kPa	AASHTO TP5	1.0	-	1.34

Table 2 Gradation of AC14 virgin aggregate with RCA

BS Sieve (mm)	Gradation		Virgin Agg. (%)	RCA (%)
	% Passing	% Retained		
20.0	100	0	-	-
14.0	95	5	2.5	2.5
10.0	81	14	7.0	7.0

5.0	56	25	12.5	12.5
3.35	47	9	9	0
1.18	26	21	21	0
0.425	18	8	8	0
0.150	10	8	8	0
0.075	6	4	4	0

The samples are prepared in accordance with the Marshall Mix Design approach (ASTM D 1559) to determine the optimum binder content (OBC) for the control and RCA mixtures. For this research, both mixes were prepared used the mid-gradation of AC14 aggregate gradation limit and the binder content ranged from 4.0% to 6.0% in accordance with the PWD Malaysia Specification for Roadworks. Marshall Test was then conducted to determine Marshall Stability and Flow value as per ASTM D 1559 (Fig. 1). The graphs of Stability, Flow, Bulk Density, Voids Filled with Bitumen (VFB) and Air Voids in Mix (VIM) versus the bitumen content were plotted to obtain the required value for the determination of the optimum binder content (OBC). The OBC was determined by obtaining the average of the five parameters.



Fig. 1 Marshall stability and flow test equipment

2.2 Resilient Modulus Test

The stiffness of the asphalt mixture was assessed by the indirect tensile repeated load test utilizing a Universal Testing Machine (UTM), as seen in Fig. 2. Two distinct temperatures, 25 °C and 40 °C, were employed. The samples were maintained at the designated temperature for a minimum of 24 hours before testing. The load was applied for 0.1 seconds at a temperature of 25 °C. The maximum loading force is 900 N, and the Poisson's ratio is assumed to be 0.35. The load applied at a temperature of 45°C, with a loading duration of 0.1 seconds, was supposed to be 900N, and the Poisson's ratio was set at 0.5. Three samples of Hot Mix Asphalt and modified asphalt were prepared and evaluated at pulse repetition intervals of 1000 ms, 2000 ms, and 3000 ms, respectively.



Fig. 2 Indirect tensile repeated load test apparatus (UTM-5P)

2.3 Moisture Susceptibility Test

The moisture susceptibility test assesses the HMA mixture's resilience against moisture-induced damage. The test involves compacting samples to attain an air void percentage of six to eight percent. Three samples are selected as a control group and tested without moisture conditioning for the test. Furthermore, another set of three samples is chosen for conditioning, which involves saturating them with water, exposing them to a freeze cycle, and subsequently immersing them in warm water. The conditioned samples are subsequently exposed to a constant load at a controlled rate to assess the force necessary for their failure, so measuring their indirect tensile strength. The tensile strength of the conditioned samples is compared with that of the control samples to get the tensile strength ratio (TSR). This test can also be conducted on cores obtained from the finished pavement.

Following the removal of the samples from the moulds, they were maintained at ambient temperature for a duration of 24 hours. After determining the air void percentage of 7%, the samples were divided into two subgroups, each containing a minimum of three samples to calculate the average value. Under dry conditions, the sample was wrapped in a leak-proof plastic bag and subsequently immersed in a 25°C water bath for 2 hours. The saturated wet samples were positioned in a vacuum container elevated at least 25mm above the bottom of the container. The container was subsequently filled with potable water at ambient temperature. A vacuum of 13-67 kPa absolute pressure was maintained for roughly 5-10 minutes. The vacuum was eliminated, and the sample was immersed in water for 5 to 10 minutes. The mass of the saturated, surface-dry specimen post-vacuum saturation was ascertained. The samples were then immersed in a water bath for 24 hours at a temperature of 60°C. The samples were subsequently extracted and immersed in water at ambient temperature for two hours. The samples were subsequently subjected to an Indirect Tensile Strength test (ITS). The specimen was extracted from the bath, its thickness was measured, and thereafter positioned on its side between the bearing plates of the testing apparatus. The highest load was documented, and the load was maintained until the sample fractured. A tensile strength ratio (TSR) will be employed to assess the moisture sensitivity of the sample. The TSR will be defined as the ratio of the average split tensile strength of the unconditioned sample to that of the conditioned sample. The tensile strength ratio will be determined using the subsequent Equation (1):

$$TSR = \frac{S2}{S1} \quad (1)$$

where:

TSR = tensile strength ratio

S1 = average tensile strength of the dry specimen, kPa (unconditioned)

S2 = average tensile strength of the conditioned specimen (wet, freeze-thaw), kPa (conditioned)

The tensile strength of each of the samples will be calculated using the following Eq. (2):

(2)

$$St = \frac{2000P}{\pi tD}$$

where:

St = tensile strength, kPa

2.4 Dynamic Creep Test

The evaluation of permanent deformation in the asphalt mixture was conducted using the dynamic creep test utilizing a Universal Testing Machine (UTM), as seen in Fig. 3. The test was performed in accordance with BS EN 12697-25. The testing was conducted on a standard Marshall sample of 63.5 millimeters in height and 101.5 millimeters in diameter. The dynamic creep test started after maintaining the sample at 40°C for two hours in a universal testing machine (UTM) to ensure the attainment of equilibrium temperature. The sample was thereafter placed between the platens. The completed platens containing samples were aligned to be concentric with the loading axis of the testing equipment. The Linear Variable Displacement Transducers (LVDTs) were employed by affixing them to the platens to quantify the resultant deformation.



Fig. 3 Dynamic creep test setup

The sample was preloaded for a few minutes to ensure connectivity between the samples and the applied stress prior to the commencement of the test. The loading parameters in this test included a haversine wave with a stress level of 300 kPa and a temperature of 40°C. The sample was terminated following 3600 load cycles. The results were obtained in both graphical and numerical forms from the computer connected to the APA via an automated data collection system. The sample's performance was characterized by its Creep Stiffness Modulus (CSM) and Creep Strain Slope (CSS). Consequently, the Creep Stiffness Modulus (CSM) and Creep Strain Slope (CSS) were obtained from this test utilizing Equations (3) and (4) below:

$$CSM = \frac{\sigma}{(\varepsilon_{3600} - \varepsilon_{2000})} \quad (3)$$

$$CSS = \frac{(\log \varepsilon_{3600} - \log \varepsilon_{2000})}{(\log 3600 - \log 2000)} \quad (4)$$

where:

σ = Applied stress (kPa)

ε_{3600} = Accumulated strain at 3600 cycles

ε_{2000} = Accumulated strain at 2000 cycles

3. Results

3.1 Volumetric Analysis and Optimum Bitumen Content

Marshall Mix Design was used in this study to identify the optimum bitumen content for the mix design. The samples were produced in accordance with the JKR Standard Specification, with a bitumen content range of 4% to 6% for AC14 samples. The parameters from the data of Marshall Mix Design was used to plot the graph of specific gravity, air voids, VFB, flow and stability. From this analysis, the graph that stated above were plotted and the Average OBC could be gained as Table 3:

- Bulk Specific Gravity vs. Bitumen Content
- Air Void (%) vs. Bitumen Content
- VFB vs. Bitumen Content
- Stability vs. Bitumen Content
- Flow vs. Bitumen Content

Table 3 OBC for control Sample and RCA modified mixture

Property	Control Sample	Modified Bitumen
Bulk Specific Gravity	5.50	4.75
VTM	5.30	5.25
VFB	5.30	5.56
Stability	4.90	4.80
Flow	4.50	5.75
Average OBC	5.10	5.22

The control sample had 5.1% OBC value while the modified bitumen had 5.22% of OBC value. Both results were determined in accordance to the JKR Standard Specification. According to the results of the average OBC for both samples, the modified bitumen has slightly higher OBC value than the control sample.

From the results, it could be seen that the samples achieved the required properties as specified in the JKR Specification for Road Works. All of the properties both control and modified sample has satisfied the JKR specification. Both samples can be used for pavement because it has passed all the requirements of the JKR specifications.

3.2 Resilient Modulus Test

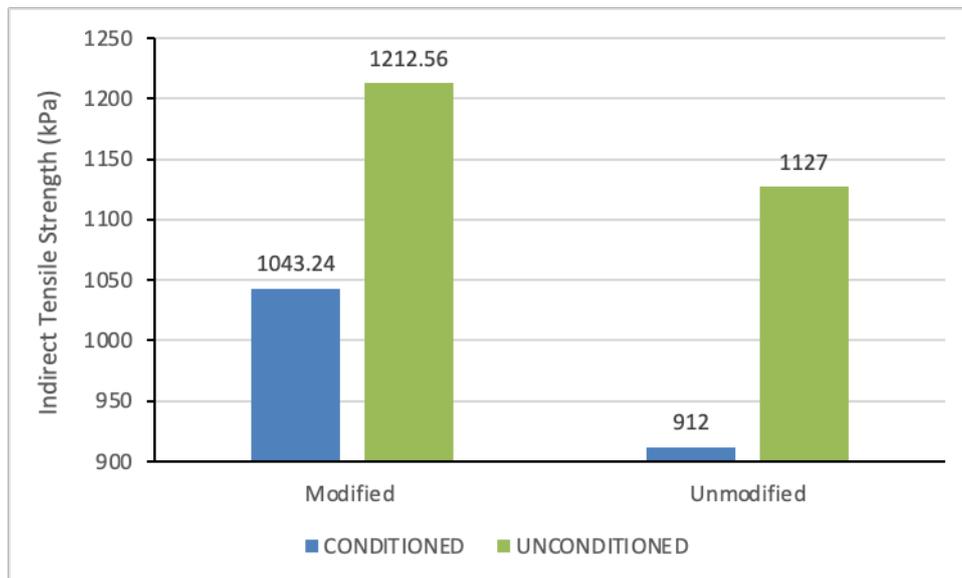
Table 4 shows the resilient modulus results for both the control and modified bitumen with RCA. The resilient modulus results for all mixes at temperature of 25°C is higher than the results at temperature of 40°C. For each temperature (25°C and 40°C) and loading pulse (1000ms, 2000ms, and 3000ms), the values of the resilient modulus control sample are higher than those of the modified sample. It can be interpreted from the data that the combination of latex bitumen and RCA does not produce mixtures that are stiffer than the control mixtures. Therefore, in terms of resilient modulus, the modified bitumen sample with RCA has lower stiffness than the control sample. It is likely that the RCA aggregates with existing cement on the aggregates has lower interlocking among the aggregate particles hence, lowering the stiffness of the samples.

Table 4 Resilient modulus test results

RESILIENT MODULUS	Control Sample			Modified sample (with RCA)		
	1000	2000	3000	1000	2000	3000
Pulse Repetition Period (ms)	1000	2000	3000	1000	2000	3000
Average 25°C	4867	4861	4651	2675	2380	2221
Average 40°C	1119	1032	948	953	777	656

3.3 Moisture Susceptibility Test

From Fig. 4, for conditioned samples, the NRL modified mix with 50% RCA exhibits a slightly lower ITS value (1043.24 kPa) compared to the controlled sample (912.00 kPa). Likewise, for unconditioned samples, the modified bitumen with 50% RCA samples demonstrates a slightly lower ITS value of 1212.56 kPa in contrast to the control mixes' value of 1127.00 kPa. However, when considering moisture susceptibility of asphalt mixtures, the ratio of wet to dry sample ITS values is more significant than the individual dry or wet ITS values. Fig. 5 shows the TSR values for both mixes; the TSR value for NRL modified bitumen mix with 50% RCA is higher (86.04%) compared to the mix with conventional bitumen (81.00%). A higher TSR (Tensile Strength Ratio) value suggests that the mixture is likely to exhibit improved resistance against moisture-induced damage.

**Fig. 4** Indirect tensile strength test result

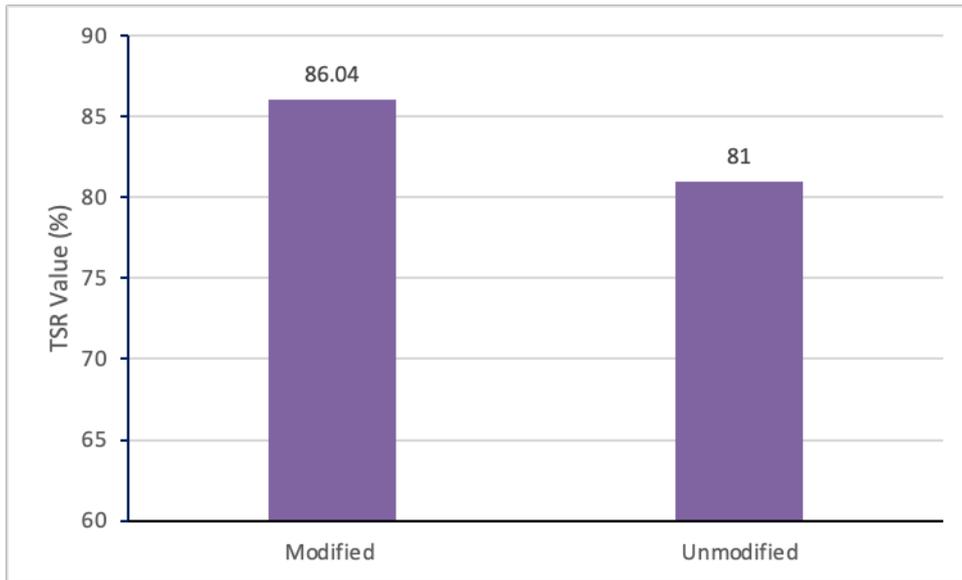


Fig. 5 Tensile strength ratio result

3.4 Dynamic Creep Test

Fig. 6 shows the cumulative strain versus load cycle, which is represented by all of the sample creep curves. Each creep curve was plotted using the average results of the three samples. As the load cycle lengthens, the cumulative strain increases as expected. As shown in Fig. 2, the findings demonstrate that each dynamic creep curve has two stages, the primary and secondary stages, at test temperatures of 40°C and stress levels of 100 kPa. Meanwhile, neither the changed nor the control sample combinations reached the tertiary stage of the specimen under this test setting.

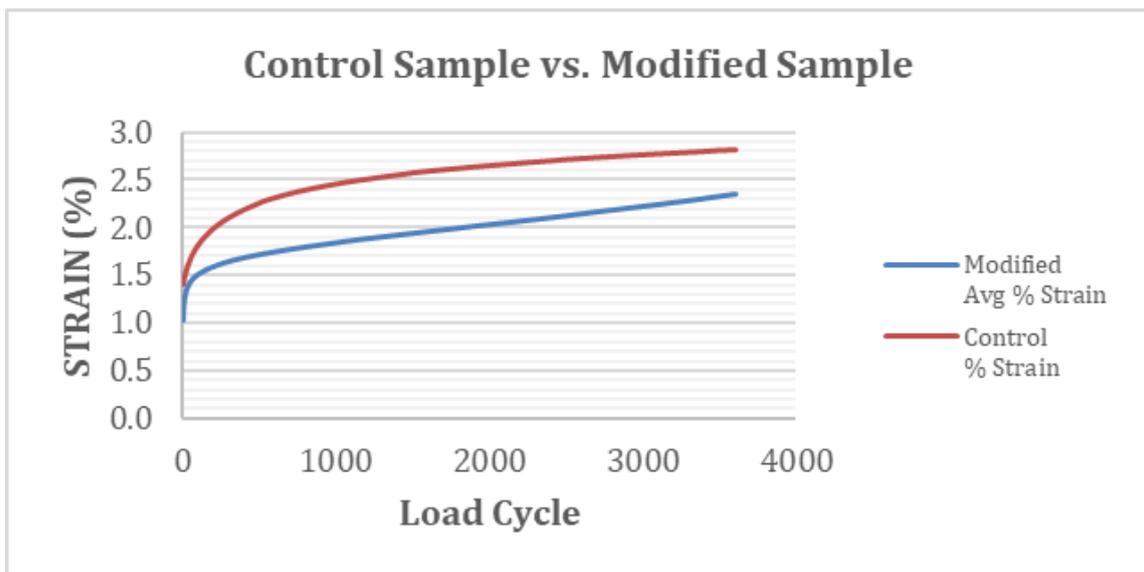


Fig. 6 Dynamic creep test result

Fig. 6 clearly shows that the samples treated with Latex Modified Bitumen had less accumulated strain than the control sample. Lower cumulative strain indicates greater resistance to permanent deformation. This is due to the high viscosity properties of Latex Modified Bitumen, which promote bonding in asphalt mixes and thereby reduce deformation of the asphalt mix. It can be concluded that the lower the strain, lower the rutting potential of the sample.

The link between Creep Stiffness Modulus (CSM) and Creep Strain Slope (CSS) was used to assess the permanent deformation resistance of asphalt mixes. Fig. 7 shows that asphalt mixes with Latex Modified Bitumen had higher CSM (108 MPa) compared to the control sample (101 MPa). The results showed that using Latex

Modified Bitumen instead of the conventional mixture increased the stiffness modulus by 6.93%. As a result, the greater the CSM, the lower the CSS. Table 5 shows that the modified sample had the lower CSS value of 0.101 compared to the control sample with a CSS value of 0.111. The material with the higher resistance to permanent deformation has the lowest CSS but the highest CSM. The addition of Latex Modified Bitumen to the asphalt mixture produced a better chemical bond, increase binder's adhesion strength to the aggregate and strengthen the resistance to permanent deformation.

Table 5 Creep stiffness modulus and creep strain slope of control and modified samples

Parameters	Sample		Limit	Status
	Control	Modified		
Creep Stiffness Modulus (CSM), MPa	101	108	> 75 MPa	Pass
Creep Strain Slope, (CSS)	0.111	0.101	< 0.25	Pass

Referring to Table 5, the results of the dynamic creep test for CSM and CSS complied with the JKR Specification. The CSM value is significant because it reflects the sample stiffness, whereas CSS is an extra permanent deformation parameter that characterizes the pace of deformation development. As a result, cumulative strain, CSM, and CSS are recognized as important parameters for measuring mixtures' permanent deformation resistance. These results suggest that using Latex Modified Bitumen improves specimen behaviour by extending their life when subjected to repeated creep tests. This is a critical stage in the development of high-performance bituminous paving materials.

4. Conclusions

The findings of this study lead to the conclusion that the application of natural rubber modified bitumen and recycled construction aggregate (RCA) in mix designs, as determined by the Marshall method, is feasible. This conclusion is supported by the fact that the volumetric parameters of the modified sample meet all the requirements specified in the JKR Malaysia Road Standard Specification. This study highlights the potential of natural rubber latex modified bitumen and recycled construction aggregate as viable alternatives for enhancing the performance and sustainability of asphaltic concrete mixtures. It is also recommended that further study for other percentages of RCA and field performance on deformation and crack development be carried out in the future to evaluate the viability of these mixes.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Ahmad Kamil Arshad, Ekarizan Shaffie; **data collection:** Mohd Izzat Asyraf Mohamad Kamal, Wardati Hashim; **analysis and interpretation of results:** Ekarizan Shaffie, Noor Azreena Kamaluddin; **draft manuscript preparation:** Ahmad Kamil Arshad, Mohd Izzat Asyraf Mohamad Kamal. All authors reviewed the results and approved the final version of the manuscript.

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