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Pavement Performance with Carbon Black and Natural Rubber (Latex)

Saad Abdulqader Ali, Ismail bin Yusof, Madi Hermadi, Marwan B.S. Alfergani, Abdalla Ab Sinusi

Abstract -Many studies have been done to find other alternative material to use as modifiers in asphalt mixes on the improvement of its properties and highway quality. In this research Carbon Black and Natural Rubber (Latex) have been used as bitumen modifiers, bitumen is sensitive to rate of traffic load and temperature susceptibility. Therefore, bitumen modification has become the main factor to improve the hot mix asphalt properties and permanent deformation (Rutting).The use of carbon black and natural rubber in this project was identified to have the potential of becoming a modifier in HMA mixes due to the elastic behavior and in reducing the rutting potential. This study presents the viability of carbon black and natural rubber as an additive in bitumen as binder and hot mix asphalt concrete with different ratios of 10,15,20% CB and 1,3,5% NR blended separately and with each other. The behaviors of the two modifiers were investigated by comprehensive laboratory testing and evaluation. The DSR was used to determine the rheology of the modifiers with bitumen and Superpave mix design method was used to determine the optimum bitumen content and one aggregate gradation was considered under this investigation. The performance of carbon black and natural rubber mixtures at 40° C was determined by the dynamic creep test and indirect tensile test. It was observed that the addition of carbon black and natural rubber gave better overall performance in the bituminous mixes. The stiffness modulus decreases as the addition of carbon black and natural rubber increase. However, the performance of 10% CB gave better stiffness modulus whereas, the stiffness is higher. The creep values are also the lowest with 10% CB. Thus, this shows carbon black and natural rubber may contribute toward better flexible roads in the future.

Keywords - Carbon Black, Natural Rubber (Latex), Polymers, Modified Bitumen.

I. INTRODUCTION

The concept of using carbon black as a reinforcing agent for asphalt was first introduced by ALLIOTTI (1962) [1], who described the characteristic of carbon black and identified its potential advantages as an asphalt additive [2]. The use of Carbon Black (CB) as a reinforcing agent for hot mixed asphalt may produce a similar benefit [7]. It has been reported that CB is also used to reinforce asphalt cement pavements (Rostler et al., 1977). Yao, Monismith (1986), Vallerga and Gridley (1980) reported that the use of CB increased the rutting resistance at high temperature and the durability of asphalt [3], [4]. They found that the temperature susceptibility and the cracking propagation potential of asphalt at low temperature decreased. In spite of its effectiveness as a modifier, however, the use of CB has been somewhat limited due to its relatively high material cost [14]. Natural rubber type of main polymers is used to modify bitumen properties in some way to effect a perceived improvement in asphalt performance [8], [12]. Improvements in the mechanical or structural properties of asphalt can often result in reduced stiffness, though some improvement in deformation resistance and cohesive strength can be obtained and used to reduce rutting i.e., permanent deformation, Improve asphalt cohesive strength and Reduce risk of low-temperature thermal cracking by reducing the temperature susceptibility of the bitumen [16],[17].
The application of natural rubber by mixing with asphalt materials in roadwork could improve the quality of road pavement, extend service life of the road, and reduce expenditures in maintaining road pavement [21].

II. PROBLEM STATEMENT

In Malaysia, rutting is the dominant deterioration problem because of its hot climate. The average temperature in Malaysia is around 27°C. Therefore, the existing pavement should be improved to increase rutting resistance. In order to obtain the better pavement, the bitumen properties as one of the important component in the mixture itself must be enhanced. (CB, NR) has been found to improve the performance of asphalt. The research is to be carried out to determine the mechanical properties of the paving mixture that include permanent deformation of the paving mix.

III. OBJECTIVE OF RESEARCH

This research aims to:
1) To investigate the viability of using carbon black and latex as additives in flexible pavement;
2) To determine the performance characteristics of asphalt mixture such as (Indirect Tensile Test-Rutting); and
3) Produce combination of aggregate into asphalt mixture which will result in the better performance of flexible pavement.

IV. SCOPE OF RESEARCH

The scope of the study focuses on obtaining a mixture that contains a good proportion of the mixture by laboratory test, including (Super-pave Mix Design to obtain the optimum binder content of bitumen), (DSR) to determine the rheological characteristic between (bitumen + NR), (bitumen + CB) and (bitumen + CB + NR), the important thing needed to know the performance test between the materials and investigations to ensure the mixture to get a good mix which has a high quality [18].

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***** Correspondence Author (s)
Saad Abdulqader Ali, Civil Engineering, University Tun Hussein Onn, Batu Pahat, Malaysia.
Ismail bin Yusof, Civil Engineering, University Tun Hussein Onn, Batu Pahat, Malaysia.
Madi Hermadi , Civil Engineering, University Tun Hussein Onn, Batu Pahat, Malaysia.
Marwan B.S. Alfergani, Civil Engineering, University Tun Hussein Onn, Batu Pahat, Malaysia.
Abdualla Ab Sinusi Saiah, Technology Management, University Tun Hussein Onn Malaysia, Batu Pahat, Malaysia.

V. SIGNIFICANCE OF THE RESEARCH

The properties of bitumen are important to ensure satisfactory long term performance, stability and elasticity when designing asphalt layer. Since bitumen is a viscoelastic material, its properties are very sensitive to temperature as well as to the rate of loading. With respect to temperature, the most frequent problems of road pavement are rutting, fatigue cracking and thermal cracking. Besides, bitumen viscosity is a function of its temperature. The study is aimed to increase the durability and rheological properties while increasing the resistance of rutting cracking by the modification of those materials and to ensure the performance of asphalt concrete and this research will reduce the cost of the mixture and get a high quality pavement (road) and reduce the cost of maintenance.

The identification of chemical and physical properties of bitumen after modification is important to determine the changes caused by (CB, NR) on the hot mix asphalt (HMA) performance. It is essential to ensure that (CB, NR) do not much affect the bitumen bind mechanisms with the aggregate particles [19].

VI. LITERATURE REVIEW

A. Introduction

The first use of asphalt pavement was in the nineteenth century, different types of modifiers have been used in an attempt to reduce specific undesirable characteristics of the asphalt paving mixture or to improve the overall performance of the pavement. This study will focus on two types of modifiers and know the behavior of their performance in the mixture.

1) Filler (CB):
   i. Fill voids and therefore reduce optimum asphalt content;
   ii. Meet aggregate gradation specifications;
   iii. Increase stability; and
   iv. Improve the asphalt cement-aggregate bond.
2) Polymer (NR):
   i. Increase HMA stiffness at high service temperatures;
   ii. Increase HMA elasticity at medium service Temperatures to resist fatigue
   iii. Cracking; and
   iv. Decrease HMA stiffness at low temperatures to resist thermal cracking

B. Material characteristic

Bitumen is a viscoelastic material with suitable mechanical/rheological properties for traditional paving and roofing applications because of its good adhesion properties to aggregates[20], [22].

Important properties of bitumen are as follows:

(i) Viscosity
(ii) Cohesion
(iii) Adhesion
(iv) Temperature susceptibility
(v) Stiffness

C. Natural rubber (Latex)

Natural rubber is sensitive to decomposition and oxygen absorption. It has a molecular weight that is too high to be directly dissolved in the bitumen, and must be partially decomposed and mechanically homogenized [23], [24]. Natural rubber in this research is used to:

(i) Reducing rutting i.e., permanent deformation.
(ii) Improve asphalt cohesive strength.
(iii) Reduce risk of low-temperature thermal cracking by reducing the temperature susceptibility of the bitumen [13], [16].

D. Carbon Black

Carbon Black is defined as an industrial raw material consisting of 95 percent or more of amorphous carbon, and its size is in the order of nanometers, produced under a well-controlled manufacturing process. The use of carbon black is intended to improve rutting resistance, reduce temperature susceptibility, and decrease low temperature cracking [5].

VII. RESEARCH METHODOLOGY

A. Introduction

The laboratory works can be divided into two stages with bitumen of 80-100 PEN are used in this study.

(i) Sample preparation (for 1st stage):

For stage one, Normal bitumen 80-100 PEN will be prepared at 160^{0}C meanwhile Carbon Black (CB) and 100^{0}C meanwhile Natural Rubber (NR) added to modified bitumen. (CB) was crushed to fine powder to be easier to mix with bitumen separately and with (NR) and bitumen together. The blending of modifiers and bitumen using manual mixer takes about 25 minutes to mix with CB, 30 minutes to mix with NR.

The numbers of sample required are:

1) 1 sample of normal bitumen (DSR test);
2) 3 samples of normal bitumen and 3 samples for each percentage of CB by weight of bitumen for modified bitumen (DSR test);
3) 3 samples of normal bitumen and 3 samples for each percentage of NR by weight of bitumen for modified bitumen (DSR test); and
4) 9 samples of normal bitumen and 3 samples for each percentage of CB and NR by weight of bitumen for modified bitumen (DSR test).

a. Binder selection and acquisition

The selection of binders was according to the Super-pave binder specification (ASTM D6373,) requirement of several tests, in this specification. The binders are selected on the basis of the climate and traffic in which they are intended to serve. The location of the road selected for this study is Malaysia. Therefore, the DSR test was selected to use in the performance grade method to characterize and to determine the Rheological properties of the asphalt binder. The asphalt binders are tested in conditions that simulate its critical stages during the service, such as:

1) During transportation, handing, and storage-original binder is tested.
2) During mix production and construction-simulated by short-term aging of the original binder, a rolling thin film oven (RTFO).
3) After 5 to 10 years of service - simulated by long term aging the binder in the rolling thin film oven test plus the pressure aging vessel (PAV).

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4) In the PAV, the RTFO residue is exposed to high air pressure and temperature for 20 hours to simulate the effect of long-term pavement aging.

(ii) Sample preparation (for 2nd stage):

For stage two, Normal bitumen 80-100 PEN will be prepared to use with the different percentage but the temperature will be different to the mixture between the CB, NR, and bitumen and aggregate. The next steps show the Superpave mix design process.
The numbers of samples required are:

1) 2 samples for each percentage of bitumen content by weight of mixture for normal bitumen (Superpave Mix Design);
2) 2 samples for each percentage of bitumen content by weight of mixture for modified bitumen (Superpave Mix Design):
3) 2 samples for optimum normal bitumen content by weight of mixture (Rutting test), which involves sampling of the research population and the collection of data based on the questionnaire's survey.

a. Aggregate gradations:

The percentages of aggregate required for every sieve size were determined according to Superpave (SP-2/1996). Then the mass retained were calculated using the percent passing for every sample size. Table below summaries the percentage passing for the aggregate.

Sieve Size (mm)	%Passing By weight
19	99.31
12.5	93.53
9.5	88.61
4.75	59.2
2.36	46.63
1.18	32.78
0.600	23.3
0.300	13.82
0.075	4.99

b. Super-pave mixture design:

Many organizations have published Superpave mix design procedures. The publications are the Asphalt institute's Super-pave Mix Design, SP-2, second edition, the AASHTO test procedure, TP4, Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt by means of the SHRP Gyration Compactor, and AASHTO PP2, short-and long-term aging of bituminous mixes. For the purpose of this study, the AAHSTO TP4 procedure was adopted.
A total of 90 specimens were prepared for compaction levels of (262 gyrations) and 18 specimens for compaction levels of (158 gyrations), fifteen mix type of (Bitumen, Natural Rubber and Carbon Black), two binder content for each type of mix with two specimens for each binder content, and one loose specimen for each mix prepared to determine the theoretical maximum density.

A. Determination of optimum bitumen content (OBC)

The optimum bitumen content is the amount that provides the desired air voids of 4% in the mix, according to Superpave second edition (SP-2). Table below shows the specification of bitumen content. Below are the procedures to obtain optimum bitumen content:

Optimum Bitumen Content	specifications		
	Nini	Ndes	Nmax
	>11	= 4	>2

D. Performance test

After having determined the OBC, two types of test were conducted in UTM to investigate the performance of the mixture after paving. Before conducting the tests, the 18 specimens with different percentages of OBC were prepared and each specimen's skin should be heated up to 40°C inside UTM and the tests were:

A. Indirect tensile test (IDT)

This test was conducted to evaluate the mixture stiffness test conforming to the AS 2891.13.1–1995, DD213: 1996, ASTM D4123–82 and AASHTO TP31-94. Calculation of the stress controlled was with British DD 213.

B. Dynamic creep test

Creep is defined as the continuous time dependent deformation under constant stress or load. Creep test data characterizes the permanent deformation properties of asphalt mixtures. Creep compliance and mix stiffness are good parameters for relative mix stability and the expected rut depth or permanent deformation.
Test was carried out on universal test machine (UTM), with feedback control hydraulic tester and in a temperature controlled environmental chamber. By loading and measuring, device data were collected and analyzed by automated testing system.

IX. DATA ANALYSIS AND DISCUSSION

a. Data Collection

All of these experimental works have been carried out in University Tun Hussein Onn Malaysia and University Technology Malaysia transportation and highway laboratories..

b. Results and discussion

A. Introduction

The aim of this study was to investigate the viability of using CB and NR as modifiers to the binder and mixture. The laboratory tests were done and analysed to compare between the percentages of the modifiers and which percentage will give the better performance pavement.

B. Performance grade binder selection (PG)

Performance grade was selected based on the climate (temperature) and traffic load condition. The DSR was used to characterize the viscous and elastic behavior and the three tests were carried out in order to obtain the max of PG with deferent percentage of modifiers.

(i) Original binder test

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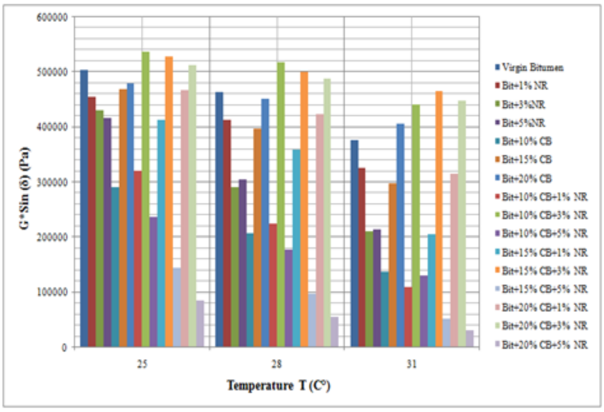
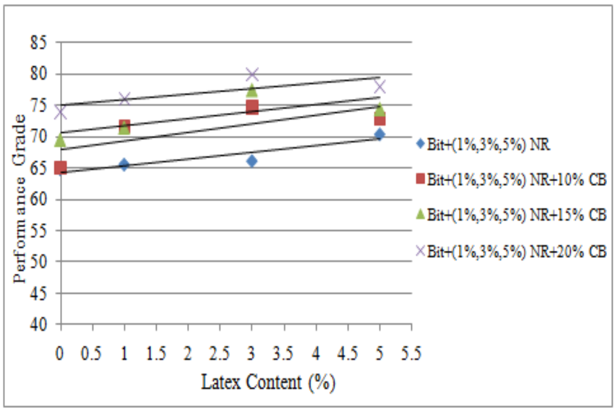


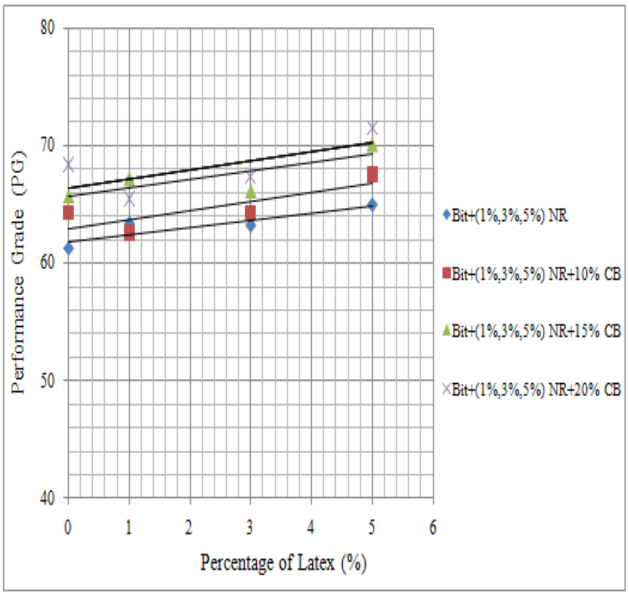


The next figure illustrates the results of the tests after DSR of the specimens and the graph shows the comparison between the percentage of the modifiers (CB, NR). The PG index significantly increases with the increasing CB and NR content.

The PG values increase as the content of Carbon Black with Latex increases. The bitumen becomes harder and viscous.

This would be useful to obtain stiffer asphaltic concrete and will also increase the internal strength of bitumen. According to the physical properties of CB and Latex, it is expected that the CB and Latex will harden the bitumen.

(ii) Rolling thin film oven



RTFO test was carried out at a temperature of 163˚C for 85 minutes, during the second stage of the binder residue mix and to prepare the aged binder materials and was represented short-term aging of the binder.

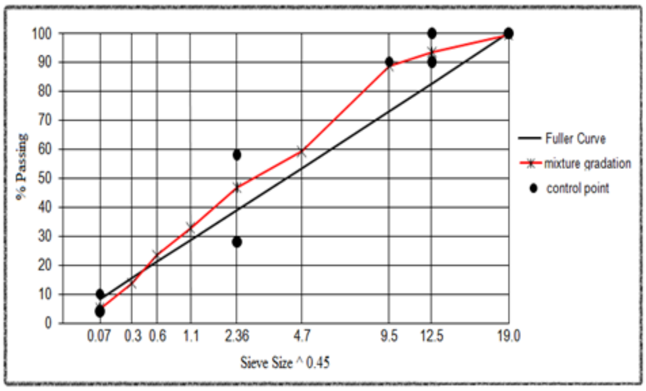
The figure shows the short-term aging value with various CB and Latex. There was a proportional increase in PG with the increase in Carbon Black and Latex, but it decreased compared to the original binder test. This decrease was due to the increase of temperature which represented for four years in life service.

(iii) Pressure aging vessel

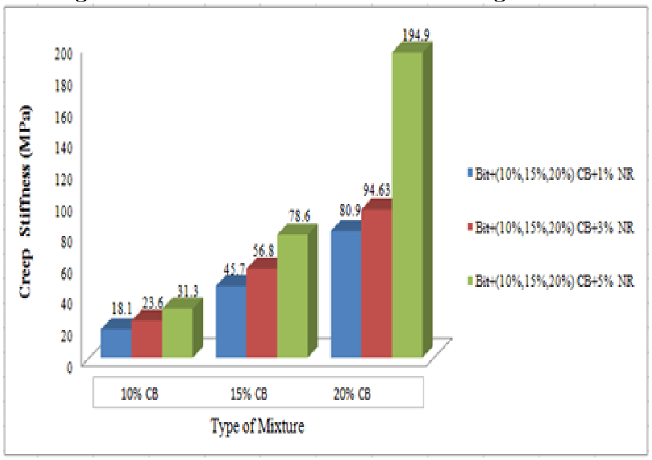
PAV test was carried out during the third stage of the binder residue from RTFO test. The samples were exposed to high air pressure within temperature for 20 hours to simulate the effect of long term pavement aging, this test was represented after 5 to 10 years of service. The next Figure shows the graph of G*sin (δ) value against temperature.

The figure shows that an increase in CB will increase G*sin (δ), it means decreasing the crack resistance because it will make the bitumen more stiff and brittle, increase NR will decrease G*sin (δ) it means, will increase the crack resistance because NR has a good elastic recovery. 10, 15, 20% CB with 3% NR has a higher stiffness, it means that it will not resist the crack but, as shown in the figure when increasing the NR to 5% the G*sin (δ) became lowest and this is a better resistance to the crack.

C. Aggregate gradation



In Superpave specification there is an area called restricted zone between sieve number 2.36mm and 0.300mm. The main use of Carbon Black in this study was included as filler, which will increase the percentage of passing to avoid the crossing with that zone as shown in the next figure.



D. Performance test

Performance tests were used to relate laboratory Superpave mix design to the actual field performance. The next two tests were intended to evaluate the percentage that is consistent with 40C° temperature which gives a better and more fundamental performance.

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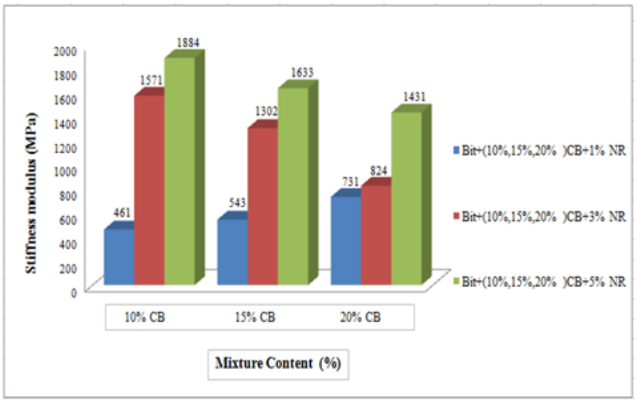
(i) Indirect tensile test (IDT)



The indirect tensile test in this study was used to measure the stiffness modulus and will represent the first of the two tests that were presented according to British DD 213: 1993 method to evaluate the sensitivity of mixture obtained to the damage caused by temperature. The summary of the IDT (stiffness modulus) values with different percentages of mixture are shown in the next figure.

The Figure shows that the increase in CB has different effects on the design mixes. When the NR content was increased to 3% and 5%, the design mixes seem to lose its elasticity as shown in the above figure. The lost in stiffness may be due to the effect of temperature on CB. NR when exposed to high temperature will loose its elasticity and become brittle when it is cold after heating. Thus, the stiffness modulus is higher compared to low values of NR. CB when heated will be more elastic as compared to its original properties. This is clearly demonstrated in the middle and right columns. Even though with high NR values of 3% and 5%, it still manages to sustain and have an effect on the design mix elasticity, and the figure also demonstrates that with an NR of 1% the stiffness modulus seems to increase proportionally but with less values than when NR are set at 3% and 5%. This effect shows that the design mixes are more elastic and prone to temperature changes whereas for design mixes with NR of 3% and 5%, they are stiffer and may perform better at high loading temperatures.

(ii) Dynamic creep test

The dynamic creep occurs under fluctuating load or temperature and that could cause permanent deformation. This test according to British DD 213: 1993 method was carried out to obtain the creep stiffness values with a constant 40°C temperature. The next figure shows the creep stiffness results test.

From the tests conducted, a graph was produced as shown in Figure above, with the increase of CB, the design mixes seem to demonstrate an increase in creep stiffness values. However, when the NR percentages were increased, the creep stiffness increases were more pertinent especially when 20% of CB was mixed with 5% of NR. This indicates that higher CB and NR mixes were able to sustain a higher loading. This behavior is advantage for road design mixes especially for hot weather conditions but, it may have some disadvantages such as:

(i) It will lose its elasticity/flexibility faster than the original mixes.
(ii) The design mixes will be more brittle and prone to cracking and deformation.

The value of 194.9 MPa, the design mix of 20% CB and 5% of NR indicates that the creep stiffness can increase temporary with an increase in NR. As explained earlier, the NR has a direct impact on elasticity and stiff values due to its properties whereas, when heated it will become hardened and brittle, Even though the design mix may sustain higher loads and produce high creep stiffness values, but the mix will not have a long serviceability as a flexible road pavement.

X. CONCLUSION AND RECOMMENDATION

A. Introduction

The aim of this study was to compare the performance pavement with various percentages of carbon black and natural rubber as modifiers by Superpave mix design method to evaluate the effects of using modifiers on improving the resistance permanent deformation (rutting). This chapter will include the conclusions and recommendations on the experimental works conducted in this study.

B. Conclusion

This study covered all the processes from primarily stages of design up to the analysis of the data obtained.

(i) The results of the laboratory and the predicated pavement performance have shown that the two modifiers used in this research can improve the mechanical properties of paving mixture in the reduction of distress factors and increasing expected pavement life.
(ii) It can be noted that the performance of hot mix asphalt (HMA) mixes was significantly affected with the increasing percentage of the addition of carbon black and natural rubber (latex).
(iii) Optimum bitumen content (OBC) values were obtained to increase as the percentage of carbon black and latex increased.
(iv) Following is a brief summary of the improved characteristics of mixtures with the addition of each of the modifiers:
    1) From the laboratory test results, it can be concluded that latex modified paving mixture has a moderate effect in improving paving mixture stiffness and reducing permanent deformation (rutting) and shows that latex modified binders improve the elasticity of the binders.
    2) The laboratory test results show that carbon black modified was the most promising in improving resistance to permanent deformation with high and low viscosity.

The results of laboratory tests and pavement prediction on carbon black and latex were promising and will form a basis for future utilization. Road experiments should, therefore, be carried out to establish that these improvements are reflected in better road performance under actual condition

C. Recommendation

Based on this study, many recommendations are drawn as follows:

(i) The mixture can be tested on different compaction temperature to identify the effect of compaction temperature. This must be based on viscosity and mixing temperature diagram.
(ii) The manual mixes better than mechanical mix to get high quality mixture.

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(iii) This project was used one type aggregate gradation and one source of asphalt. To obtain a more general conclusion, the laboratory investigation should be extended to include other aggregate types and gradations and different source of asphalt.

(iv) In this study the characterization of the paving mixture was limited to permanent deformation. Thus it is recommended that in order to assess the effect of the modifiers on different types, more Super-pave tests should be studied.

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Saad Abdulqader Ali, Master degree Ph.D Student in Civil Engineering. Faculty of Civil Engineering University Tun Hussein Onn Malaysia

Ismail Bin Yusof, Associate Professor Faculty of Civil Engineering University Tun Hussein Onn Malaysia.

Madi Hermadi, S.Si. MM. Ph.D. Highway material researcher in public Work Department. Faculty of Civil Engineering University Tun Hussein Onn Malaysia

M. B. S Alfergani, Master degree Ph.D Student in Civil Engineering. Faculty of Civil Engineering University Tun Hussein Onn Malaysia

Abdalla Ab Sinusi Saiah, Master degree PhD student in Technology Management Universiti Tun Hussein Onn Malaysia

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