VOL. 11, NO. 24, DECEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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www.arpnjournals.com

IDENTIFICATION OF THE RUTTING PERFORMANCE ON MODIFIED ASPHALT MIXTURES BY A LABORATORY INVESTIGATION APPROACH

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ABSTRACT

Asphalt concrete is used as the surface layer for roads and airport pavement.Road pavement has experienced a more rapid deterioration due to increasing traffic loads and changing environmental circumstances. Road damage often occurs due to heavy traffic loads that damage the rutting performance of asphalt mixtures. Some researchers have added additives to improve the performance of asphalt concrete. The utilization additives can improve the performance of asphalt mixtures with the aim to increase the strength of the road pavement structure.In this study, laboratory investigations studied Crumb Rubber Powder (CRP) and Buton Asphalt Natural Rubber (BNA-R) additives to asphalt mixtures. The laboratory analyses used a series of tests: Marshall Standard, Marshall immersion and Wheel Tracking Machine (WTM). Both material additives were added at 5%, 10%, 15%, 20%, or 25% to Asphalt Concrete Wearing Course (AC-WC) with bitumen pen 60/70.Both additive materials showed an increase in the value of the Marshall stability and Marshall immersion compared to the virgin asphalt mixture. However, this condition does not occur with the WTM test results; the addition of 10% CRP had the deepest rutting compared to asphalt mixture without additive. The addition of 10% BNA-R was better able to support the wheel load, resulting is decreased rut depth. The results indicated the ability to predict the asphalt mixture rut depth using WTM. The number of cycles of the WTM test determines the level of the accuracy of the prediction of asphalt mixtures resistance to the pressure of the wheels of the vehicle. The limited ability of WTM is often an obstacle, which can be overcome using an empirical model of the behavior of the rut depth, as presented in this paper.

Keywords: rutting, temperature, viscosity, asphalt concrete.

INTRODUCTION

One mode of damage to roads is rutting. This type of damage often occurs in areas of high temperature. In addition to high temperatures, there are several other factors that affect the rutting of asphalt roads, for example, overloading, low speed trucks, and the flatness of the road [1]. Rutting can cause premature damage to the pavement and require expensive repair costs. This type of road damage leads to reduced road user comfort and can even interfere with the safety of road users. Traffic loads and high temperatures can lead to a failure rutting. Research on improved additive materials for hot mix asphalt (HMA), the design of the mixing, the method of analysis, laboratory tests and field tests are necessary to obtain optimal pavement function [2]. Pavement performance optimization can reduce the cost of maintenance and repairs.

Pavement rutting characteristics are derived from the non-linear properties, viscous and plastic properties of the HMA. These properties result from the characteristics of the viscoelastic and viscoplastic asphalt and plastic properties of aggregates. Rutting can be described as a vertical elastic deformation [3]. The analysis of rutting behavior in a model of HMA is necessary to analyze the structure of the pavement and predict the response of pavement structure during use. Rut depth is very sensitive to heavy loads and loading time. On roads with a lengthwise slope, vehicle speed will decrease when the road is in the uphill position.

Rutting is a longitudinal deformation due to the accumulation repetition of traffic loads on the wheel track. Rutting is a major concern for pavement structure and traffic safety. Laboratories have developed prediction models and rut models based on field data collected from the condition of the pavement structure [4]. It is important to study the development of ruts due to actual vehicle load and environmental conditions to predict rutting using field data.

Efforts to make full use of each pavement material for an economical design of the pavement must have a sufficient balance of the occurrence of rutting and fatigue modes of distress [5]. The improved rutting and decreased fatigue life of flexible pavement may be due to a lack of implementation of flexible pavement analysis and a lack of attention to identifying the components of pavement with the aim of striking a balance. Proper design can provide a level of service of the pavement with adequate enough time until the occurrence of rutting and fatigue.

Plastic properties contribute to permanent deformation, which is a cumulative effect of repeated load. There are several factors that affect rutting: vehicle speed/time and the contact pressure are expressed in the model of the creep rate [6]. Meanwhile, the temperature and characteristics of the asphalt mixture, as well as the quality of construction, affect the rutting.

As a tropical country, Indonesia experiences variations in its temperature that can affect its asphalt concrete road surface conditions, especially during the increased temperatures of the dry season.

Rutting is caused by the accumulation of irreversible (or permanent) deformation in all pavement

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layers under the action of repeated traffic loading [7]. This condition can occur in some asphalt concrete pavements with high traffic volume, especially when the trajectory path is followed repeatedly by trucks.

This study shows that the performance of rutting due to wheel load of vehicles on hot asphalt mixtures using additive materials to obtain an increase in the strength of the pavement to traffic load is mainly a result of overload. The use of additive material is also intended to give the asphalt mixtures resistance to the effects of weather, especially temperature changes. A series of laboratory tests have been conducted separately to determine the characteristics of hot mix asphalt.

MATERIALS AND METHODES

Several types of hot mix asphalt wearing course of asphalt concrete (AC-WC) were used in this study with the addition of additives to the asphalt pen 60/70, with the characteristics shown in Table-1. Buton Asphalt Natural Rubber (BNA-R) and Crumb Rubber Powder (CRP) additives were added to the bitumen pen 60/70. Virgin asphalt mixed with the additive material had altered characteristics due to bitumen modification.

The asphalts with aggregate modification were used to determine the characteristics of rutting using the Wheel Tracking Test Machine (WTM) at a temperature of 40 °C. The characteristics of the bitumen modification were used to test the physical properties of the additive materials BNA-R or CRP to obtain the best percentage for addition to virgin asphalt.

Aggregate

The material aggregate consisted of course, medium and fine aggregate with the largest size of 19 mm and the composition shown in Figure-1. The physical characteristics of each type of aggregate can be observed in Table-2.

Buton natural asphalt-rubber (BNA-R).

BNA-R was produced from rock asphalt in Buton Island (Indonesia) called Asbuton. Rock asphalt is composed of bitumen and minerals and is used as an additive material. The rock asphalt is extracted to separate the minerals from the bitumen. The extracted bitumen is then mixed with the rubber. The rubber bitumen mixture is used as an additive material to improve the performance of virgin asphalt.

Crumb rubber powder (CRP)

The increasing number of vehicles has increased the number of waste tires of vehicles. The utilization of waste tires includes processing them into new materials, e.g., rubber powder. Scrap tire application to roads dates to the 1960s when Charles MacDonald used waste tires for maintenance work in urban areas. Tire rubber has advantages as an additive in asphalt cement for repairing potholes [9]. This material can be used for a variety of civil engineering projects: rubberized asphalt pavements, flooring for playgrounds and sports stadiums, as shock absorbing mats, paving blocks, and roofing materials. [10]

Table-1. Properties of base asphalt binder (Pen.60/70).

No	Laboratory test	Method	Unit	Indonesian asphalt 60/70
1	Penetration at 25 °C	ASTM-D5	0.1 mm	69.3
2	Softening point	ASTM-D-36	°C	50.4
3	Flash point (Cleveland)	ASTM-D92	°C	254
4	Ductility at 25 °C	ASTM-D113	cm	>100
5	Specific Gravity at 25 °C	ASTM-D-70	g/cm^3	1.023
6	Loss on heating (TFOT)		%	0.1
7	Penetration after TFOT	ASTM-D5	%	63.3
8	Penetration Index			-0.295

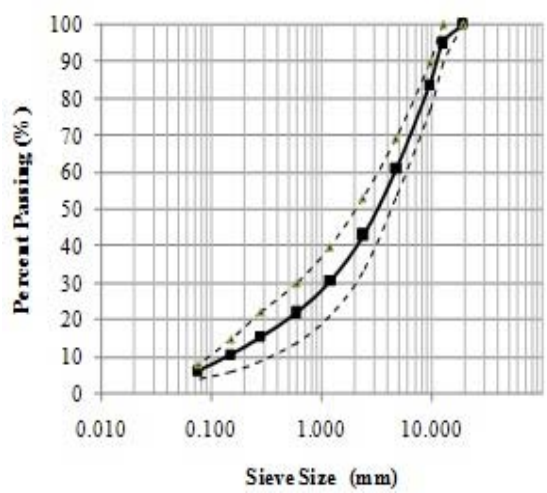

Figure-1. Aggregate gradation used for asphalt concrete mixes.

Bitumen blend

The mixing process between virgin asphalt and additive materials (BNA-R and CRP) must be performed in a specific way. BNA-R and CRP additive was added to the virgin asphalt at rates of 5%, 10%, 15% and 20%. The mixing was performed in the laboratory at a temperature of 177 °C for 30 minutes in an open blade mixer with a speed of 700 rpm [11].

The asphalt characteristics of the samples were investigated, and the results are shown in Table.3. The optimum bitumen content of this asphalt was determined by testing the rut depth using a Wheel Tracking Machine.

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Table-2. Coarse, medium and fine aggregate [8].

No.	Laboratory Test	Method	Results
	Coarse aggregate		
1	Bulk specific gravity (Gsb)	AASHTO T84/T85	2.505
2	Surface saturated dry gravity (SSD)	AASHTO T84/T85	2.605
3	Apparent specific gravity (SG)	AASHTO T84/T85	2.704
4	Absorption (%)	AASHTO T84/T85	2.78
5	Los Angeles abrasion (%)	AASHTO T96	18.94
6	Solubility (%)		98
7	Impact	SNI 03-4426-1997	5.22
8	Angularity		>95
9	Flat and elongated particles (%)	BS-812	10.8
	Medium aggregate		
1	Bulk specific gravity (Gsb)	AASHTO T84/T85	2.72
2	Surface saturated dry gravity (SSD)	AASHTO T84/T85	2.81
3	Apparent specific gravity (SG)	AASHTO T84/T85	2.91
4	Absorption (%)	AASHTO T84/T85	2.64
5	Sand equivalent (%)		28.84
6	Specific gravity	ASTM C-128	2.86
	Fine aggregate		
1	Passing no.200 (%)		15.2
2	Specific gravity	ASTM C-128	2.78

Experimental design and test procedures

All testing in this study was conducted using hot mix asphalt (HMA) of bitumen type Pen. 60/70 and aggregate gradation, as shown in Figure 1. The different forms of hot mix asphalt were analyzed by the Marshall standard, Marshall immersion, and wheel tracking machine. There are 2 types of samples in this experiment, the Marshall test and WTM test, and the density and content of the virgin bitumen and modified bitumen are the same, namely 5.7%. In the Marshall immersion test, the samples were stored for 24 hours at 60 °C in a water bath before being tested to determine the HMA resistance to the effects of water and temperature. The Marshall test was performed on a 101.6-mm diameter and 67.2 mm tall specimen with compaction 2 x 75 punches, whereas the WTM test was performed on 300 x 300 x 50 mm^3 specimen compacted to a density equal to the Marshall test sample using a standard test WTM compactor. WTM test use wheel load 4.4 kg / cm2 which is equivalent to the load of a load equivalent to a standard single-axle double wheel load weighing tons 8:16. The test object was traversed by 3,780 cycles for three hours at a speed of 21 cycles (42 tracks) per minute at 40 °C**.** Wheel tracking was used to assess the permanent deformation resistance of asphalt mixtures under conditions that simulated the effects of traffic. A loaded wheel tracks a specimen under specified loading conditions, speeds and temperatures, and the development of the rut profile is monitored and continuously measured during the test [4].

Table-3. Properties of base asphalt modified (CRP additive) [12].

No.	Laboratory test	Method	Unit	Percentage of CRP			
				5%	10%	15%	20%
1	Penetration at 25 °C	ASTM-D5	0.1 mm	66.1	63.7	61.7	59.2
2	Softening point	ASTM-D-36	°C	50.25	51.5	52	52.5
3	Flash point (Cleveland)	ASTM-D92	°C	256	282	246	246
4	Ductility at 25 °C	ASTM-D113	cm	74.4	54.5	49.6	42.3
5	Specific Gravity at 25 °C	ASTM-D-70	g/cm^3	1.033	1.04	1.046	1.052
6	Loss on heating (TFOT)		%	0.17	0.2	0.22	0.33
7	Viscosity at 135 °C 30 mnt	AASHTO T21-10	cP	525	750	875	1383
8	Penetration after TFOT	ASTM-D5	%	59.6	57.4	53.6	51.7
9	Penetration Index			-0.295	-0.239	-0.198	-0.183

Table-4. Properties of base asphalt modified (BNA-R additive) [12].

No.	Laboratory test	Method	Unit	Percentage of BNA-R			
				10%	15%	20%	25%
1	Penetration at 25 °C	ASTM-D5	0.1 mm	63.7	61.5	59.9	58.2
2	Softening point	ASTM-D-36	°C	52	52.75	53.1	53.5
3	Flash point (Cleveland)	ASTM-D92	°C	272	272	270	265
4	Ductility at 25 °C	ASTM-D113	cm	52.8	48.6	45.2	42.8
5	Specific Gravity at 25 °C	ASTM-D-70	g/cm^3	1.034	1.037	1.038	1.042
6	Loss on heating (TFOT)		%	0.24	0.37	0.62	0.65
7	Viscosity at 135 °C 30 mnt	AASHTO T21-10	cP	250	317	475	575
8	Penetration after TFOT	ASTM-D5	%	50.33	47.8	46.2	45.2
9	Penetration Index			-0.116	-0.025	-0.010	0.011

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RESULTS AND DISCUSSION

Marshall immersion

In the test results from the Marshall standard or immersion, there is a peak value for the variation of the bitumen modifications of 0%-20%. The additions of 10% CRP and 10% BNA-R resulted in the best Marshall Stability (MS) and Marshall Quotient (MQ). Figure 2 and Figure-3 show that the MS values for CRP additive were greater than for BNA-R. However, the residual value of each MS asphalt mixture with the additive material is in the range of 92%. There is an increase compared to virgin asphalt of 88%. These data show that the use of additive materials can improve the value of MS by 41% for CRP and 11% for BNA-R.

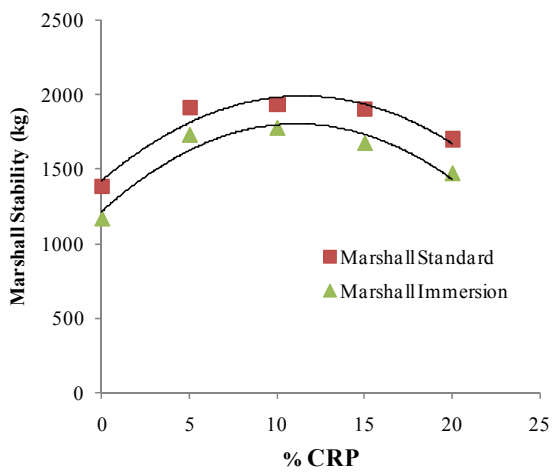

Figure-2. Influence of CRP additive on the Marshall stability.

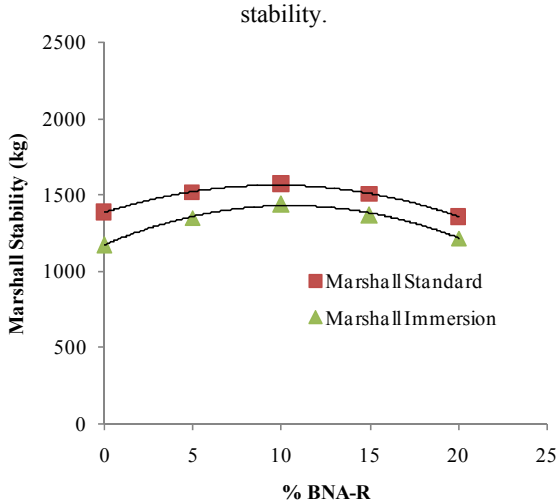

Figure- 3. Influence of BNA-R additive on the Marshall stability.

Rutting performance

Figure-4 and Figure-6 show that the rut depth at the beginning of the cycle increases rapidly [7,13], especially in the HMA with CRP. Increasing the amount of CRP in HMA does not decrease the depth of the groove wheel and rutting deformation. The addition of 20% CRP resulted in more visible grooved wheels than the addition of 10% and 15% CRP. The addition of BNA-R showed better results. The addition of 10% and 15% BNA-R resulted in smaller groove wheel depth; however, the addition of 25%BNA-R had the opposite result.

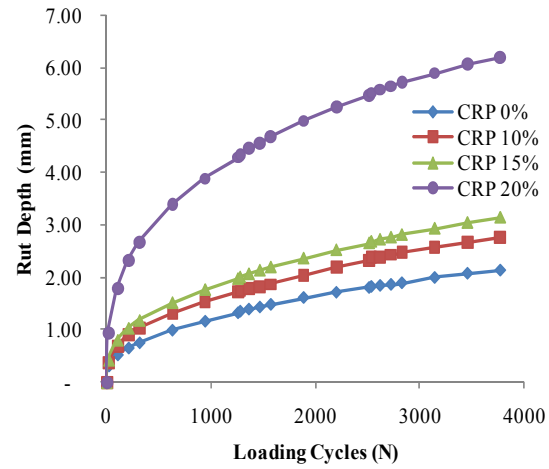

Figure-4. Rutting performance at 40 °C with CRP additive.

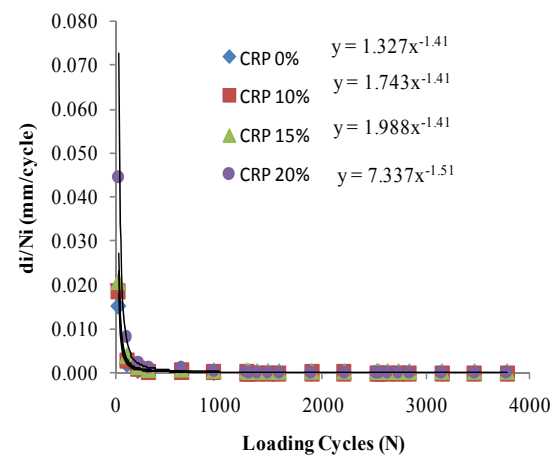

Figure- 5. Rate of deformation at 40 °C with CRP additive.

Figure-5 and Figure-7 illustrate the rate of deformation, which is the ratio between the rut depth (d_i) at cycle (N_i) to the number of loading i. At the beginning of the loading area, the value d_i/N_i is high, and the value decreases rapidly to near zero. Several studies [7,13] determined the relationship between the permanent strain and resilient strains using the following equation:

$$\varepsilon_{pn} = \mu \, . \varepsilon_r \, N^{-\alpha} \quad (1)$$

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where ε_{pn} is the permanent strain due to a single load application, i.e., at the N*th* application; ε_r is the resilient strain, generally assumed to be independent of the load repetition (N); and μ is the permanent deformation parameter, which represents the constant of proportionality between the permanent strain and the elastic strain (i.e., permanent strain at N= 1).

Figure-5 and Figure-7 show that the relationship between d_i/N_i and N_i is a power function that can be written as:

$$d_i/N_i = a.(N_i)^{-b} \quad (2)$$

or

$$d_i = N_i .a . (N_i)^{-b} \quad (3)$$

The curves illustrated in Figure-5 and Figure-7 show that the value of (N_i x a) for each additional additive is different. The value of "b" for 0%, 10%, and 15% CRP is 1:41, and for 20% CRP b = 1.51. For the curves with BNA-R, there is a difference between 0% BNA-R and 10%, 15% and 25% BNA-R. The value of the coefficients "a" and "b" are the parameters of the HMA characteristics that can be identified through a series of WTM tests. The comparison between the rutting performance of HMA without and with the addition of 10% is shown in Figure 8. HMA without additive at the beginning of the cycle has a rut depth that is smaller than the HMA with additive. However, after 945 cycles, HMA with BNA-R is capable of supporting the wheel load. On the curve of HMA with additive CRP, at initial loading, the wheel grooves increased rapidly, which was in contrast to the other curves.

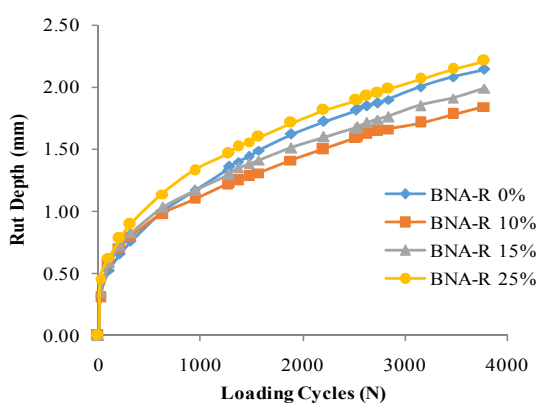

Figure-6. Rutting performance at 40 °C with BNA-R additive.

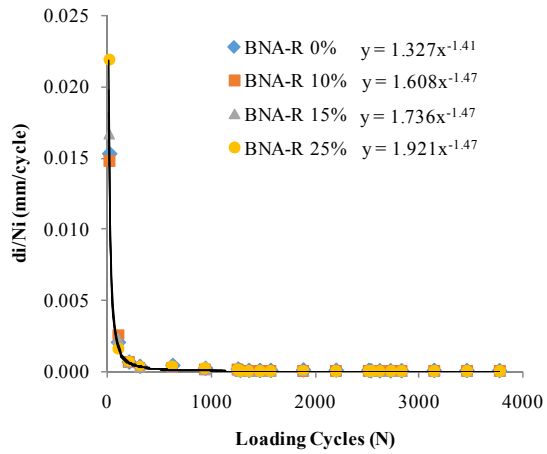

Figure-7. Rate of deformation at 40 °C with BNA-R additive.

Influence of bitumen on rut depth

In the modified HMA, the addition of 10% additive to the HMA influenced the content of bitumen. Because the BNA-R additive contained 60%bitumen, the addition of 10% additive resulted in increased bitumen content. Conversely, the addition of 10% CRP reduced the content of bitumen in the asphalt mixture. These additions resulted in differences in the performance of rutting deformation. The addition of bitumen content was not visible in the Marshall test results, where the values of the Marshall Stability (MS) and Marshall Quotient (MQ) of the CRP additive were greater than HMA with BNA-R additive.

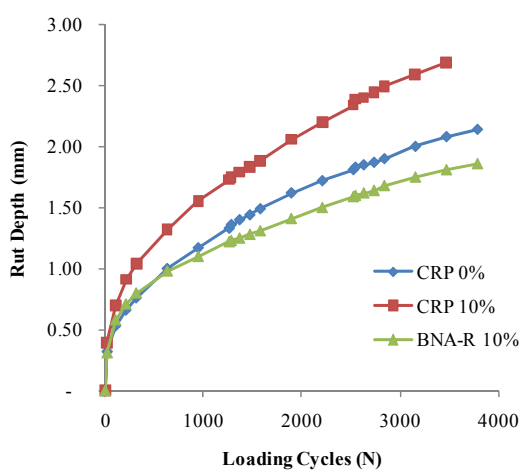

Figure-8. Rutting deformation on different number of cycles with 40 °C.

CONCLUSIONS

Increasing the amount of CRP in HMA does not decrease the depth of the groove wheel and rutting deformation. The addition of BNA-R showed better results. The addition of 10% and 15% BNA-R resulted in

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smaller groove wheel depth; however, the addition of 25%BNA-R had the opposite result. HMA without additive at the beginning of the cycle has a rut depth that is smaller than the HMA with additive. However, after 945 cycles, HMA with BNA-R is capable of supporting the wheel load.

Additives have been widely used to improve the performance of asphalt mixtures. The use of local materials and used tires is common to increase the economic value of the asphalt mixture. However, research using material additives must be supported by sufficient test equipment to demonstrate the performance of asphalt in overcoming the effects of wheel load, temperature, and water. Test wheel grooves using a Wheel Tracking Machine showed an almost identical picture to the conditions in the field. However, due to the limited ability of WTM, forecasting of the depth of the wheel grooves with a greater number of cycles can be performed using empirical models of wheel groove performance for short periods of less than 4,000 cycles.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Directorate for Research and Community Service at the Universitas Indonesia, which provided funding through a 2015 Research Grant (HibahPascaSarjana 2015) for this research activity.

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