

Effect of Rheology of Modified Bitumen to the Permanent Deformation Performance of Asphalt Mixture

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Abstract

With increasing truck traffic and tire pressure, the excessive permanent deformation or rutting become a major concern in asphalt concrete pavements. Road safety is the main concern of rutting. There is reduced frictional characteristics for vehicles, e.g., wheel path flushing, changing lanes becomes hazardous and water ponds in wheel paths. It is therefore important to characterize the permanent deformation behaviour of asphalt mixes before they are placed in roadways. Improving the characteristic of bitumen can support the ability of asphalt mixture to be more resistant to permanent deformation. This paper focuses on the characteristics of permanent deformation of asphalt mixture with the asphalt modified. Modified bitumen with the natural asphalt Buton of 5, 10 and 15% by weight of base bitumen gave positive results on bitumen stiffness as indicated by decreasing penetration values and softening point, as well as complex shear modulus (G^*). The phase angle (δ) decrease that correlated with the resistance of bitumen after modified by Buton Natural Asphalt-Rubber (BNA-R). The result of wheel tracking test for asphalt mixture with bitumen modified shows the decreasing of rut depth at the vary temperature tests. The addition of BNA-R applied to the virgin bitumen causing the rut depth of asphalt mixture decrease.

Keywords: bitumen rheology, rutting, wheel tracking test

I. INTRODUCTION

The surface of road pavement should be smooth to serve the comfortability and safety for driver. Rutting is an undesired condition in a flexible pavement. It gives an increase of fuel consumption, also an increased risk of hydroplaning under rainy season for the road users. Many factors causing rutting viz stress conditions, low density of the layers, and number of load applications, and occurs in different layers of pavement. At the surface of road pavement, rutting appears as longitudinal depressions in the wheel paths and upheavals to the sides. these conditions cause the difficulty in steering and leading to safety concerns. Rutting is caused by several factors such as low density of the layer, stress conditions, and number of load

applications, among others, and occurs in different layers of the pavement [1]–[3].

In analysis of pavement, traffic loads on the pavement surface produce two strain which are believed to be critical for design purposes. The horizontal tensile strain (ϵ_t) at the bottom of the asphalt layer and the vertical compressive strain (ϵ_v) at the top of the subgrade layer. The pavement distresses due to rutting if the vertical compressive strain (ϵ_v) is excessive, permanent deformation occurs on the surface in the pavement structure from the load of subgrade is overload. Thus, permanent deformation is an important factor in flexible pavement design. Most of permanent deformation occurs in the upper layers rather than in the subgrade [1].

To evaluate the rutting performance of asphalt mixtures, different test methods have been applied by many researchers. Producing asphalt rubber is one alternative to reduce permanent deformation in asphalt pavement layer. Asphalt rubber mixtures generally have greater rutting resistance as a result of their higher binder viscosity [4]. Generally, asphalt rubber mixtures were produced use bitumen modified by crumb rubber form waste tire as binder. The use of crumb rubber (CR) is an interesting alternative from both economically and environmental perspectives [5].

Improving the physical properties of bitumen as a binder in asphalt mixture often done by adding additives from polymer materials, non-polymer, or chemical modifier. General purposes with modifying base bitumen are enhancing workability and adhesivity, improving rheological or properties, or develop the volume of bitumen [6]–[8]. Addition of natural asphalt like Buton rock asphalt on the virgin bitumen also can change the property of bitumen like penetration and softening point [9]. And other research reported that Buton asphalt as a modifier increased the dynamic stability, a parameter of permanent deformation characteristic of asphalt mixture at the certain temperature [10], and improved its compressive stress and elastic modulus [11].

This research is intended to observe the influence of changes of bitumen rheology to the rutting performance of asphalt mixture.

II. LABORATORY INVESTIGATION

II.I Materials

The 60-70 penetration grade asphalt cement was used in this study as a bitumen base. Aggregates particles were prepared from a quarry in West Java province Indonesia according to the Indonesian specification for Asphalt Concrete-Wearing Course (AC-WC) with the maximum size of 0.75 inches or 19.1 mm. The gradation limits of aggregate shown in Fig. 1 and Table 1 shows the physical properties of materials used.

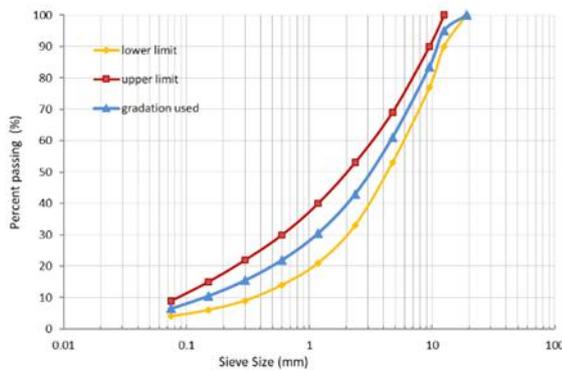


Fig 1. The Gradation of Aggregate (AC-WC)

Table 1. The Physical Properties of Materials

Properties	Value	Specifica-tion
Coarse Aggregates		
Bulk Density	2.647	>2.5
Saturated Surface Dry Density	2.682	>2.5
Apparent Density	2.751	>2.5
Absorption	1.486 %	<3%
Flakyness Index	13.15 %	<25%
Los Angeles Abrasion	21.72%	<40%
Fine Aggregates		
Bulk Density	2.622	>2.5
Saturated Surface Dry Density	2.661	>2.5
Apparent Density	2.728	>2.5
Absorption	1.474 %	<3%
Sand Equivalent	3 %	<8%
Asphalt Cement Pen 60-70		
Penetration, 25°C, dmm	64.2	60-70
Softening Point, °C	51.5	>48
Penetration after TFOT	61.3	>54
Kinematic Viscosity, c St	460	>300

Modifier agent named BNA-R was applied at the content of 5%, 10% and 15% by bitumen weight. BNA-R is a factory-made material consist of 60% semi-extraction of Buton asphalt and 40% of crumb rubber. The BNA (Buton Natural Asphalt) specifications as reported by the producent are as shown in Table 2.

II.II Sample Preparation and Test Procedure

The samples of bitumen were prepared by adding 0 – 15% BNA-R of bitumen weight to the virgin (base) bitumen, asphalt

cement Pen 60-70, in order to modify its properties. BNA-R was blended to the base bitumen Pen 60-70 with asphalt mixer at the temperature of 140° C at the speed about 2,000 rpm for 30 minutes until completely homogen.

Table 2. The Properties of BNA

Properties	Value
Penetration, 25°C, dmm	0 – 5
Softening Point, °C	90 – 105
Specific Gravity	1.35 – 1.40
Bitumen, %	55 – 60
Mineral, %	40 – 45
Asphalten, %	29 – 31
Malteen, %	69 – 71

Source : [12]

The conventional tests, such as; penetration and softening point measurements were done according to ASTM specifications to evaluate the properties changes of modified bitumen binder compared to the base bitumen binder. In order to determine the rheology parameters of bitumen such as, complex shear modulus (G^*) and phase angle (δ) were performed using Dynamic Shear Rheometer test. The testing was performed at the original (unaged) binder and aged binder which conditioned by Rolling Thin Film Oven Test (RTFOT). This condition describes the first stage of the bitumen age during the process of transportation, storage, and handling. The bitumen aging process in a RTFO simulates the second stage, namely during the production and construction process or short-term aging.

Marshall testing (ASTM D1559) was carried out to obtain optimum bitumen content (OBC) of each mixture. OBC obtained for mixtures with unmodified asphalt (0% BNA-R) and those that have been modified with BNA-R 5%, 10% and 15% respectively are 6.4%, 6.85%, 6.9% and 6.95%. The standard and immersion Marshall Stability was observed based on the mixture at the OBC. Then, the remaining strength index of asphalt mixture can be determined.

Furthermore the sample for Wheel Tracking Machine (WTM) test was made. Wheel tracking test is used to assess the permanent deformation resistance of asphalt mixtures under conditions which simulate the effect of road traffic. A loaded wheel tracks the sample under specified conditions of load, temperature and speed, while the development of the rut profile is observed and continuously measured during the test. The sample tested were in a slab form with dimensions of 300 x 300 mm and thickness of 50 mm. The mounted test samples were conditioned for 10 hours at the specified test temperature prior to testing. During wheel tracking test, the sample was confined in the rigid mold and a loaded wheel with the contact pressure of 6.4 ± 0.15 kg/cm² driven backward and forward at 21 ± 0.2 cycles per minute. The depth of tracking was recorded at the midpoint of the sample length. Normally test was performed for 60 minutes or 1,260 cycles or 2,520 repetitions, but for more deeper analysis the test was performed until 3 hours. The previous researcher has been the similar test with exceeding from the normal testing time based the assumption that 60

minutes testing may have limitation to explain the long term development of rutting [13].

III. RESULT AND DISCUSSION

III.I Properties and Rheological of Bitumen

Properties of base bitumen and modified bitumen shown in Table 3. Buton Natural Asphalt-Rubber added to the asphalt cement as a bitumen base generally lowering the penetration

grade and increasing softening point. This is caused by the penetration of this natural asphalt is very low as presented in Table 2. It make the bitumen stiffer or have penetration grade low if blended with this material. As the penetration decreases, the softening point increases. The increasing of softening point is favorable since bitumen with higher softening point may be less susceptible in permanent deformation or rutting.

Table 3. The Properties Changes of Bitumen

Properties	Base Bitumen	5% BNA-R	10% BNA-R	15% BNA-R
Penetration, dmm	64.20	55.60	52.40	50.80
Softening Point, °C	51.50	52.00	53.00	54.25
Penetration after RTFOT	61.30	53.8	51.00	49.10
Kinematic Viscosity at 135°C, cSt	410	420	470	550
Mixing Temperature, °C	151	152	153	159
Compacting Temperature, °C	142	142	143	149

Based on the analisis of kinematic viscosity of each binders, the mixing and compaction temperature for asphalt mixture can be determined. The viscosity has measured at the temperature of 120° C until 160° C with interval of 10° C. Table 3 shows the changes of mixing and compaction temperature because of BNA-R addition. It looks the mixing and compacting temperature became higher. This correlate with the penetration lowering and softening point increasing or its mean the bitumen more stiffer, so for have a good workability in mixing and compacting, need the higher temperature.

The parameter of rheology such as G^* (complex shear modulus), G' (storage modulus), G'' (loss modulus) and δ (phase angle) can be obtained from dynamic shear rheometer test. In the Superpave system, G^* is the ratio of total shear stress to total shear strain. This G^* parameter is a fundamental property of material. In general, bitumen and mixture with higher complex modulus value at a given service temperature

will exhibit lower permanent deformation value than the bitumen or mixture tested at the same temperature that have lower complex modulus values. Phase angle, δ , is an indicator of viscosity and elasticity characteristics of an asphalt binder in Superpave system. The higher phase angle, the bitumen became more viscous (non elastic).

Fig 2 shows the change of complex shear modulus and phase angle to the temperature sweep at the different condition, at the original and the short term aging bitumen or conditioned by RTFOT in laboratory. At this temperature sweep test, the angular frequency of 10 rad/sec or equivalent with traffic speed of 55 mph (90 km/hour) was selected.

It shows that the increasing temperature will decreasing G^* and increasing δ , for every type of bitumen. It is a normal phenomenon of all bitumen type, where high temperature will softening bitumen and if the phase angle increase the bitumen tend to the viscous (non elastic) condition.

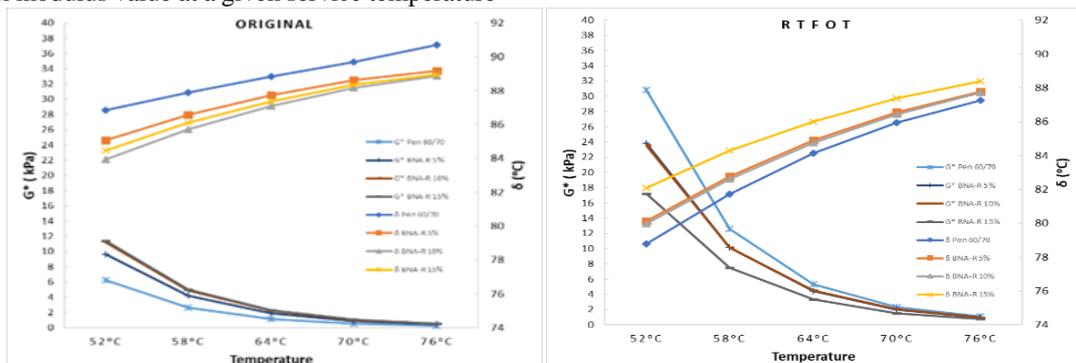


Fig. 2. Change of G^* and δ at the Temperature Sweep

At the same temperature, modified bitumen shows have a higher G^* than unmodified and tends to increase with

addition the percentage of modifier. At the other hand, the phase angle became low due to addition of modifier. Its mean

that BNA-R as a modifier to the base bitumen Pen 60/70 will cause the bitumen more elastic with the lower value of δ . And the higher temperature of test the lower of G^* and higher δ .

For measure the change of bitumen rheology at the same temperature, the test by frequency sweep was conducted, at the angular frequency of 1.3 to 88.5 rad/s temperature of 25°C, 45°C and 60°C. These frequency were equivalent with the traffic speed of 11.3 km/hour until 1,696.5 km/hour. The results of the frequency sweep of DSR to the bitumen base Pen 60/70 and modified bitumen has shown at the Fig 3. Addition of BNA-R to the base bitumen tends to increasing the value of shear complex modulus (G^*) along with the increasing speed or frequency.

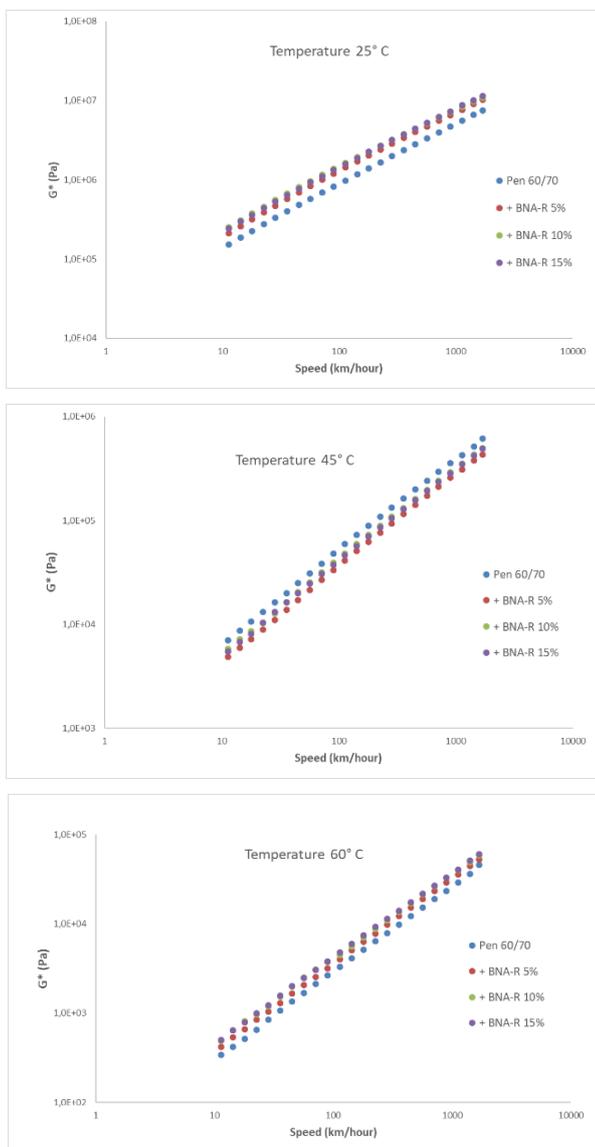


Fig 3. Change of G^* at the Frequency Sweep

The changes of phase angle, δ , at the DSR test frequency sweep was presented in Fig 4. The result show that the value of phase angle tends to decrease with the increasing frequency or speed. At the temperature 25°C and 45°C, the phase angle under 90° that indicate both bitumen unmodified

and modified by BNA-R still can use at the traffic speed 11.3 km/hour until 1,696.5 km/hour. But at the higher temperature, 60°C, there different performance between unmodified bitumen and modified bitumen. The higher speed, the decrease phase angle for all modified bitumen. But at the base bitumen, the value of phase angle decrease at the first then increase at the speed about of 400 km/hour with the value of phase angle more than 90°.

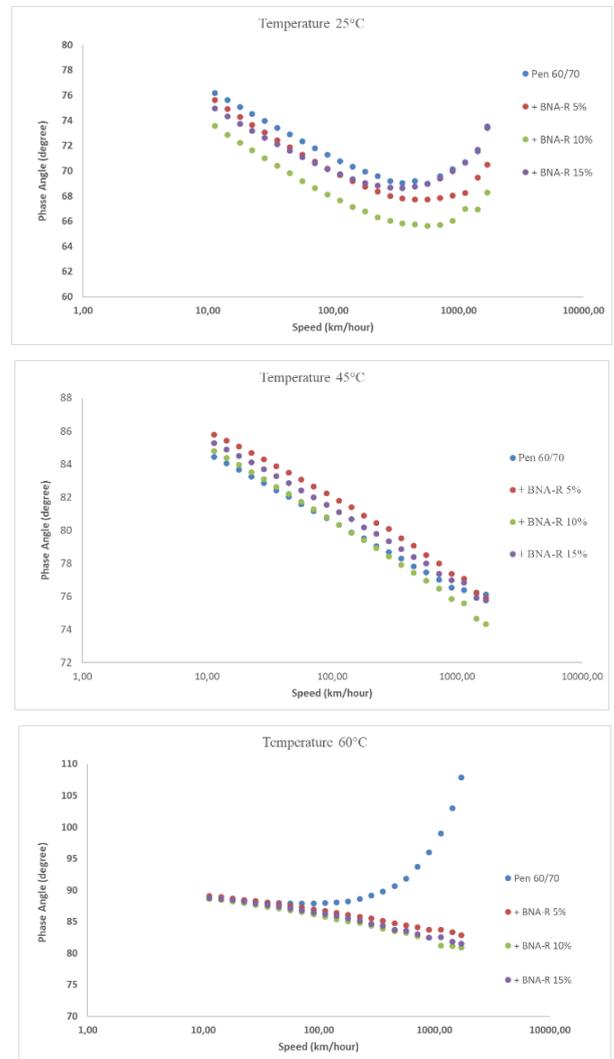


Fig 4. Change of δ at the Frequency Sweep

Based on the value of G^* (complex shear modulus), the bitumen stiffness modulus (E^*) can be calculated with the following formula:

$$E^* = 2 G^* (1 + \nu) \quad (1)$$

with ν (Poisson ratio) assumed of 0.5. The correlation between bitumen stiffness modulus and phase angle as known as black diagram as shown in Fig 5 can be used to analyze the position of bituminous viscoelasticity with a phase angle at a certain value of the stiffness modulus.

Black diagram can also illustrate the durability of bitumen. Bitumen which has a small phase angle shows more durable and vice versa if the phase angle is large indicates the bitumen

is less durable. The decreasing value of the stiffness modulus along with the increase in phase angle, this means that the proportion of loss modulus is increasing.

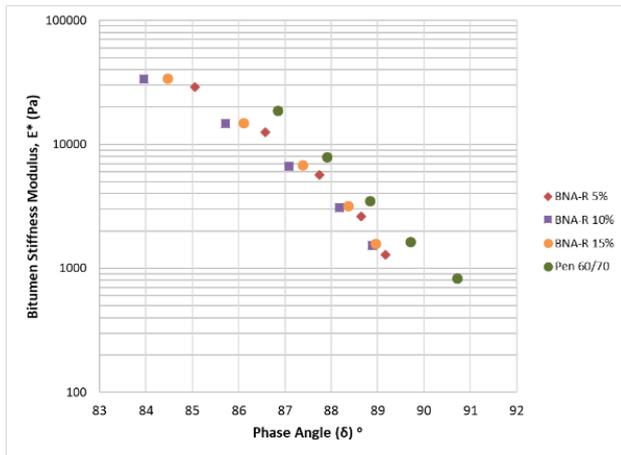
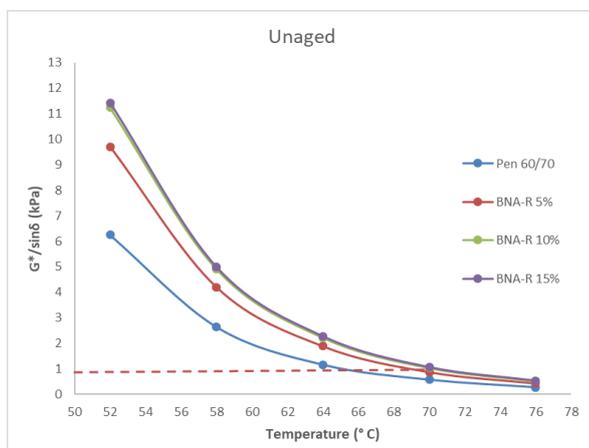


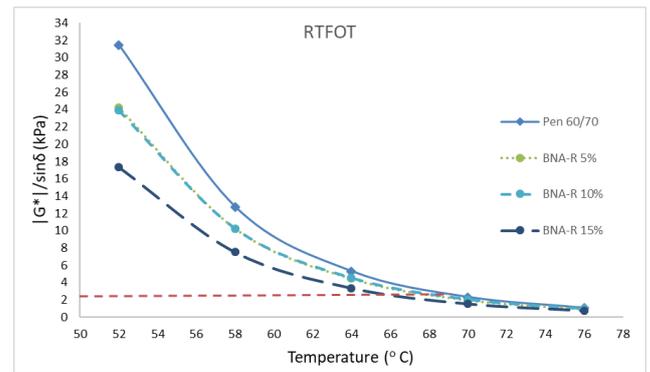
Fig 5. Black Diagram

III.II Rutting Performance

The parameter of $G^*/\sin\delta$ from the DSR test above, often said as the anti rutting factor. The value of $G^*/\sin\delta$ corresponding to the rutting performance and was considered to correlate highly with rutting of asphalt mixture in Superpave system [14], [15]. Fig 4 shows the performance grade of bitumen that reflected with the value of $G^*/\sin\delta$ at the temperature sweep test. The minimum criteria for $G^*/\sin\delta$ according to SHRP is 1 kPa for unaged bitumen and 2,2 kPa for short term aging (RTFOT). The addition of Buton asphalt to the base bitumen made the differences between original condition (unaged) and short term aging (RTFOT) not too far. Its mean that modify the rheology of base bitumen with Buton asphalt made the bitumen not too sensitive to the aging changes. This is very beneficial for asphalt pavement in climates like Indonesia.



(a)



(b)

Fig 6. The Change of $G^*/\sin\delta$ (anti rutting factor)

The dynamic stability and rate of deformation of asphalt mixture which obtained from wheel tracking machine showed in Fig 7 to Fig 9. The rut depth (permanent deformation) is recorded as a function of the number of wheel passes in the followings intervals of time: 1, 5, 10, 15, 30, 35, 45, 60 minute, and repeat until 3 times. Testing was finished after 3 hours. The dynamic stability obtained from the data at the 45 minutes and 60 minutes of test. After 45 minutes of testing, the rate of deformation illustrated by the tangent graph is relatively constant. So the measurement of the deformation rate measured at 60 minutes (1260 passes) and 45 minutes (945 passes) was appropriate.

From the result of long cycle WTM, until 3 hours testing, the curve of deformation looks still at the second stage of deformation evaluation of asphalt mixture. This can be seen from relatively constant slope of the curve after load repetition of 200th. The first stage was showed with the steep slope of the deformation curve. it seems tha the third stage still not reached which the asphalt mixture start to failure.

The rheology of bitumen has a role to the performance of permanent or plastic deformation of asphalt mixture. At the low temperature, the addition of BNA-R to the base bitumen correlate with the decreasing of the deformation of mixture. The dynamic stability became higher at the 10% of modifier agent. But it is not showed in high temperature, where dynamic stability tends to decrease. This is also shown in the result of rut depth. At high test temperatures, no good pattern was seen with the addition of BNA-R to the asphalt mixture. This is maybe caused by the composition of Buton asphalt that not full extraction, still has mineral aggregate that influence the whole mixture aggregate composition. In this research, the BNA-R was added to the bitumen and the composition of aggregate for all sample mixture made uniform.

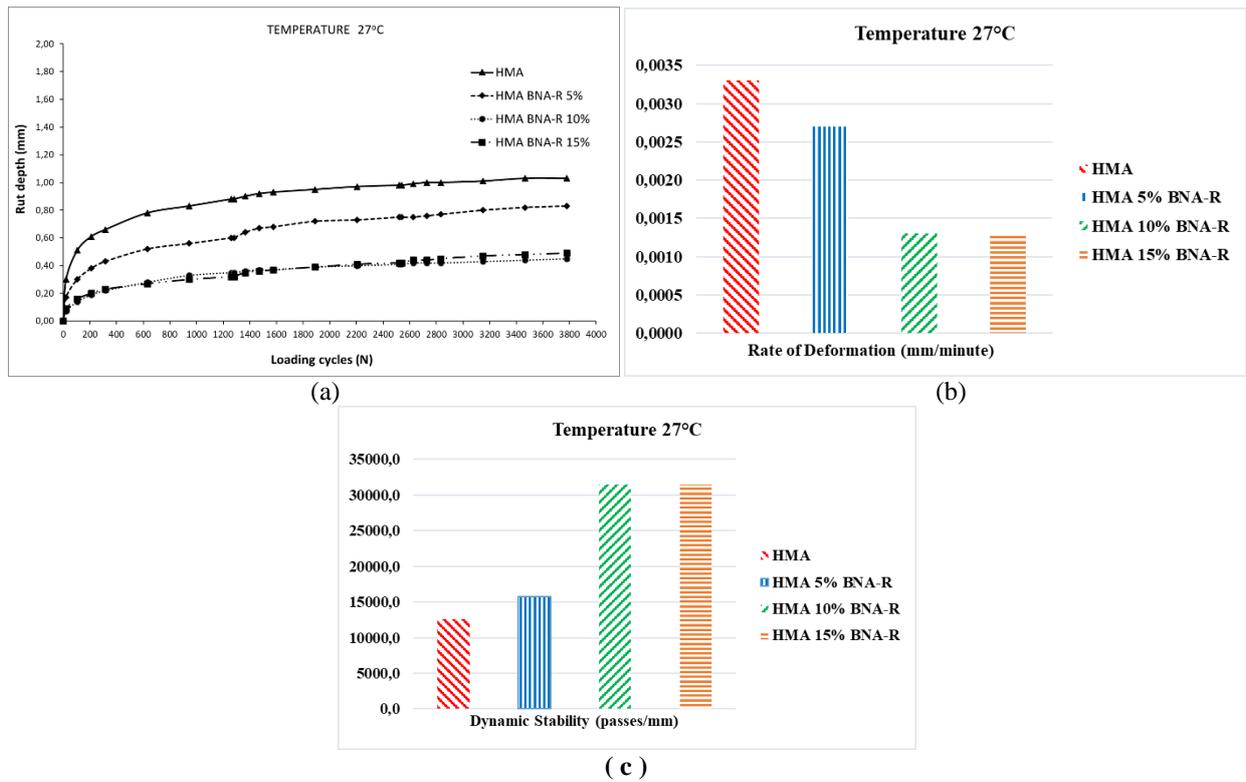


Fig. 7. WTM Result at Temperature of 27 °C

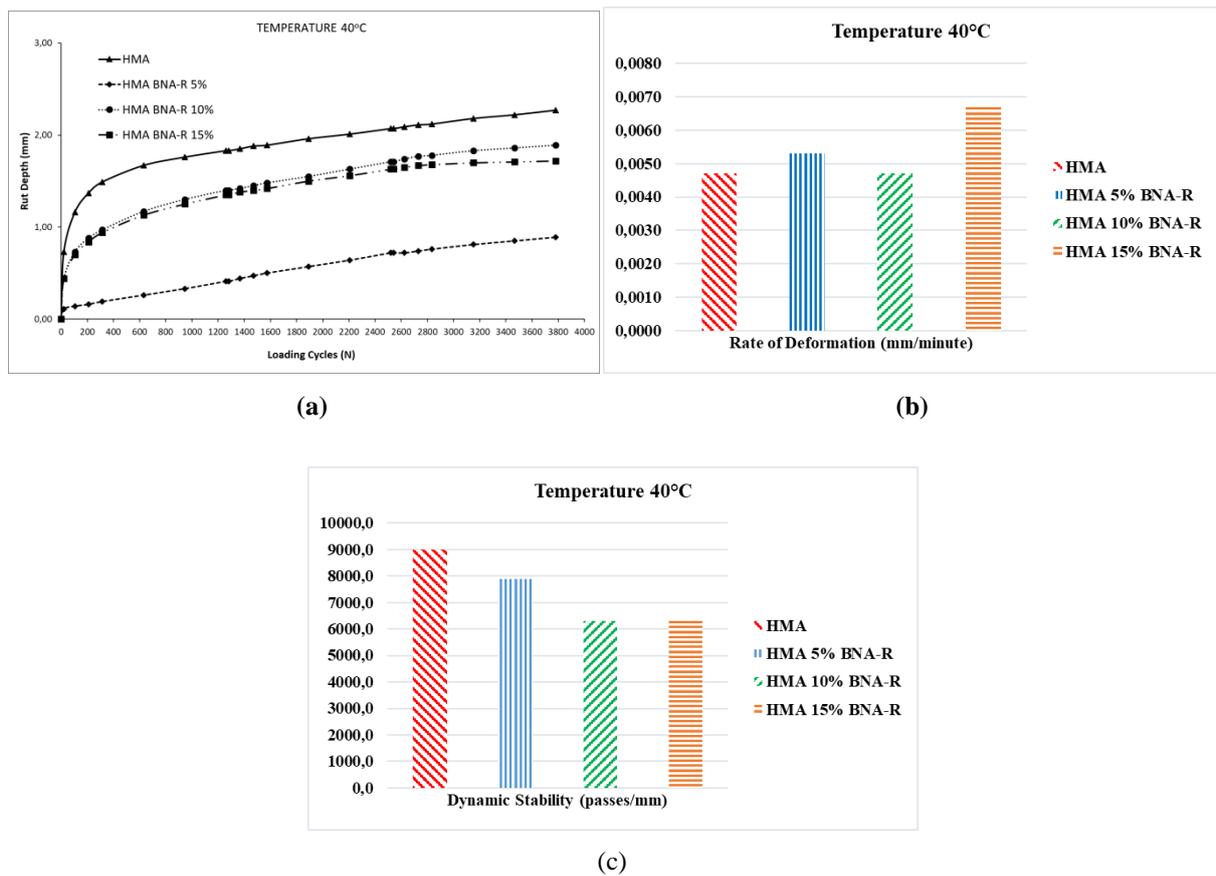


Fig. 8. WTM Result at Temperature of 40°C

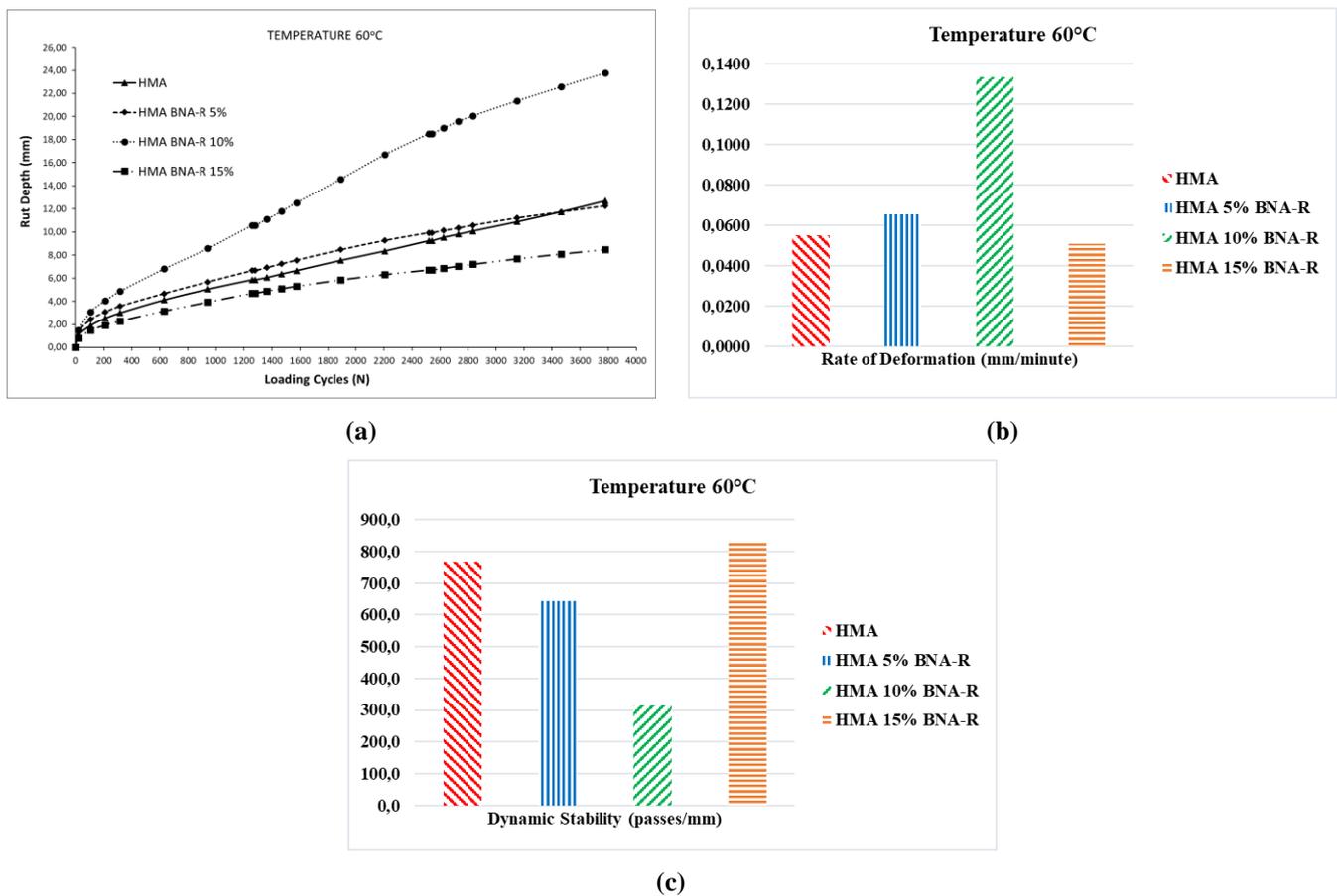


Fig. 9. WTM Result at Temperature of 60°C

IV. CONCLUSION

The following conclusions can be drawn based on the results and discussions above:

1. In general, Buton natural asphalt can be used as a bitumen modifying material on hot mix asphalt. Decreased penetration value, increased softening point, decreased phase angle, increased bitumen rigidity modulus indicates that bitumen is more resistant to rutting potential under certain conditions.
2. The dynamic stability, a parameter of permanent deformation characteristics, of HMA containing Buton Natural Asphalt Rubber was higher than without BNA-R at the lower temperature. But decrease at the high temperature.
3. Bitumen which is modified with natural asphalt such as Buton asphalt which is not fully extracted, can cause anomaly in observing its effect on rheology and its characteristics, because it is contain minerals.

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