

# Rut Depth Characteristics on Hot Mix Asphalt with Addition Nano Crumb Rubber

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**Abstract** The pavement construction is designed by considering the factor of resistance to deformation due to the repetition of wheel loads. Other factors are the influence of the wheel load, the condition of the increase in temperature on the road surface, which is the cause of the decrease in the strength of the road surface layers. The deformation of the road surface due to wheel tracks occurs when an increase in tensile stress at high temperatures due to wheel loads occurs. The relationship between the number of wheel tracks and permanent stresses that occur on the road surface can be known to be analyzed through the wheel tracking test. This study aims to determine the effect of the addition of nano-sized use of rubber tires on increasing the resistance of hot mix asphalt to the effect of temperature due to vehicle wheel loads. This use of tire waste has been processed to nano-sized granules called nano crumb rubber; this material is added to the Asphalt Concrete Wearing Course hot mix asphalt. This material addition of 0%, 1.25%, 2.5%, 3.75%, and 5% of the asphalt content in hot mix asphalt. The Nano Crumb Rubber is added to the aggregate at the mixing temperature 130 °C, before mixing the aggregate with asphalt. The optimum asphalt content is obtained through a Marshall standard test; the research is continued by conducting the Wheel Tracking Machine test. The results of the test found that the addition of Nano Crumb Rubber in the asphalt mixture will improve the quality of the mixture, especially at high temperatures, increase the quality of the addition of 1.25% and continue the addition of 5%. However, the addition of Nano Crumb Rubber > 1.25% decreased performance due to high temperatures. The test results at 40 °C and 60 °C with the addition of 1.25% are the hot mix asphalt with the best performance. The use of Nano Crumb Rubber in hot mix asphalt requires a smaller amount compared to Crumb Rubber.

**Keywords** Hot Mix Asphalt, Crumb Rubber, Dynamic Stability, Deformation Rate, Temperature, Rutting

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## 1. Introduction

The increase in road surface temperature in some tropical countries is affected by the increase in environmental temperature and the increasing number of vehicles. Surface layers in flexible road construction generally use concrete asphalt mixture. This structure is called flexible pavement; the structure of this pavement can be deflected or flexible due to vehicle loads. This type of pavement usually consists of several layers of material. It can be seen that the material from asphalt is not perfectly elastic, but deformation occurs after getting repeated loads. However, if the load is smaller than the strength of the material and deformation due to repetitive loads can still be restored to its original state, then the material can be considered elastic (NPTEL, 2009). The development of road technology has made changes that contribute to the development of more environmentally friendly such as the use of pavement recycling, the use of waste materials in asphalt mixtures, and low-temperature asphalt mix technologies. Some of these technologies have increasingly been utilized in recent years. One of them is the use of scrap tires as a powder in asphalt mixtures that have changed their mechanical properties (Aravind& Das, 2007; Chavez, Marcobal, &Gallego, 2019; Kaloush, 2014; Kim, Lee, &Amirkhanian, 2011; Taylor, n.d.; Wei, He, Jiao, Chen, & Hu, 2016; Xie& Shen, 2016).

Asphalt mixture resistance can be influenced by several factors such as temperature, air, and water conditions. In the condition that environmental factors make it possible to obtain quality materials such as asphalt and rock, the main condition that can occur is damage such as traffic loads or wheel pressure causing permanent deformation or fatigue cracking (Iskender, Aksoy, &Ozen, 2012).

Tire waste will continue to increase as an increasing number of vehicles. In large quantities, this waste will

become a severe environmental problem in many countries. The problem has accumulated because it is not utilized.

Using recycled crumb rubber from tire waste reused as an added material 10%-15% for asphalt binding to aggregate asphalt mixtures is an interesting alternative. The asphalt-rubber process is formed from the binding of hot asphalt and recycled tire rubber in which crumb rubber reacts with bitumen to cause swelling of rubber particles (Fransqui, Yepes, Gallego, & Yepes, 2018). Using this crumb rubber in aggregate asphalt mixture can be an alternative to minimize the ecological impact while increasing the mechanical properties of asphalt mixture (Arega, Bhasin, & Kesel, 2013). The use of crumb rubber on asphalt mixes can be done for hot mix asphalt or warm mix asphalt. The use of crumb rubber as a mixture of rubber asphalt (modified asphalt) for road pavement has shown an increase in the mixture's performance compared to conventional asphalt mixes (Kartika, Hadiwardoyo, & Sumabrata, 2019).

(Chavez et al., 2019) explains that high rubber content can produce binders with a viscosity above 1500 cP at 177 °C. The high viscosity value of the modified asphalt type enables better coating of aggregate particles and increases elasticity and resistance at high temperatures.

The ideal bitumen should be strong enough, at high temperatures, to withstand rutting or permanent deformation, and soft enough to avoid excessive thermal stresses, at low pavement temperatures, and fatigue, at moderate temperatures (Moghadas, Aghajani, Modarres, & Firoozifar, 2012). It is time to improve the quality of conventional asphalt due to extreme weather, increasing traffic loads, and increasing axial loads in the last decade. Therefore, some experiments are needed to use modified asphalt as a binding material.

Damage to road pavement from hot mix asphalt often occurs in the form of rutting and stripping damage. There are many causes of rutting and stripping that cause the reduced shear strength of hot mix asphalt (Iskender et al., 2012). The addition of crumb rubber is expected not only to fill cavities between aggregates but also in the cavities of

aggregate particles. This process can increase the relative stiffness of asphalt at high temperatures. Modification of bitumen by adding crumb rubber that is processed from tires that can not be used is an alternative to improve the performance of bitumen modification in asphalt mixture and prevent plastic deformation. The physical properties of asphalt can change with the addition of crumb rubber. The value of elasticity and Viscosity increases so that it can increase the resistance to the aging process (Moreno, Sol, Mart ın, P erez, & Rubio, 2013). Wheel tracking testing is needed to determine path deformation. The value of the flow deformation includes several performance evaluation indexes for asphalt mixtures that can be used, such as dynamic stability, and dynamic modulus from repeated creep tests (Bonaquist & Christensen, 2003).

The focus of this research is to use added material in the form of nano-sized rubber powder. The content of nano rubber powder on asphalt mixture as much as 1.25% -5% is able to improve the quality of the mixture by testing the Marshall and Wheel Tracking Machine (WTM) test. This tool shows the groove deformation that occurs in the hot mix asphalt. In this research, tire waste, which has been processed into nano-sized granules, has been used as an additive in hot asphalt mixtures. Observations have been made of the effect of this added material on deformation as resistance to the influence of high temperatures.

## 2. Materials and Methods

### Asphalt Binders

Asphalt in this study was obtained from PT. KADI International, from the asphalt type Pen 60/70. The thin film oven test (TFOT) is used to simulate short-term thermal aging, which is referred to as the aging of the mixing process. Some other asphalt tests have been carried out to determine the characteristics of virgin asphalt, as shown in Table 1.

**Table 1.** Virgin Asphalt Test Results

No	Properties	ASTM Test Method	Unit	Indonesian Specification	Result
1.	Penetration at 25 °C	D-5	mm	60 -70	64.3
2.	Softening Point	D36	°C	≥ 48	48.5
3.	Flash Point	D-92	°C	≥ 232	304
4.	Ductility at 25 °C	D113	Cm	≥ 100	>100
5.	Specific Gravity at 25 °C	D70	kg/m <sup>3</sup>	≥ 1.0	1.048
6.	Loss on Heating (TFOT)	D1754	%	≥ 0.8	0.108
7.	Penetration after TFOT	D5	mm	≥ 54	61.5
8.	Kinematic Viscosity at 135 °C	D21 70-67	cSt	≥ 300	459.6

## Aggregate

Aggregates in this study have been prepared based on the middle specifications for asphalt concrete wearing coarse (ACWC) asphalt concrete mixes in Indonesia. The composition of aggregates is formed from coarse aggregates, fine aggregates, and fillers based on the amount needed for each size according to specifications. Figure 1 shows the aggregates in the middle position of the upper and lower limits.

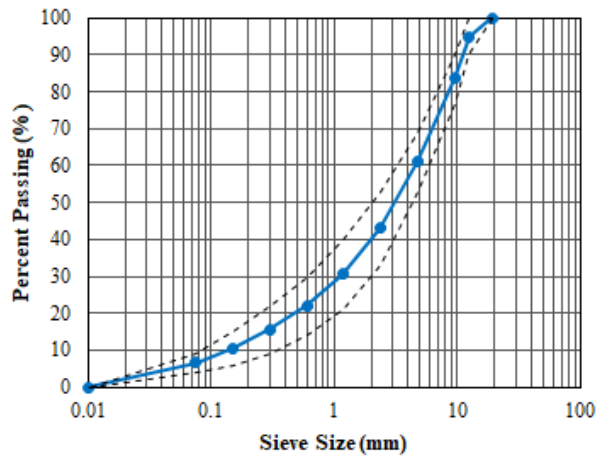


Figure 1. AC-WC Aggregate Gradation

## Nano Crumb Rubber (NCR)

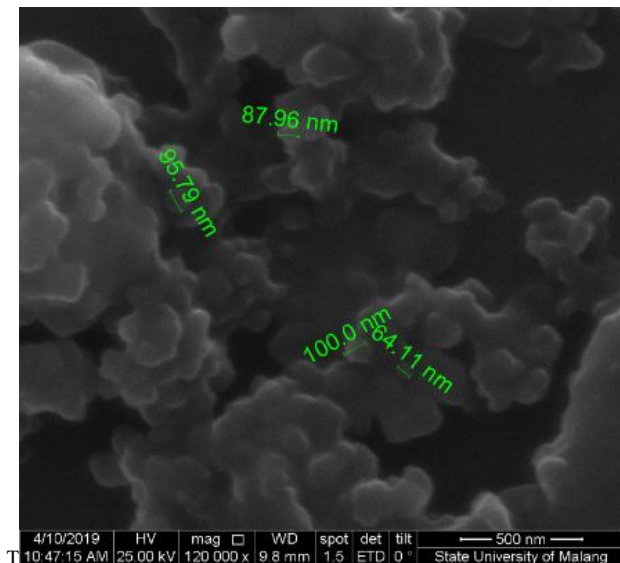


Figure 2. SEM image Nano Crumb Rubber

The benefits of asphalt modified by using nanomaterials have increased the resistance to rutting, cracking, and fatigue (Shafabakhsh & Ani, 2015). The use of nanomaterial as an added material is currently being developed. Different nanomaterials have been used to improve the behaviour of mixtures, such as carbon nanotubes, nano clay, or nano-SiO<sub>2</sub>. Nanotechnology is the

Design, manufacture, and use of materials which are measured using nanometers (López-Montero, Crucho, Picado-Santos, & Miró 2018). Therefore, nano-sized rubber was used to determine the increase in mechanical behaviour and resistance to asphalt mixture susceptibility. In this study, Crumb Rubber was obtained from PT. Daurindo Daya Abadi, Bogor, Indonesia. This material has a size of 0.15-0.6 mm, which is then processed into smaller sizes, as shown in Figure 2 at the Fuad Laboratory, Malang, Indonesia. CR has been processed in a rotating ball mild sided tube for 10 hours.

## Asphalt Mixture Modification

Rubber asphalt, which is included in the type of asphalt polymer elastomer, consists of a mixture of asphalt rubber waste tires and certain additives where the rubber component is at least 15% of the total weight of the asphalt mixture (ASTM D6114). Utilization of Crumb Rubber as a road pavement material can be done by two methods, the first dry process by directly mixing dry crumb rubber with asphalt and aggregate, and the second method is a wet process, by adding crumb rubber to cold asphalt or heated asphalt, then stirring with mechanical ways to interact between asphalt and material added (Celauro, Celauro, Lo Presti, & Bevilacqua, 2012; Moreno, Rubio, & Martinez-Echevarria, 2012). In this research, mixing with the dry process method was carried out by mixing additive material (Nano Crumb Rubber) on the aggregate at 150 °C. This dry mixing is done by adding additive material to the aggregate with an additional level of 2.5% and 5% by weight of asphalt.

## Wheel Tracking Test

The wheel tracking machine (WTM) test aims to determine the resistance of the wheel path deformation. This test also simulates the traffic loading or vehicle wheel load on an asphalt layer repeatedly until the wheel path deformation is formed on the asphalt layer. Road surface temperature, especially in areas with high temperatures, can affect the characteristics of asphalt mixes.



Figure 3. Wheelpath deformation test

Wheel path deformation is formed when tensile stresses are generated due to high temperatures (Moreno & Rubio, 2011).

WTM testing has been carried out in the laboratory of the Road and Bridge Research Center of the Ministry of Public Works and the Public Housing Republic of Indonesia in Bandung (Figure.3). The test is carried out at temperature 27 °C, 40 °C, and 60 °C by providing wheel loads weighing  $6.4 \pm 0.15 \text{ kg/cm}^2$ , which repeatedly move over the sample. Resistance to the deformation path can be seen from the depth of deformation after several traversed. The standard cycle in the WTM test only reaches 1,260 passes and can be extended by testing the standard cycle WTM as needed. To achieve a standardized total test takes 60 minutes for a set of short cycles.

Sample preparation for weight and volume of WTM sample has been carried out with reference to the density used in marshall standard optimum samples of 2.04 gr/cm. The density is used to calculate the needs of the WTM samples with dimensions of 300 mm x 300 mm x 50 mm so that the aggregate and asphalt mixture needs are obtained in this study weighing 9,171.97 gr. Asphalt aggregate mixture for WTM tests with optimum asphalt content of 6% and using nano crumb rubber 1.25%, 2.5%, 3.75%, and

5%.

### 3. Results and Discussion

#### *Optimum Asphalt Content*

Marshall tests have been carried out to obtain optimum asphalt content as a reference for asphalt content for further testing, using asphalt content of 5%, 5.5%, 6%, 6.5%, and 7%. The asphalt mixture compaction process has been carried out at compaction temperature following standard Marshall procedures. The sample was compacted with two directions of the surface, with 75 blows from a cylindrical sample. The diameter of the sample is 101.6 mm and has a thickness of 63.5 cm. The optimal bitumen content was found to be 6.0% by weight of the unmodified asphalt mixture. The physical properties of the mixtures are something such as density, air voids (VA), voids filled with asphalt (VFA), and voids in mineral aggregates (VMA). The results of the Marshall test have different asphalt content, with Nano Crumb Rubber content 0% to 5% (Figure 4).

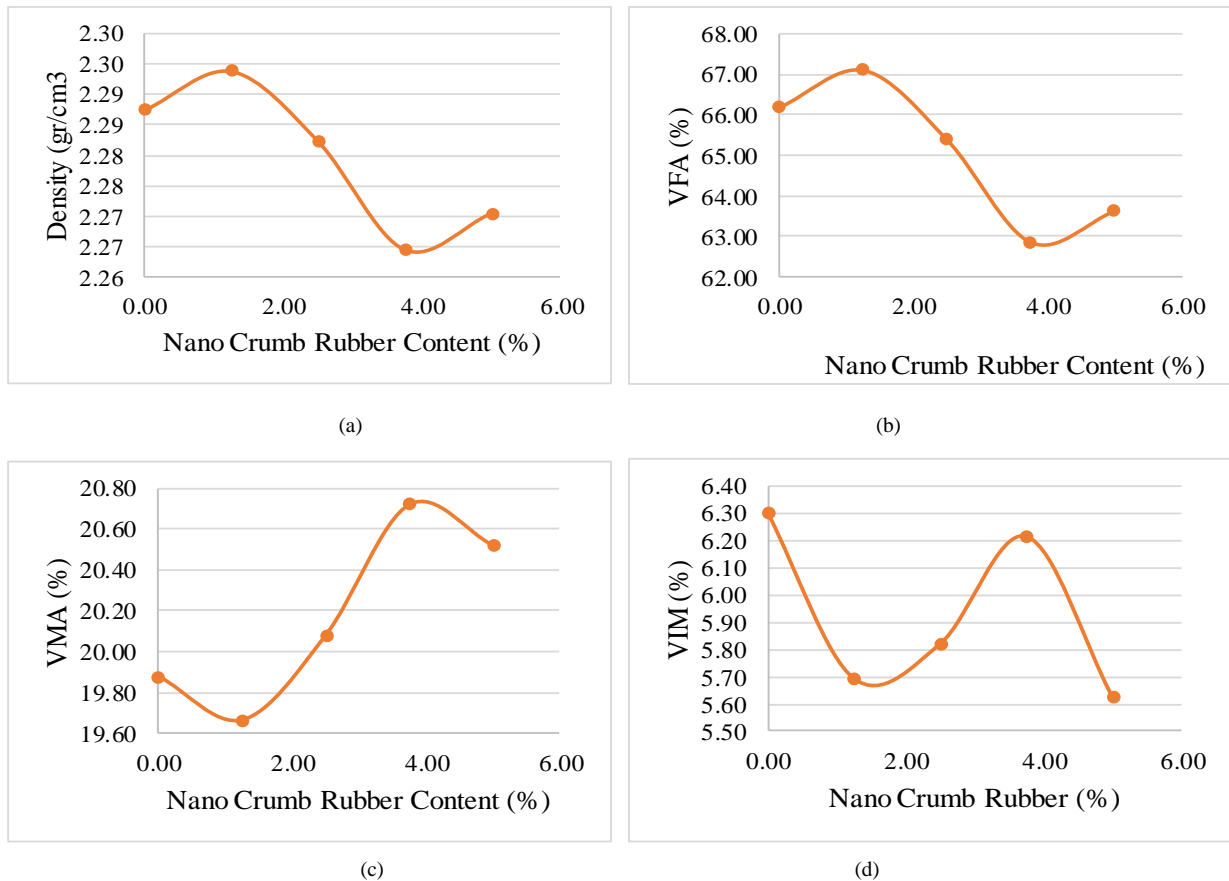


Figure 4. Marshall Test Result

### Deformation Rate and Dynamic Stability

WTM testing has been carried out in a one-cycle test, obtained initial deformation at 0%, 1.25%, 2.5%, 3.75%, and 5% tested at temperatures of 27 °C, 40 °C, and 60 °C. The deformation rate (DR) is calculated at the 45th and 60th minutes expressed in  $d_{45}$  and  $d_{60}$  expressing:

$$DR = (d_{60} - d_{45}) / (t_{60} - t_{45}) \quad (1)$$

The deformation rate (DR) is measured in millimetres per minute calculated at  $t_{45}$  and  $t_{60}$ , which shows the

measurement time of deformation at the 45th minute of the test time at the 60th minute. Dynamic stability (DS) is the number of passes for each deformation decrease with unit paths per millimetre measured on deformation, used as a parameter of material resistance to permanent deformation or rutting.

$$DS = 42 \{ (t_{60} - t_{45}) / (d_{60} - d_{45}) \} \quad (2)$$

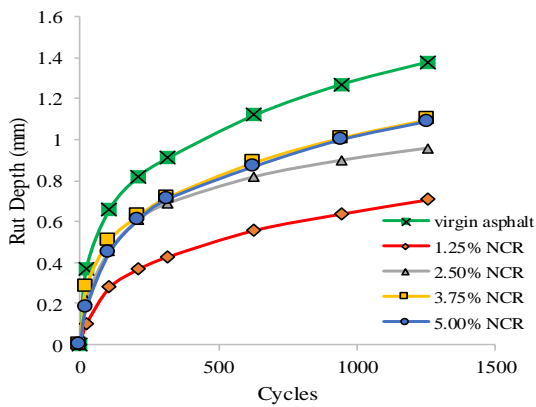
The results of the calculation of deformation rate (eq. 1) and dynamic stability (eq. 2) are summarized in Table 2.

**Table 2.** Deformation Rate and Dynamic Stability with Temperature

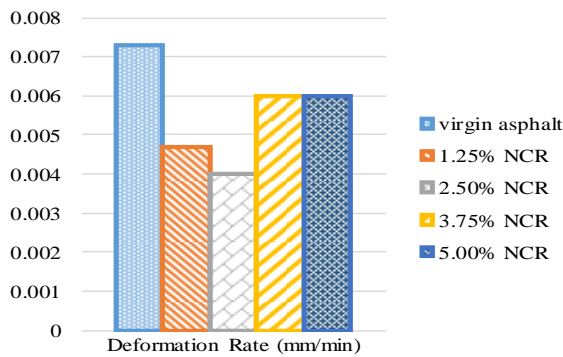
Temperature (°C)	NCR Content	Deformation Rate (mm/minute)	Dynamic Stability (Cycle/mm)	Temperature (°C)	NCR Content	Deformation Rate (mm/minute)	Dynamic Stability (Cycle/mm)
27	0%	0.007	5,727.30	40	2.50%	0.021	2,032.30
	1.25%	0.005	9,000.00		3.75%	0.020	2,100.00
	<b>2.50%</b>	<b>0.004</b>	<b>10,500.00</b>		5%	0.017	2,423.10
	3.75%	0.006	7,000.00	60	0%	0.052	797.47
	5%	0.006	7,000.00		<b>1.25%</b>	<b>0.032</b>	<b>1,312.50</b>
40	0%	0.012	3,500.00		2.50%	0.073	572.70
	<b>1.25%</b>	<b>0.010</b>	<b>4,200.00</b>	3.75%	0.069	611.70	
	2.50%	0.021	2,032.30	5%	0.055	768.30	

**Impact of Temperature Changes on the Characteristics of the Modified Asphalt Mixture**

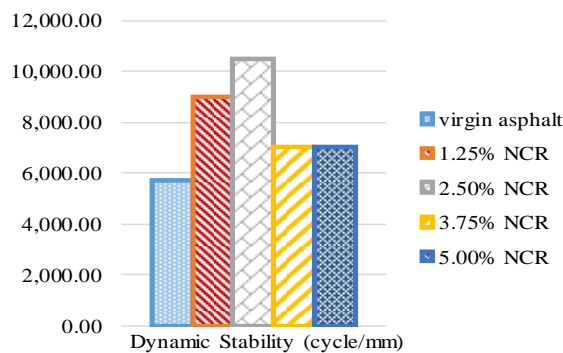
From Figure 5, the WTM sample test at 27 °C can be seen that the initial deformation in the virgin asphalt mixture increased faster than the modified asphalt mixture. Asphalt mixture modification of NCR 1.25%, an increase in the rut depth on cycles up to 1,260 (Figure 5a), shows the lowest value compared to other asphalt mixtures. However, when considering the increase in the deformation rate (Figure 5b) and dynamic stability (Figure 5c) appear to be different, the addition of NCR 2.5% achieved the lowest DS and highest DS values. It can be concluded, the best asphalt mixture at 27 °C is with an additional NCR of 2.5%.



(a)



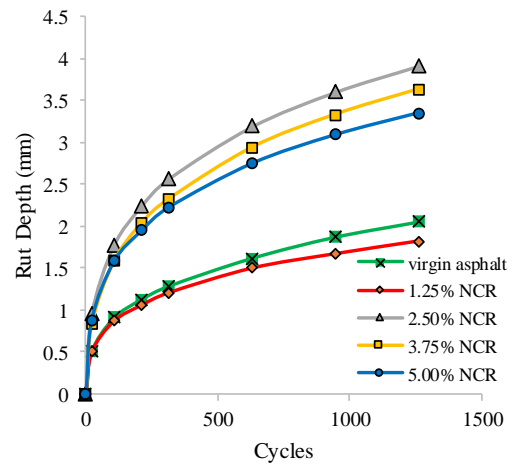
(b)



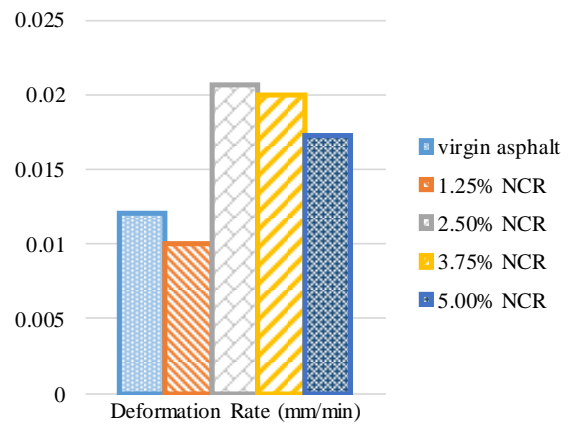
(c)

**Figure 5.** WTM results with a temperature of 27 °C

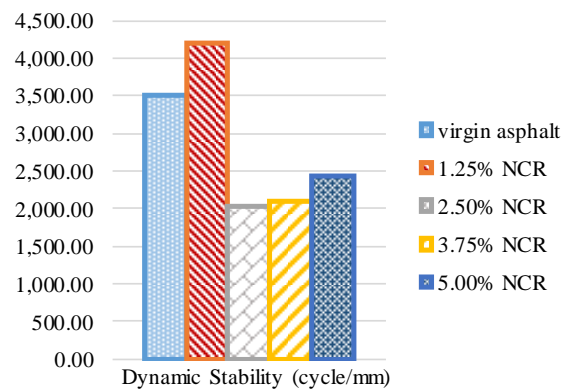
From figure-6 in the test with a temperature of 40 °C, the smallest initial deformation at 1.25% NCR content Virgin asphalt mixture looks smaller than the deformation value with the addition of NCR > 1.25%, and this occurs until the cycle reaches 1,260 (Figure 6a). This tendency is as shown in figures-6b and 6c, where the lowest deformation rate and highest dynamic stability are achieved at an additional NCR of 1.25%.



(a)



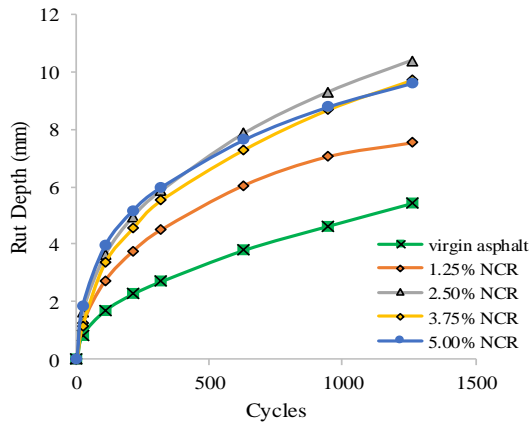
(b)



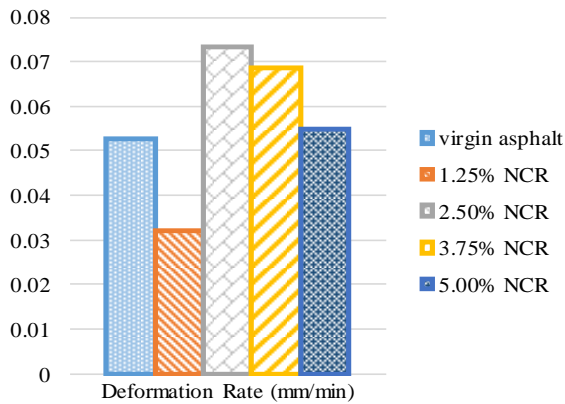
(c)

**Figure 6.** WTM results with a temperature of 40 °C

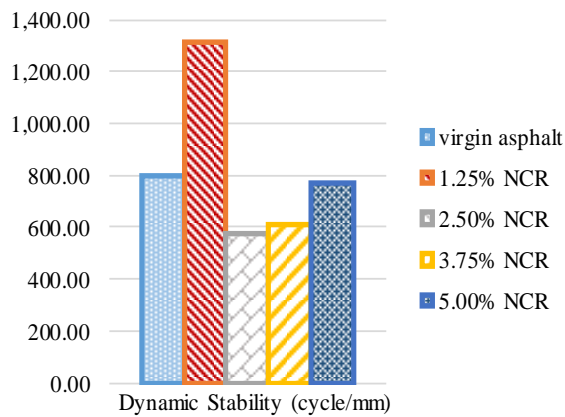
The performance of the modified asphalt mixture at an increase in the temperature reaching 60 °C was more evident that the addition of NCR 1.25% showed the best performance, and the mixture of virgin asphalt had a lower performance. However, they were still better than the addition of NCR > 1.25% (figure-7a, b, c).



(a)



(b)



(c)

Figure 7. WTM results with a temperature of 60 °C

The addition of NCR to the 1.25% to 5% content of virgin asphalt, as illustrated in Figures 5, 6, 7, shows that

analysis to determine the optimum NCR content in asphalt mixtures cannot be seen only from the rut depth vs. loading cycles curve (figure-7a). In this case, the WTM test is carried out with a small number of cycles (1,260 cycles) within 1 hour, as shown in Figure 7-a. The curves formed are not yet stable so that if the cycle is extended to a more extended number up to 3,500-4,000 cycles with time ± 3 hours, then the shape of the curve will approach the actual rut depth characteristics. The method of calculating the rate of dynamic deformation and stability at t60 and t45 (eq.1 and eq.2) is approaching. However, it must be proven by the formulation of the value of the dynamic stability and deformation rate using a long cycle (> 1,260 cycles).

## 4. Conclusions

From the results of the research that has been done, it can be concluded that:

1. The use of NCR as a dry added material in ACWC aggregate asphalt mixture has changed the performance of virgin asphalt mixture into the value of deformation rate and dynamic stability.
2. The addition of NCR has shown the optimum content of 1.25% of the asphalt content in the aggregate asphalt mixture and has achieved better-modified asphalt mixture performance than asphalt mixture without NCR.
3. The use of Nano Crumb Rubber in hot asphalt mixture requires a smaller amount compared to Crumb Rubber Fiber.
4. Analysis of WTM test results at low temperatures (40 °C) and short cycles will provide incorrect information. Therefore, it is recommended to use long cycles (minimum 3,500 cycles) or use temperature variations up to 60 °C.

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