Proceedings of the 4th ITB Graduate School Conference
Innovation and Discovery for Sustainability
July 6, 2023

Permanent Deformation Characteristic of Reclaimed Asphalt Pavement with Coconut Shell Bioasphalt (BTK) on AC-WC Hot Mix Asphalt

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Abstract. Based on the Ministry of PUPR Bina Marga`s report (2022), the need for asphalt in 2021 will reach 1.2 million tons. If the annual need for asphalt is around that number, natural resources as asphalt will be required. Therefore, asphalt modification is needed. The use of reclaimed asphalt pavement (RAP) is considered an effective fulfillment of domestic asphalt requirements of asphalt demand. Thus, some rejuvenators must be found to effectively use RAP from the old road pavements and utilize it as natural waste. In this research, the bioasphalt from coconut shells, which are processed to obtain oil from pyrolysis results. The use of coconut shell bio asphalt (BTK) as a rejuvenator in this study was reviewed by adding asphalt to RAP asphalt with a percentage of 35%, 40%, and 45% to the AC-WC HMA mixture. The asphalt mixture was tested by the marshall test, the resilience modulus using the UMATTA in KAO conditions, and the groove resistance test using the Wheel Tracking Machine. The results of bioasphalt research on RAP are the wheel tracking test on the 1260th tracks, the groove depth that occurs on HMA AC-WC without BTK+RAP, HMA AC-WC BTK RAP (35%; 40%; 45%) at 25^{O}C and 45^{O}C were 1,25; 1,20; 1,19; 0,91; 0,58; 0,49; 0,32 and 0,21 mm. It shows that the performance of HMA AC-WC BTK+RAP is better than conventional HMA AC-WC and proves that the use of RAP above 30% (the commonly used) can be carried out and provides better performance as well.

Keywords: *HMA AC-WC; RAP; bioasphalt; wheel tracking test.*

1 Introduction

Road pavement is road construction that composed of certain materials and with a certain layer thickness to be able to withstand the load of the track. Based on the loading philosophy, the closer the material quality is to the surface, the better it is. The surface layer structure has a very important role because this layer will be directly related to traffic loading from vehicle wheels (vertical and horizontal loads) and environmental conditions. In connection with the above and in line with the high price of road construction, the Bina Marga report for 2021 shows that using oil asphalt as a material for road pavement in Indonesia requires around

1,200,000 tons of oil asphalt per year [1]. In order to fulfill the supply and demand for asphalt in Indonesia, an alternative material is needed to replace oil asphalt, and preferably the product must be environmentally friendly. Therefore, this research was developed to find alternative materials as a substitute for oil asphalt based on biomass. The alternative material processed from this biomass is called bioasphalt. According to Bioenergy, using bioasphalt can lower the hot mix asphalt temperature and reduce the cost of asphalt work by 20%, saving greenhouse gas emissions by around 30% [2]. Bioasphalt provides an antioxidant effect that will increase asphalt hardening. So that bioasphalt has a competitive value in the industrial market.

The objectives of this study include: analyzing the effect of reclaimed asphalt pavement (RAP) content and coconut shell bioasphalt on the characteristics of marshall AC-WC, identifying the effect of 35%, 40%, and 45% RAP with coconut shell bioasphalt on AC-WC on mixture performance, determining the highest RAP content with coconut shell bioasphalt which has a mixture performance better or equal to the AC-WC control mixture.

2 Literature

2.1 Reclaimed Asphalt Pavement (RAP)

Suherman defines reclaimed asphalt pavement as a technology as reuses old pavement materials (aggregates and asphalt) into new pavement materials [3]. Recycled materials must improve their properties and quality before being reused, either as asphalt or aggregates. Based on the Hansen and Copeland study conducted by the National Asphalt Pavement Association (NAPA) in the United States, the amount of asphalt used in the asphalt mixture is 71,900,000 tons assuming the asphalt content produced from the asphalt is 5% [4]. Using recycled pavement will save costs, reduces the need for new materials, and maintains pavement geometry [3]. RAP is an environmentally friendly technology that utilizes waste from the road surface so that RAP can be utilized in a high proportion [5].

RAP is limited in some European countries based on bituminous hardness (penetration and softening point). The example for penetration and softening point in some countries are:

Table 1 Example For Penetration And Softening Point In Some Countries [6]

No	Country	Penetration	Softening Point (°C)
1	France	> 5	< 77
2	Belgium	> 10	> 15

3	Germany	> 15	< 70
4	Ireland	> 15	< 70

On the other hand, according to The Asphalt Institute, the percentage of asphalt in hot mix asphalt is about 10% to 35% for production units based on dosing type, while the actual number of production units based on drums is 10% to 50% [6].

2.2 Bio-asphalt

Bioasphalt is an alternative to bitumen made from biomass/non-petroleum materials based on renewable resources [7]. The existence of bioasphalt can be a solution to reduce waste (optimizing the use of biomass) and overcome the shortage of asphalt in the country. Bioasphalt raw materials are cheaper and more abundant, which makes bioasphalt a competitive product. According to [7], the raw material for making bioasphalt is divided into three sources, including industrial waste (cellulose waste, wood lignin, bottom ash, and fly ash), urban areas (scrap rubber and waste tires), and mining waste (coal mine refuse). The initial identification of plant wastes containing lignin that can produce bioasphalt are coconut, oil palm, wood, oak leaves, maple leaves, pine nuts, and sugarcane. Bioasphalt is produced from the pyrolysis process of biomass.

In Indonesia, the raw material for making bioasphalt that has been produced (through the pyrolysis process) is quite large made from coconut shells, while at the research scale the raw materials are biomass from palm oil waste, coconut shells, bagasse, and sawdust [9]. Meanwhile, in developed countries such as America and several European countries, the raw materials used to make bioasphalt include eggplant stems, grass, plastic straws, olive pits, peanut shells, miscanthus, sorghum, swine waste, and microalgae. On an industrial scale, bioasphalt that has proven benefits for road pavements is hydrogen bioasphalt (BituTech RAP) produced in America [2], made from tree/straw waste.

3 Methods

The method used in this study is shown in the research flow chart as shown in Figure 1. In stage II, the manufacture of test objects based on each variation of RAP (35%, 40%, and 45%) was used with the addition of coconut shell bioasphalt (BTK) which can be seen in Figure 2. In calculating the need for asphalt and bioasphalt, the rough asphalt contained in the RAP is calculated. Based on the RAP extraction test results, the asphalt content was 5.15% in the RAP. This study carried out the marshall test, the resilient modulus test, and the wheel tracking test (groove resistance). The resilience modulus test and groove resistance test were tested at two temperatures: 25^{o}C and 45^{o}C.

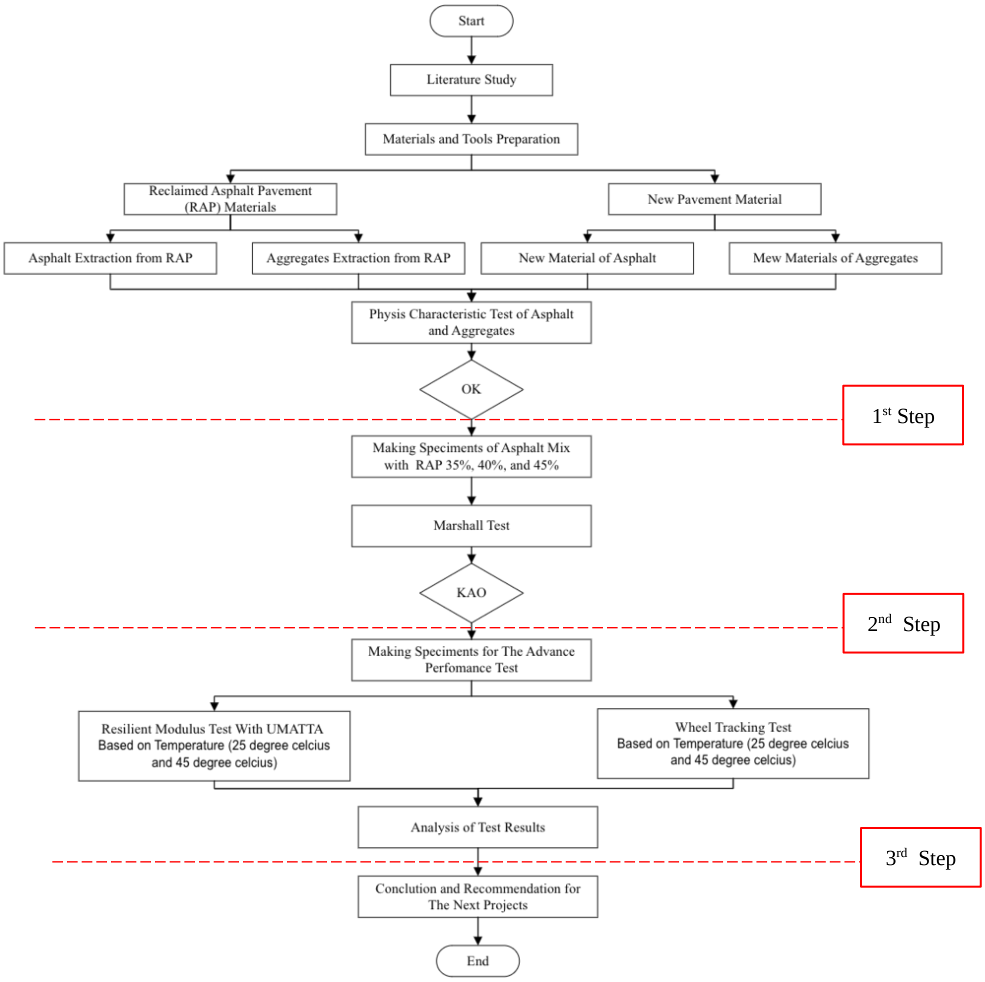

Figure 1 Flow Chart

4 Results

The results of this study include: analyzing the effect of RAP content and coconut shell bioasphalt on the characteristics of marshall AC-WC, identifying the effect of 35%, 40%, and 45% RAP with coconut shell bioasphalt on AC-WC on mixture performance, determining the highest RAP content with coconut shell bioasphalt which has a mixture performance better or equal to the AC-WC control mixture.

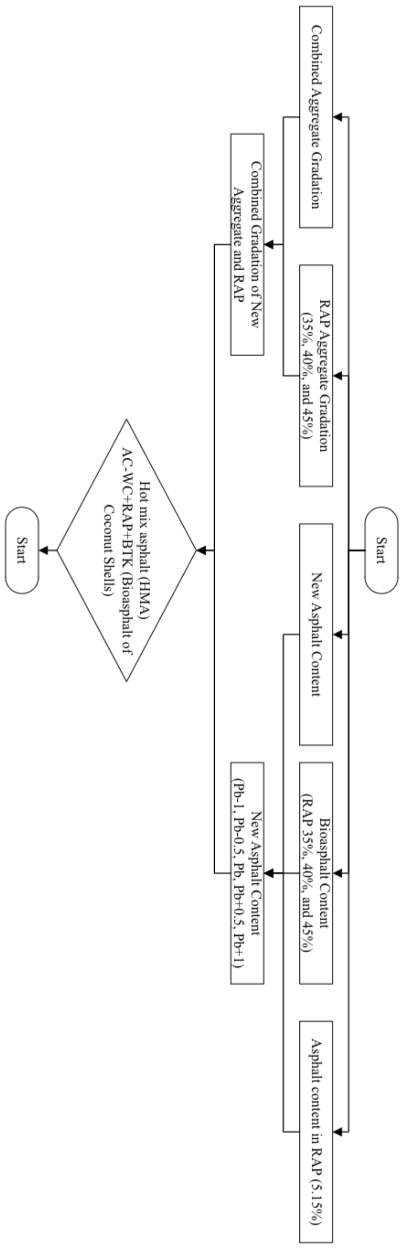

Figure 2 Speciments Design

4.1 Marshall Analysis

Marshall results were obtained with a Pb value of 6% on a mixture of asphalt ACWC + RAP (35%, 40%, and 45%) + BTK. Following are the results of the Marshall test in KAO conditions.

Table 2 Marshal test results for ACW RAP (35%, 40%, 45%) + BTK

Parameters	WMA AC-WC	WMA AC-WC + RAP 35 + BTK	WMA AC-WC + RAP 40 + BTK	WMA AC-WC + RAP 45 + BTK
Optimum Asphalt Content	6,10	5,94	5,85	5,76
Stability (kg)	1424,80	1432,00	1431,00	1430,00
Flow (mm)	3,62	3,68	3,56	3,98
MQ (kg/mm)	394,40	395,50	350,00	329,00
VMA (%)	17,20	16,40	16,40	16,50
VFA (%)	77,60	74,80	75,80	77,00
VIM (%)	3,73	3,60	3,65	4,00
Density (gr/cc)	2,34	2,28	2,30	2,27
Pass Ratio of #200 based on Pbe	1,20	1,01	1,02	0,98

Based on these test results, it can be concluded that RAP in the AC-WC mixture needs to be rejuvenated through a rejuvenator, namely coconut shell bioasphalt (BTK). After adding BTK to the AC-WC RAP mixture with a BTK content of 23% by weight of the asphalt in the RAP, a change in properties occurred, which resulted in the characteristic value of KAO. Then, make 10% to 30% AC-WC RAP test specimens added to BTK and produce good KAO values and asphalt performance. This research identified that percentage RAP above 30% still had good performance because it was still in better condition than conventional AC-WC (seen from marshall test parameters, resilience modulus, and wheel tracking test). Comparison of stability values in the AC-WC RAP 35% + BTK, AC-WC RAP 40% + BTK, and AC-WC RAP 45% + BTK is higher than conventional AC-WC. This is due to the addition of RAP+BTK to asphalt, which makes the pavement layer more rigid. However, when compared with the addition of RAP 35%, 40%, and 45% with BTK, stability was decreased. This decrease is due to the increasing proportion of RAP in the mixture making the mixture more brittle.

Figure 3 on the flow chart shows that the flow value has decreased with the increase in the proportion of RAP due to the modified asphalt properties of AC-WC RAP+BTK, which are increasingly brittle following the properties of RAP which has damaged its elastic properties. In addition, if it is reviewed based on the value of the VFA or the voids in the mixture filled with asphalt, it shows that adding the proportion of RAP in the mixture increases the VFA value. An increase in the VFA value in the AC-WC RAP+BTK mixture indicates that the mixture will be increasingly difficult to compact, which means that from a workability perspective, adding RAP to the mixture is difficult and further studies are needed to improve its workability by using the optimal BTK percentage for high RAP proportions. This is shown in Figure 3 on the VFA graph with a mixture of 45% RAP + BTK which significantly increases VFA value compared to AC-WC RAP 35% + BTK and AC-WC RAP 40% + BTK.

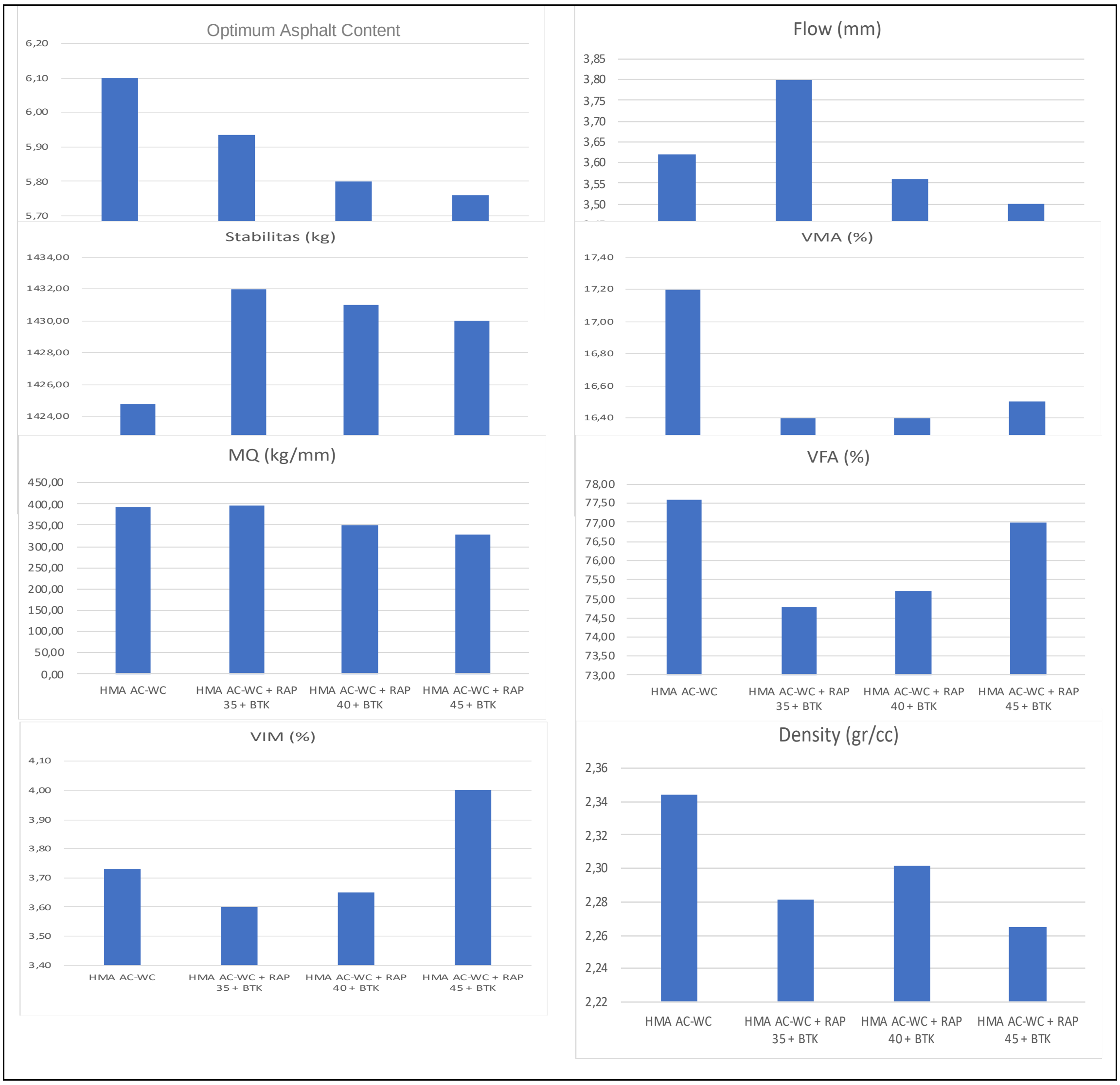

Figure 3 Marshall Charateristcs at Optimum Asphalt Content

4.2 Modulus Resilient Analysis

This test was carried out using the UMATTA test (Figure 4), which was set to a loading pulse width of 250 ms, a pulse repetition period of 3000 ms, and a testing temperature of 25°C and 45°C. Tests at this temperature variation were carried out to see the sensitivity of the asphalt mixture to temperature changes. The results of this test are presented in Table 3 and Figure 5.

Table 3 Modulus Resillient of HMA AC-WC

Temperrature	**Modulus Resilien AC-WC**			
(°C)	**AC-WC**	**RAP 35% + BTK**	**RAP 40% + BTK**	**RAP 45% + BTK**
25	2406	5424	6195	6900
45	333	696	939	1263

Figure 4 The Effect of Temperature Changes on Resilient Modulus Changes

Table 2 and Figure 3 show that at all temperatures, the resilience modulus of AC-WC RAP 45% + BTK was higher than AC-WC RAP 35% + BTK. The resilience modulus of AC-WC RAP 35% + BTK at 25oC is only 79% of the resilient modulus of AC-WC RAP 45% + BTK. This percentage will decrease as the test temperature increases. This value is in line with the Marshall stability value as the AC-WC RAP + BTK has a higher stability value and a higher resilient modulus. When the resilience modulus of AC-WC RAP + BTK is compared to the resilience modulus of AC-WC HMA without RAP and BTK in Figure 4, it can be seen that the resilience modulus of AC-WC RAP + BTK at all temperatures is always greater than the resilience modulus of AC-WC without RAP + BTC. At 25°C, the resilience modulus of AC-WC RAP 35% + BTK, AC-WC RAP 40% + BTK, and AC-WC RAP 45% + BTK each had a resilience modulus of 2.25; 2.57 and 2.87 times greater than the resilient modulus of conventional HMA AC-WC or ACWC without RAP + BTK, respectively.

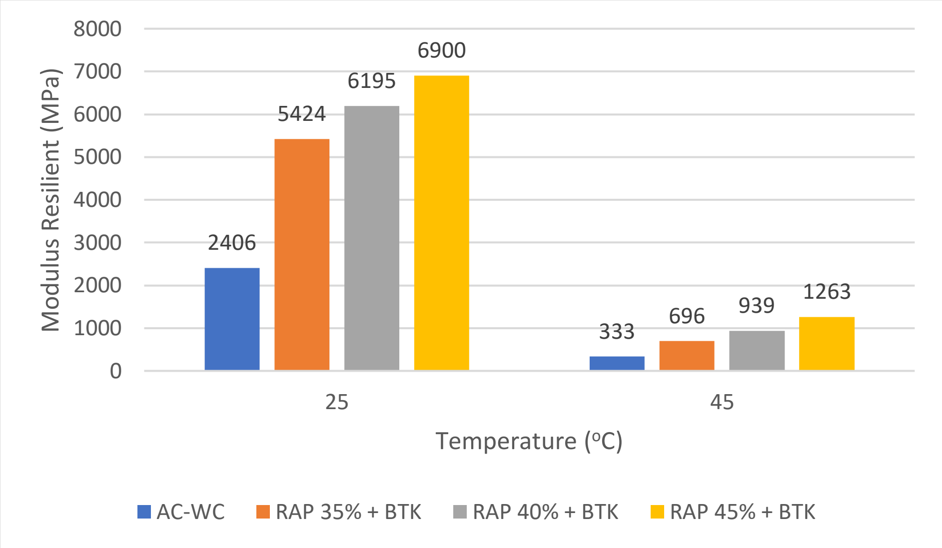

Figure 5 The Effect of Temperature Changes on Resilient Modulus Changes

At 45°C, the resilient modulus of conventional AC-WC, AC-WC RAP 35% + BTK, AC-WC RAP 40% + BTK, AC-RAP 45% decreased to 333, 696, 939, and 1263MPa. In general, the resilience modulus has an inverse relationship with temperature, meaning that the higher the temperature, the lower the resilient modulus of the mixture. This is due to the nature of asphalt which becomes softer as the temperature increases, causing the asphalt mixture to soften too. The lowest resilient modulus is found in conventional HMA or without bioasphalt. This is due to the asphalt added with bioasphalt as a binder for the HMA mixture, which has rejuvenating properties.

Figure 3 shows that an increase in temperature greatly affects the decrease in the value of the resilient modulus. This happens because the higher the temperature given the elastic properties of the asphalt will decrease, so the bonds between the aggregates in the mixture become non-interlocking. When asphalt no longer acts as a binder, a mixture that has a high Resilient Modulus value is a mixture that has asphalt with large PI and Sbit values. The effect of temperature gives a very significant difference in the value of the resilient modulus. This is because asphalt is visco-elastic, in which its properties can change from viscous to elastic and vice versa due to temperature changes. The results of the 45°C temperature test show the smallest resilient modulus value compared to the 25°C temperature test.

4.3 Wheel Tracking Test Analysis

The groove resistance test used a wheel tracking machine (WTM). The test was carried out on a rectangular specimen with dimensions of 30 cm x 30 cm x 5 cm with a wheel track of 1260 times at a temperature representing the temperature of the asphalt layer in the field. In Indonesia, it was carried out at temperatures ranging between 25^{o}C and 45^{o}C. In the WTM test, the three main parameters obtained as a result of the test are Initial Stability (DO), Deformation Speed (Rutt Depth, RD), and Dynamic Stability (DS).

In this study, the WTM test was conducted to see the resistance to HMA grooves made using RAP + BTK as a modified material, those are AC-WC RAP 35% + BTK, AC-WC RAP 40% + BTK, AC-RAP 45% + BTK . To determine the superiority or inferiority of AC-WC RAP + BTK resistance grooving, conventional AC-WC (without coconut shell bioasphalt) was used as a comparison.

Table 4 Wheel Tracking Test Results at 25^{o}C

Time	Passing	ACWC Speciments			
		RAP 0%	RAP 35%	RAP 40%	RAP 45%
0	0	0,00	0,00	0,00	0,00
1	21	0,40	0,33	0,27	0,25
5	105	0,67	0,58	0,52	0,46
10	210	0,79	0,72	0,70	0,57
15	315	0,88	0,85	0,80	0,63
30	630	1,04	0,99	0,98	0,75
45	945	1,14	1,10	1,10	0,83
60	1260	1,25	1,20	1,19	0,90

Table 5 Wheel Tracking Test Results at 25^{o}C

Time	Passing	ACWC Speciments			
		RAP 0%	RAP 35%	RAP 40%	RAP 45%
0	0	0,00	0,00	0,00	0,00
1	21	0,18	0,18	0,06	0,01
5	105	0,30	0,28	0,11	0,06
10	210	0,34	0,34	0,16	0,10
15	315	0,38	0,36	0,19	0,12
30	630	0,46	0,42	0,24	0,16
45	945	0,53	0,45	0,29	0,19
60	1260	0,58	0,49	0,32	0,21

The results of WTM testing on all types of AC-WC used in this study are presented in Table 4 and Table 4. The relationship between groove depth and number of passes can be seen in Figure 5 and Figure 6.

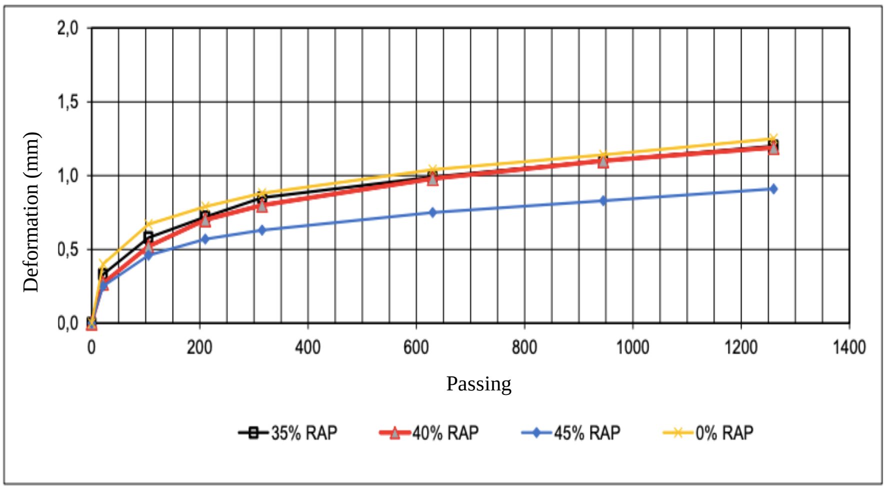

Figure 6 Correlation of Groove Depth with Number of Passes (25°C)

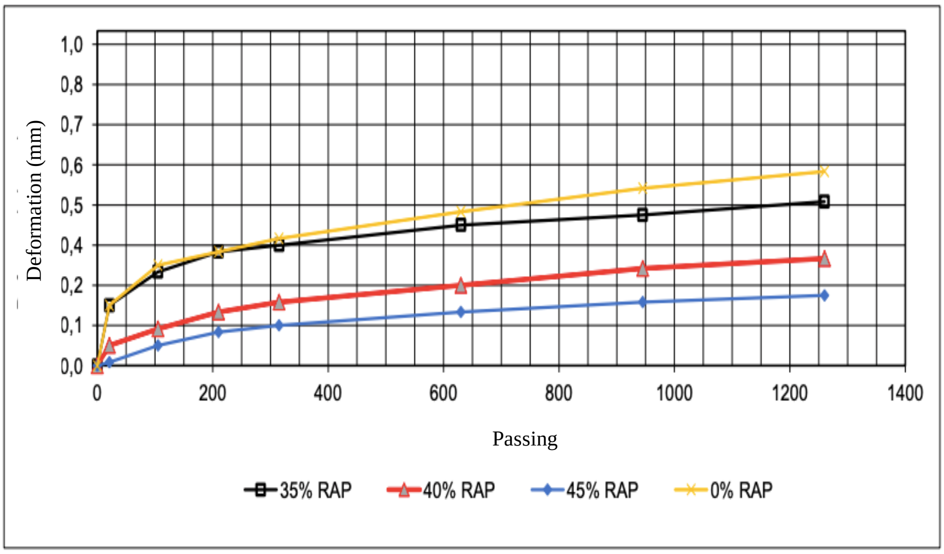

Figure 7 Correlation of Groove Depth with Number of Passes (45°C)

The 1260th track, the depth of the grooves that occur on HMA AC-WC without RAP + BTK, HMA AC-WC RAP 35% + BTK, HMA AC-WC RAP 40% + BTK, and HMA AC-WC RAP 45% + BTK at 25°C and 45°C respectively are 1.25; 1.20; 1.19; 0.91; 0.58; 0.49; 0.32 and 0.21 mm. Based on the WTM test results, it can be concluded that HMA AC-WC RAP + BTK (HMA AC-WC RAP 35% + BTK, HMA AC-WC RAP 40% + BTK and HMA AC-WC RAP 45% + BTK) have much groove resistance. Better than HMA AC-WC without RAP + BTK.

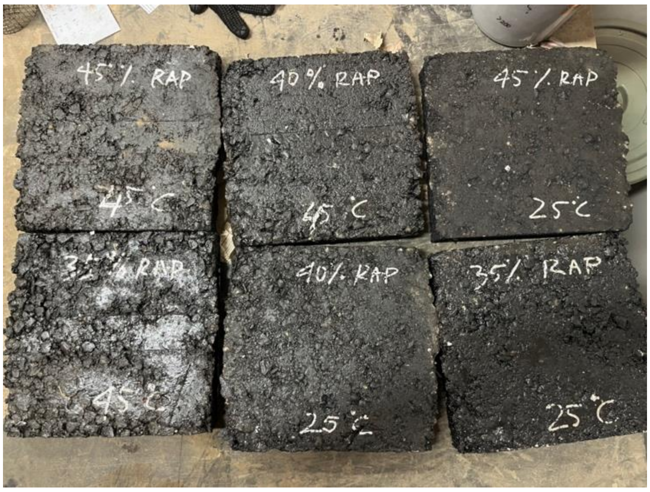

Figure 8 The Speciments Condition After Wheel Tracking Test

Based on Figure 7, it shows that the depth of the grooves mixed with coconut shell bioasphalt is very small, the average deformation that occurs is less than 1,5 mm

5 Conclutions

Based on the results of this study, several conclusions were obtained as follows.

1. Increasing the percentage of RAP and Coconut Shell Bioasphalt (BTK) affects Marshall's characteristics of the HMA AC-WC mixture. The KAO value for conventional HMA AC-WC (without RAP and BTK) was 6.10%, while for HMA AC-WC RAP + BTK with RAP percentages of 35%, 40%, and 45%, respectively it was 5.94%; 5.85% and 5.76%. The value of the conventional Marshall Quotient HMA AC-WC, HMA AC-WC RAP + BTK with RAP percentages of 35%, 40%, and 45%, respectively is 394.40; 395.50; 350.00 and 329.00 kg/mm.
2. The higher the percentage of RAP in the mix, the better the performance in testing the marshall mix, resilient modulus, and wheel tracking. At temperature modulus resilience AC-WC RAP 35% + BTK, AC-WC RAP 40% + BTK, AC-WC RAP 45% + BTK each has a resilient modulus 2.25; 2.57 and 2.87 times greater than the resilience modulus of AC-WC Conventional HMA or ACWC without RAP + BTK. wheel tracking test on track 1260, groove depth that occurs on HMA AC-WC without RAP + BTK, HMA AC-WC RAP 35% + BTK, HMA AC-WC RAP 40% + BTK and HMA AC-WC RAP 45% + BTK at 25oC and 45oC were 1.25; 1.20; 1.19; 0.91; 0.58; 0.49; 0.32 and 0.21 mm. from the performance results of this asphalt

mixture proves that further use of RAP above 30% can be carried out and provides better performance as well.

3. All speciments of AC-WC RAP + BTK mixes have better-mixed performance than conventional ones. From the laboratory test results, it can be concluded that the HMA AC-WC RAP 45% + BTK mixture is the composition that has the highest performance.

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