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Utilization of Concrete Waste as the Substitute for Coarse Aggregates in Asphalt Mixtures

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Abstract This paper aims to determine the Marshall properties of Asphalt Concrete-Wearing Course (AC-WC) and Hot Rolled Sheet-Wearing Course (HRS-WC) with the utilization of concrete waste and also to determine the percentage of concrete waste added into AC-WC and HRS-WC as the substitute for coarse aggregates. During the manufacture of asphalt mixtures, coarse aggregates, and fine aggregates are required in large quantities. To reduce fresh aggregates in the manufacture of asphalt mixtures for road pavement, concrete waste has become an alternative. This study used 60/70 penetration asphalt, coarse aggregate, fine aggregate and concrete waste of 0%, 20%, and 40%. The test was conducted using Marshall test tool, which consisted of two stages of testing. The first stage, Marshall test, was performed to determine the optimum bitumen content of asphalt mixture with a concrete waste variation of 0%, 20%, and 40%. The second stage of Marshall test was conducted to determine the Marshall properties (stability, flow, Marshall Quotient, VMA, VFWA, and VIM) by performing in the asphalt mixture with concrete waste variations of 0%, 20%, and 40%. The results showed that as a performance indicator of asphalt mixtures that acted as the variation addition in concrete waste in AC-WC and HRS-WC asphalt mixtures, Marshall properties decreased in Stability values, Marshall Quotient and VFWA, whereas the values of Flow, VIM, and VMA experienced an increase. The utilization of concrete waste up to 20% as the substitute for coarse aggregate was acceptable for respective AC-WC and HRS-WC asphalt mixture. The maximum acceptable variation of concrete waste was 35% for AC-WC asphalt mixture and 29% for HRS-WC asphalt mixture.

Keywords Concrete Waste, Marshall Properties, Asphalt Concrete-Wearing Course (AC-WC), Hot Rolled Sheet-Wearing Course (HRS-WC)

1. Introduction

In the manufacture of asphalt mixtures, coarse aggregates and fine aggregates are required in large amount [1]. By the increasing infrastructure developments using aggregate in various regions, this will prompt damages to the ecosystem around the aggregate mining area [2] and [3]. To reduce the use of fresh aggregates directly from nature, recycled materials, including waste materials have opted for asphalt mixtures on road pavement.

One of the waste materials utilized as the substitute for new aggregates is concrete waste. Concrete waste might originate from the debris remaining by earthquakes, fires in buildings, demolition of buildings, and factory defect of concrete waste from a precast process that will pollute the environment [4]. Previous studies show that concrete waste can be utilized in the manufacture of either structural or non-structural concrete, substitute material for flexible pavement, soil stabilization, and has a positive impact on the environment.

Utilization of structural/ building waste as an alternative to coarse concrete aggregate, which is structural demolition waste and concrete waste, is splintered into aggregate size of rubble stone with a maximum size of 40mm. The results of this testing indicate that structural waste can be applied as an alternative to coarse concrete aggregate, particularly as non-structural elements [5]. Bardosono and Herbudiman [6] use recycled concrete for the substitution of coarse aggregate in high-quality concrete. The rate of concrete fragment substitution as optimum coarse aggregate is 25%. Waste concrete powder (WCP) can also be deployed as a substitute for cement in mortars [7]. The use of concrete waste as coarse aggregate and fine aggregate shows the behavior of compressive strength value that is close to the use of natural aggregate at each level of resistance duration of concrete and the compressive strength value of concrete waste as fine aggregate is higher than the use of concrete waste as coarse aggregate [8]. Galitskova and Limarjeva [9] conduct a study on the characteristics of construction materials from concrete waste. The results show that small fractions of concrete fragment are better than large fractions and produces stronger concrete. It is also in line with [10] that the smaller the size of the concrete waste fragment of coarse aggregate will produce firmer compressive strength of concrete. Soelarso et al. [11] use concrete waste as the substitute for coarse aggregate for normal concrete. The results of the study explain that the greater use of concrete waste will reduce the compressive strength and elasticity modulus of normal concrete. Gyurko et al. [12] utilize waste aerated concrete in lightweight concrete fabrication. Lu et al. [13] combine waste glass and recycled concrete aggregates, which can be utilized for pervious concrete. Ghorbani et al. [14] use 25% crushed concrete waste (CCW), which can increase the strength of concrete mixtures.

Concrete waste as the substitute for coarse aggregate material for cement-treated base (CTB) in flexible pavement is researched by Saepudin [15]. The use of 25% concrete waste at 10% cement content, fortunately, qualifies for the CTB compressive strength specifications. Ansori [16] took advantage of concrete as the substitute for coarse aggregate in asphalt concrete-binder course (AC-BC) mixture. Furthermore, Hairulla et al. [17] used concrete waste for expansive soil stabilization materials. The unconfined compressive strength (UCS) value increased 85.18% along with the increase in concrete waste, and the highest UCS value was obtained at 40% concrete waste content.

The utilization of concrete waste will also bring a positive impact on the environment. Concrete production and demolition waste, and lime production waste can be processed into construction materials [18]. Widyawati [19] examines green concrete, which is environment-friendly concrete. One of them is the concrete aggregate replacement with environment-friendly material. Thus, the thread drawn from previous research is that the compressive strength of environmentally friendly concrete (green concrete) meets the requirements of compressive strength of concrete structures. Lebrun et al. [20] manage concrete waste for H2S filtration, and it will bring benefits for the humidification step in biofiltration systems. According to Letelier [21], the combination of glass powder and fine recycled concrete aggregate on mortar will reduce CO_2 emission and greenhouse gas.

Asphalt Concrete - Wearing Course (AC-WC) and Hot Rolled Sheet - Wearing Course (HRS-WC) are asphalt mixtures used as wear layers in flexible pavement construction. The two types of asphalt mixture have different gradations. AC-WC has well-graded aggregate, whereas HRS-WC has gap graded gradation [22]. Asphalt mixture performance, including stability, flow, Marshall Quotient, VMA, VFWA, and VIM, can be found through Marshall test.

This study aims to determine the Marshall properties of AC-WC and HRS-WC asphalt mixture and to compare the Marshall properties of the two types of mixtures using concrete waste as the substitute for coarse aggregate to reduce fresh aggregate use from nature and utilize concrete waste instead. Also, this research aims to find the percentage of concrete waste included in the AC-WC and HRS-WC asphalt mixtures as the substitute for coarse aggregate.

2. Materials and Methods

This research began with component testing of asphalt mixtures: asphalt, coarse aggregate, and fine aggregate and concrete waste testing as the substitute for some part of coarse aggregate and arranging gradation planning of aggregate mixture for AC-WC and HRS-WC asphalt mixture. Then, the step was to find optimum bitumen content for each percentage of concrete waste variation for asphalt mixture: AC-WC and Hot HRS-WC. The percentage of variations of concrete waste as the substitute for part of the coarse aggregate was 0%, 20%, and 40% of the total coarse aggregate. Provisions of asphalt, coarse aggregate, fine aggregate, and asphalt mixture refer to General Specifications of Bina Marga 2010 [22]. To find the performance of AC-WC and HRS-WC mixture using Marshall test, the specimens were created based on the optimum bitumen content for each percentage of concrete waste. Marshall test was carried out on both asphalt mixtures in various percentages of concrete waste. The measured performance was based on

Marshall properties; stability, flow, Marshall Quotient, VMA, VFWA, and VIM. The next step was to analyze the effect of percentage variation of concrete waste as the substitute for coarse aggregate on Marshall properties for AC-WC and HRS-WC asphalt mixture.

2.1. Materials

The materials used were asphalt penetration 60/70, coarse aggregate, fine aggregate and concrete waste qualified for General Specifications of Bina Marga 2010 [22]. Quality control of concrete waste followed coarse aggregate specifications. The results of asphalt, fine aggregate, coarse aggregate, and concrete waste are shown in Table 1, Table 2, Table 3, and Table 4, respectively, while the combined gradation for AC-WC and HRS-WC asphalt mixture is shown in Figure 1.

Table 1. Physical properties of asphalt penetration 60/70

Physical property	Specification	Value
Penetration at 25°C (0,1 mm)	60-79	66
Softening point (°C)	≥ 48	53,5
Ductility (mm)	≥ 100	≥ 100
Flash point (°C)	≥ 232	270
Specific gravity	≥ 1,0	1,07

Table 2. Physical properties of fine aggregate

Physical property	Specification	Value
Bulk Specific Gravity	-	2,59 gr
SSD Specific Gravity	-	2,70 gr
Apparent Specific Gravity	-	2,91 gr
Water Absorption	≤ 5%	4,17%
Sand Equivalent	≥ 60%	96,6%

Table 3. Physical properties of coarse aggregate

Physical property	Specification	Value
Los Angeles Abrasion	≤ 30%	20,90%
Bulk Specific Gravity	-	2,49 gr
SSD Specific Gravity	-	2,50 gr
Apparent Specific Gravity	-	2,52 gr
Water Absorption	≤ 3%	0,51%
Aggregate viscosity against asphalt	≥95%	100%

Table 4. Physical properties of concrete waste

Physical property	Specification	Value
Los Angeles Abrasion	≤ 30%	25,30%
Bulk Specific Gravity	-	2,15 gr
SSD Specific Gravity	-	2,29 gr
Apparent Specific Gravity	-	2,52 gr
Water Absorption of aggregate	≤3%	6,77%
Aggregate viscosity against asphalt	≥ 95%	100%

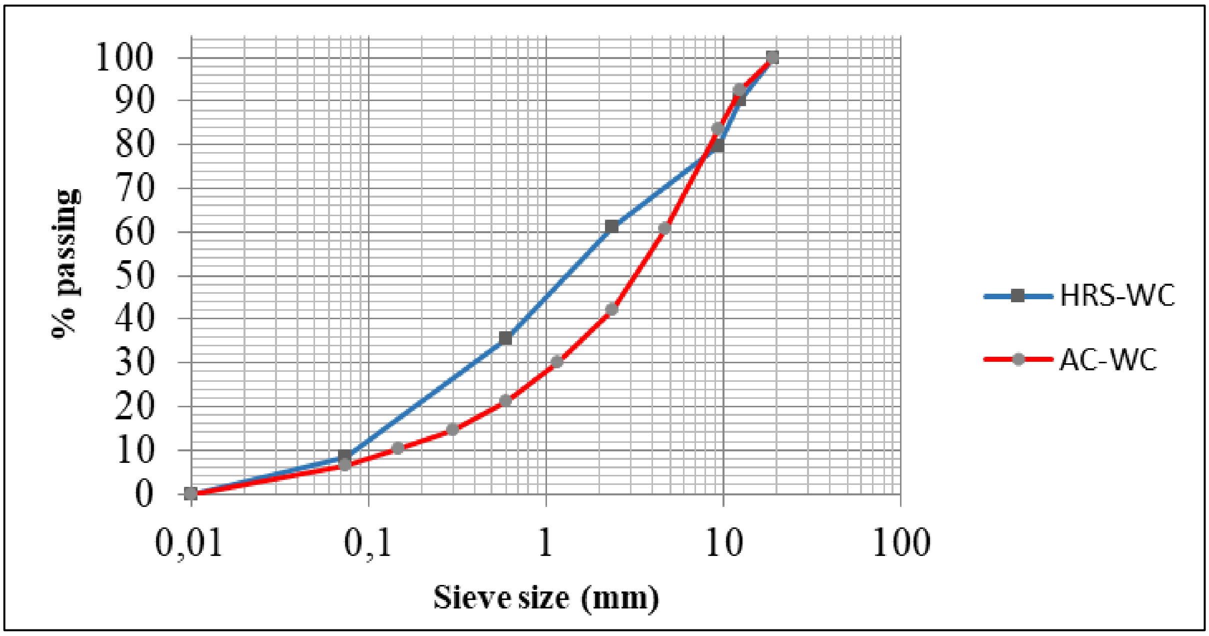


Figure 1. Aggregate gradations for AC-WC and HRS-WC mixtures

2.2. Specimens Preparation

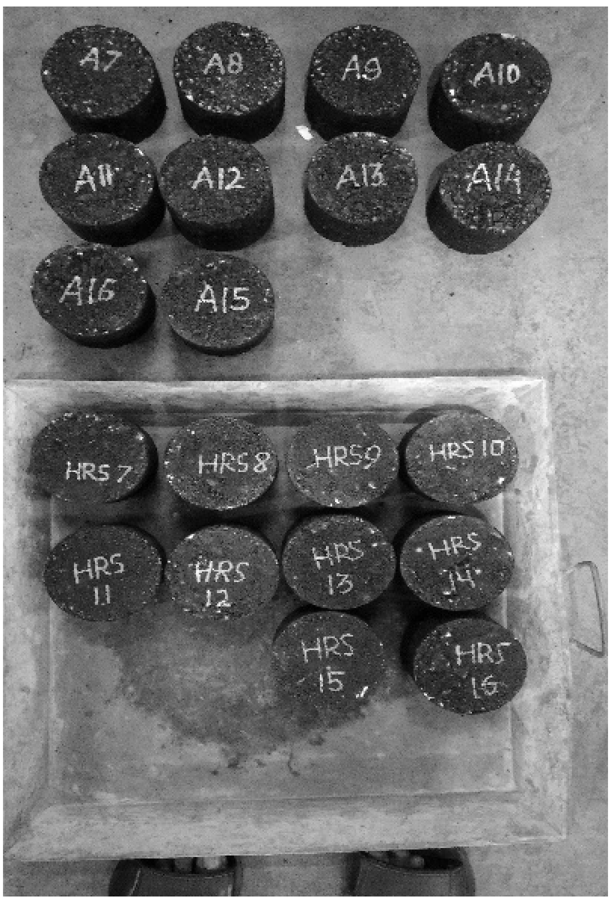


Figure 2. Specimens for Marshall Test

Specimens were made with a cylindrical shape of 100 mm diameter and 63.5 mm height as shown in Figure 2 [23], [24], [25], [26], [27], [28], and [29]. Manufacture specimens included specimens to obtain optimum asphalt content for each variation of concrete waste and specimens to obtain Marshall properties based on optimum bitumen content for each variation of concrete waste. Specimens were made into two types of asphalt mixtures, AC-WC and HRS-WC.

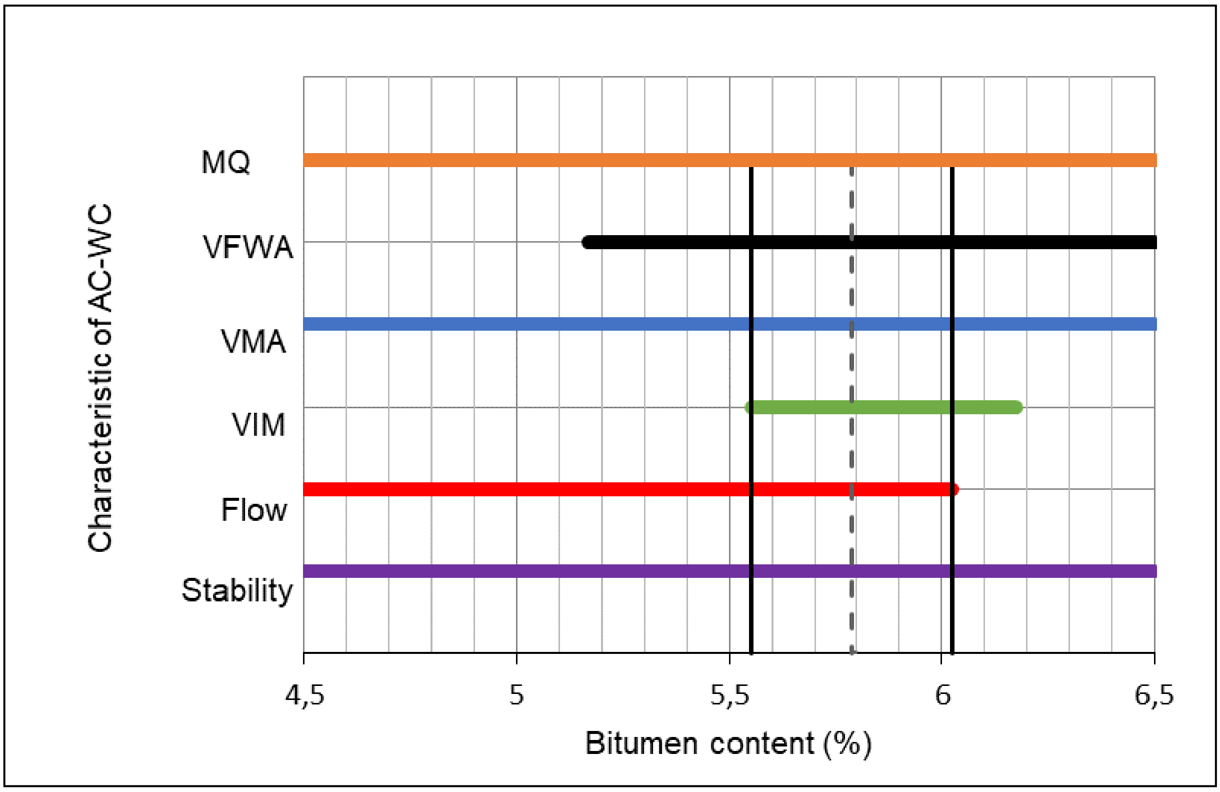
2.3. Test Method

This study used Marshall test. Marshall test was conducted in two stages for AC-WC and HRS-WC asphalt mixtures. The first stage Marshall test, was performed to determine the optimum bitumen content of asphalt mixture with a concrete waste variation of 0%, 20%, and 40%. The second stage of Marshall test was administered to determine the Marshall properties (stability, flow, Marshall Quotient, VMA, VFWA, and VIM) asphalt mixture with concrete waste variations of 0%, 20%, and 40%.

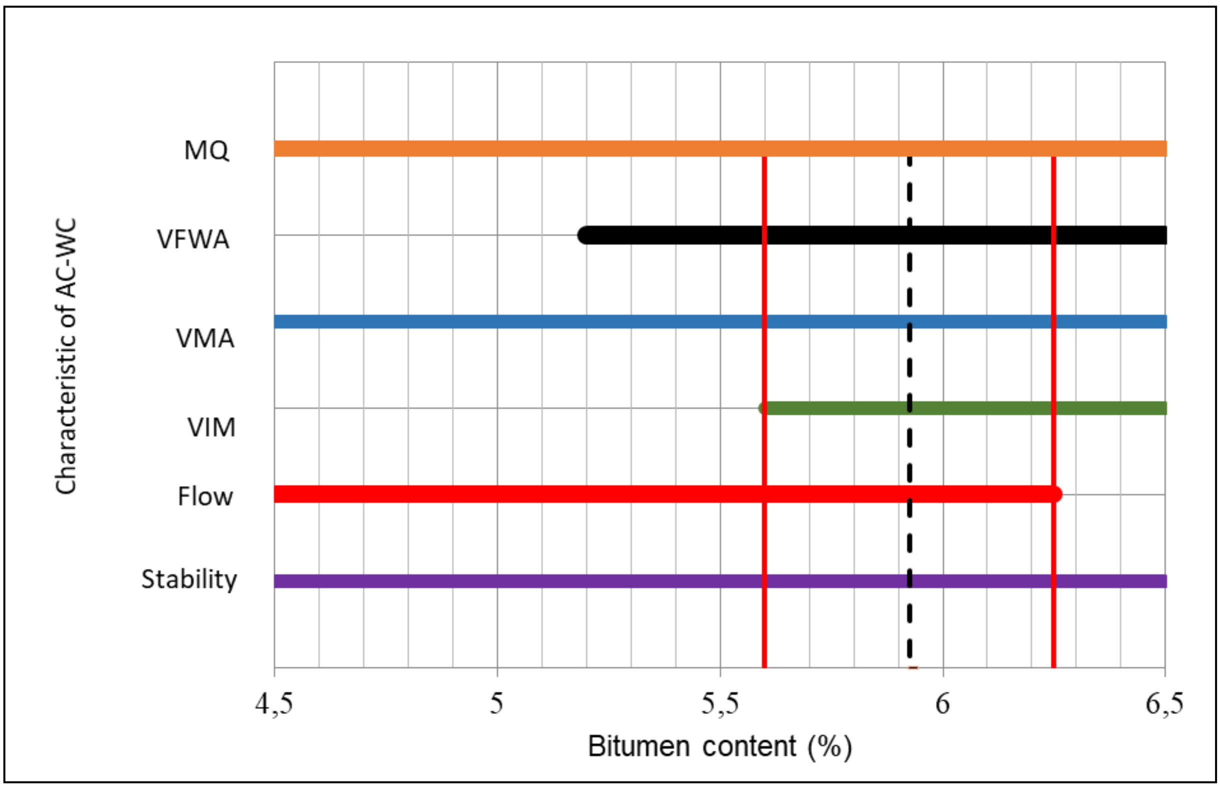
2.3.1. Marshall Test to Determine Optimum Bitumen Content

To determine the optimum bitumen content of AC-WC asphalt mixture, the variations of bitumen content used were 4.5%, 5%, 5.5%, 6%, and 6.5%, while for HRS-WC asphalt mixture the variations of asphalt content used were 5%, 5.5%, 6%, 6.5%, and 7%.

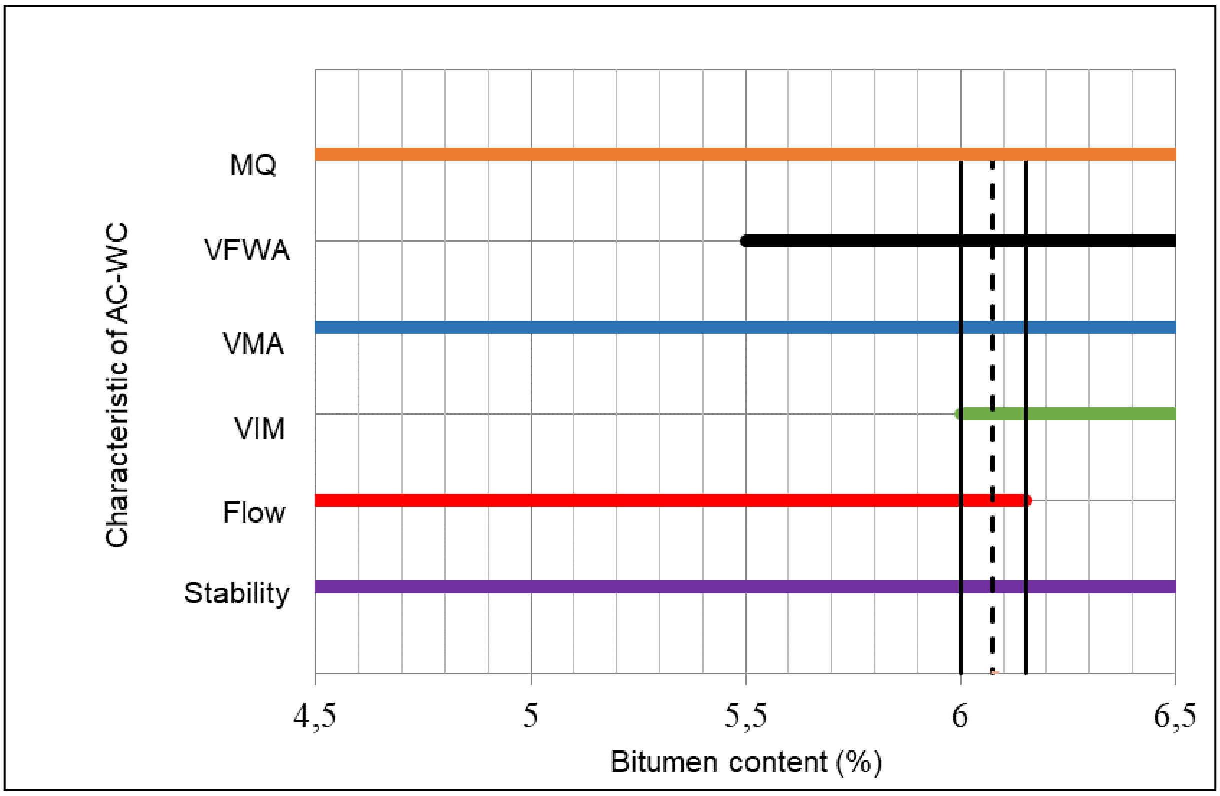
Based on Marshall test, it was obtained optimum bitumen content of AC-WC mixture for concrete waste variation 0% = 5.80%; 20% = 5.93% and 40% = 6.08% as presented in Figure 3. The optimum bitumen contents of the HRS-WC asphalt mixture for concrete waste variation were 0% = 6.35%; 20% = 6.45% and 40% = 6.60% as shown in Figure 4.


MQ
VFWA
VMA
VIM
Flow
Stability
Characteristic of AC-WC
4,5
5
5,5
6
6,5
Bitumen content (%)

(a)

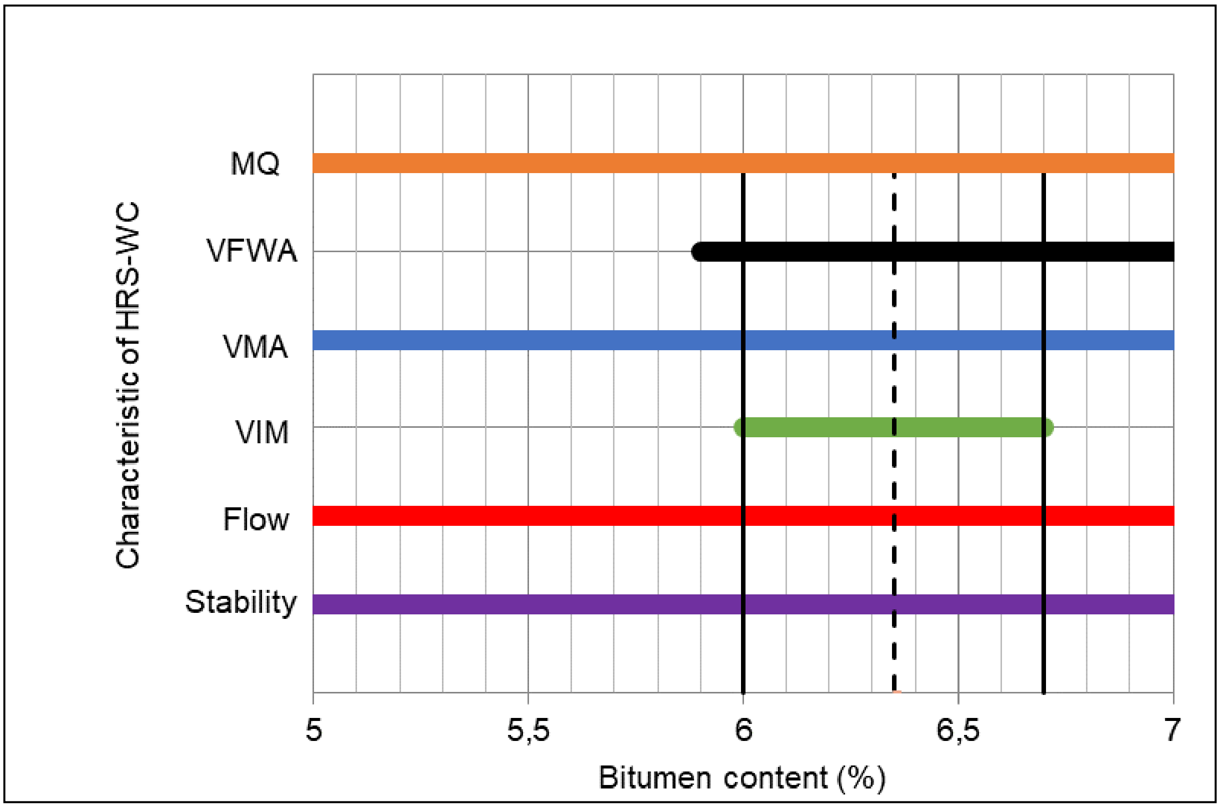

MQ
VFWA
VMA
VIM
Flow
Stability
Characteristic of AC-WC
4,5
5
5,5
6
6,5
Bitumen content (%)

(b)

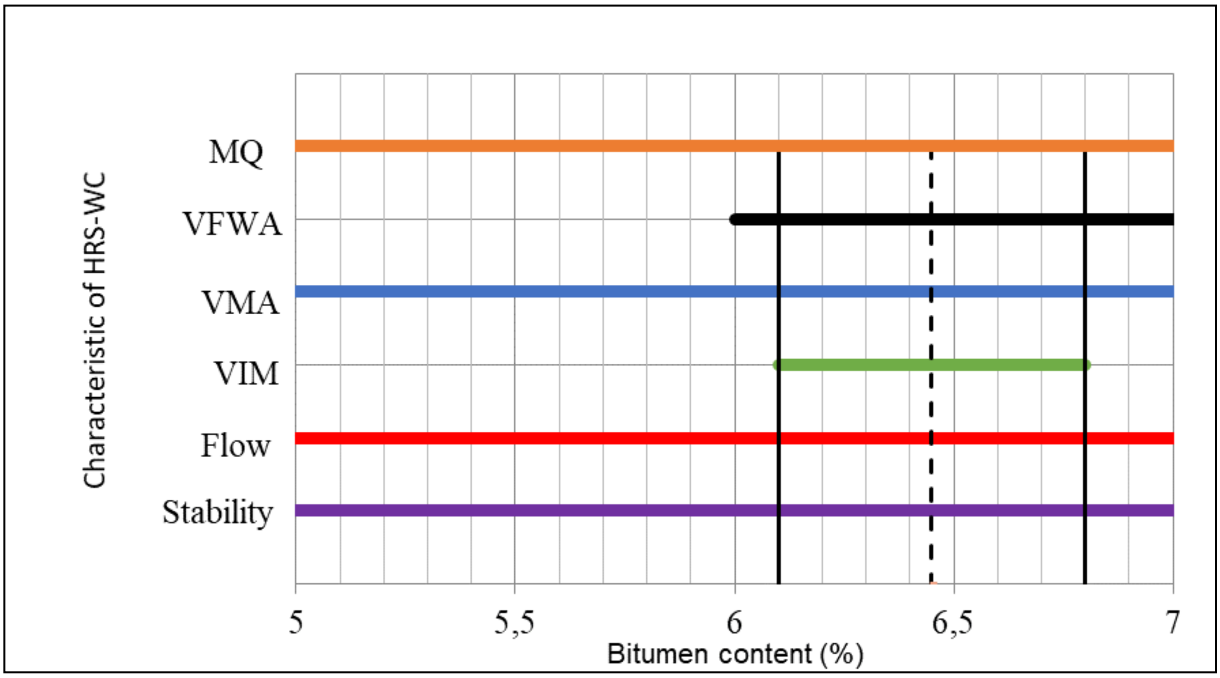


(c)

Figure 3. (a) optimum bitumen content AC-WC with 0% concrete waste (b) optimum bitumen content AC-WC with 20% concrete waste (c) optimum bitumen content AC-WC with 40% concrete waste



(a)



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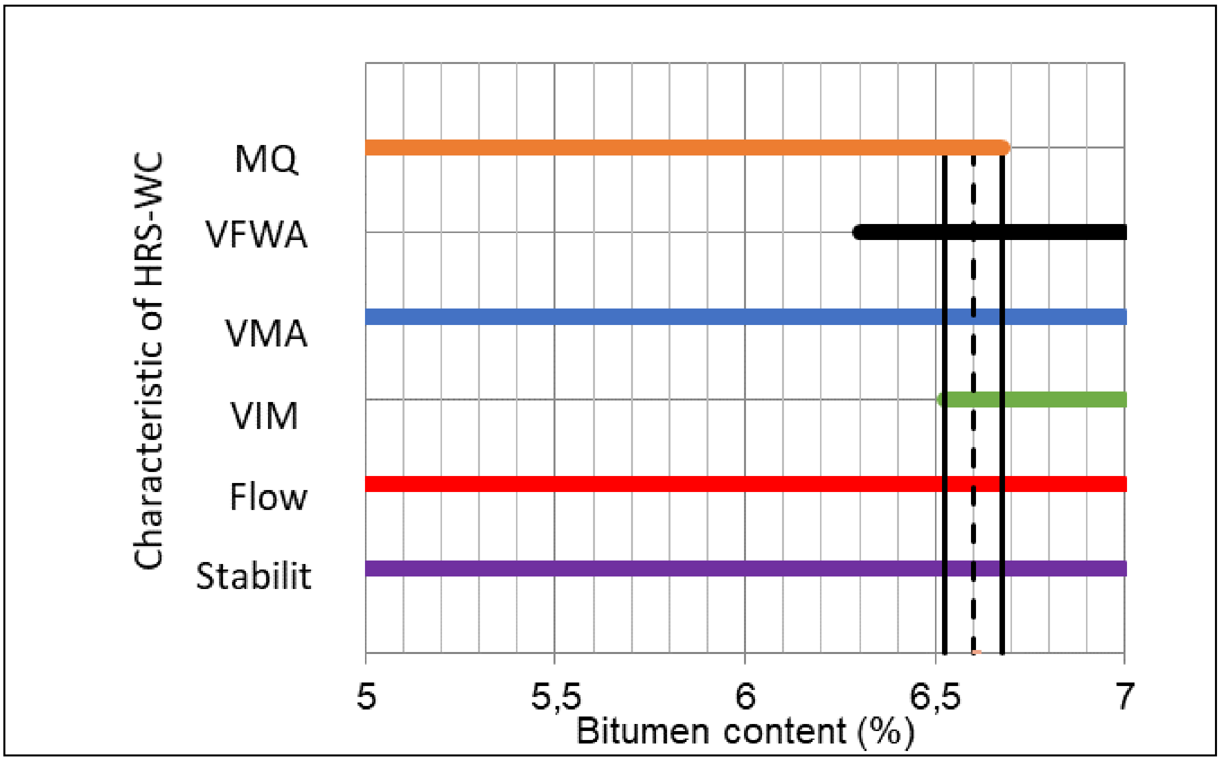

(c)

Figure 4. (a) optimum bitumen content HRS-WC with 0% concrete waste (b) optimum bitumen content HRS-WC with 20% concrete waste (c) optimum bitumen content HRS-WC with 40% concrete waste

2.3.2. Marshall Test to Determine Marshall Properties

From the obtained optimum bitumen content for each variation of concrete waste from the first phase Marshall test, Marshall test then was performed to determine the Marshall properties. Marshall test was conducted on AC-WC and HRS-WC asphalt mixture. Optimum concentrations of AC-WC asphalt mixture for concrete waste variation were 0% = 5.80%; 20% = 5.93% and, 40% = 6.08%. While the optimum concentrations of HRS-WC asphalt mixture for concrete waste variation were 0% = 6.35%; 20% = 6.45%, and 40% = 6.60%. The results of this test will be discussed in the next chapter.

3. Results and Discussion

Marshall characteristics of AC-WC and HRS-WC with concrete waste variations on each optimum bitumen content obtained values of stability, flow, VIM, VMA, VFWA, and Marshall Quotient are shown in Table 5, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10.

3.1. Comparison of AC-WC and HRS-WC Asphalt Mixture Marshall Properties with the Variation of Concrete Waste

Marshall properties, namely stability, flow, Marshall Quotient, VMA, VFWA, and VIM, are indicators of asphalt mix performance.

3.1.1. Stability

Stability is the ability of asphalt mixture against plastic deformation. Also, stability can be defined as the ability of the road pavement layer to serve traffic without undergoing permanent deformation, such as bumps and grooves. According to the General Specifications of Bina Marga 2010 [22], there is minimum requirement for AC-WC and HRS-WC mixture with minimum of 800 kg.

The stability value of each waste variation for respective AC-WC and HRS-WC asphalt mixture tended to decrease for each addition of concrete waste, as shown in Figure 5. The decrease occurred as concrete waste had a poorer ability compared to fresh aggregate, as shown in the abrasion value of concrete waste, which tended to be high or fragile. A significant decrease occurred in HRS-WC asphalt mixture, whereas in AC-WC asphalt mixture, the decrease was not significant. The stability value of AC-WC asphalt mixture tended to be higher than the HRS-WC asphalt mixture due to the use of well-graded aggregate, which evoked slightly permeable pore since it would cover from small to large aggregates and had quality density levels. Also, the ability to lock between aggregates would be good to obtain better stability than the HRS-WC mixture using gap graded aggregate.

3.1.2. Flow

Flow is the amount of decline in the specimen mixtures caused by a load to the limit of collapse or deformation of the test object. Flow is the flexibility indicator of hot asphalt mixture to serve traffic, in which the high value of the flow in the mixture may generate more plastic behavior in the mixture, which can change shape or be caused by traffic and vice versa. 2010 General Specification of Bina Marga determines the flow value limits for AC-WC asphalt mixture is 2-4 mm, while HRS-WC asphalt mixture is of 3 mm at the minimum.

Flow values tend to increase with the addition of a greater variety of concrete waste for both AC-WC and HRS-WC asphalt mixture, as presented in Figure 6. The increase was caused by concrete waste aggregate having a higher asphalt absorption value and being more fragile than fresh aggregate. The AC-WC asphalt mixture flow did not increase significantly, while the HRS-WC flow value experienced a significant increase in the variation of 40% of concrete waste. The flow value of the HRS-WC asphalt mixture was higher than the AC-WC asphalt mixture.

Table 5. Marshall Characteristics

No.	Marshall characteristics	Specification		Concrete waste aggregate content					
				AC-WC			HRS-WC		
		AC-WC	HRS-WC	0%	20%	40%	0%	20%	40%
1	Stability (kg)	≥ 800	≥ 800	1412.3	1426.54	1388.9	1319.51	1313.9	1142.33
2	Flow (mm)	2 < 4	≥ 3	3.57	3.80	3.93	3.77	3.90	4.55
3	VIM (%)	3 < 5	4 < 6	4.54	4.74	5.11	5.46	5.73	6.46
4	VMA (%)	≥ 14	≥ 18	17.53	17.82	18.31	19.61	20.31	20.98
5	VFWA (%)	≥ 65%	≥ 65%	74.14	73.60	72.08	72.25	72.01	69.44
6	Marshall Quotient (kg/mm)	≥ 250	≥ 250	402.03	376.30	354.92	356.37	337.59	251.07

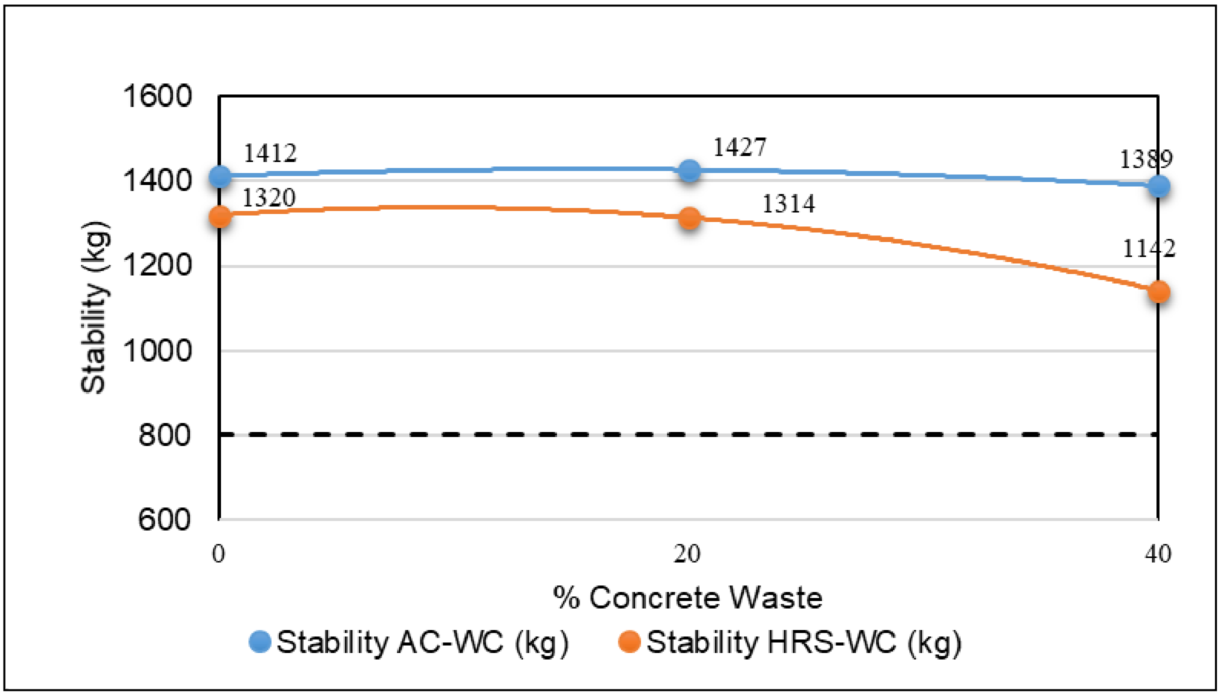

Figure 5. Comparison of AC-WC and HRS-WC Asphalt Mixtures Stability with variation of concrete waste

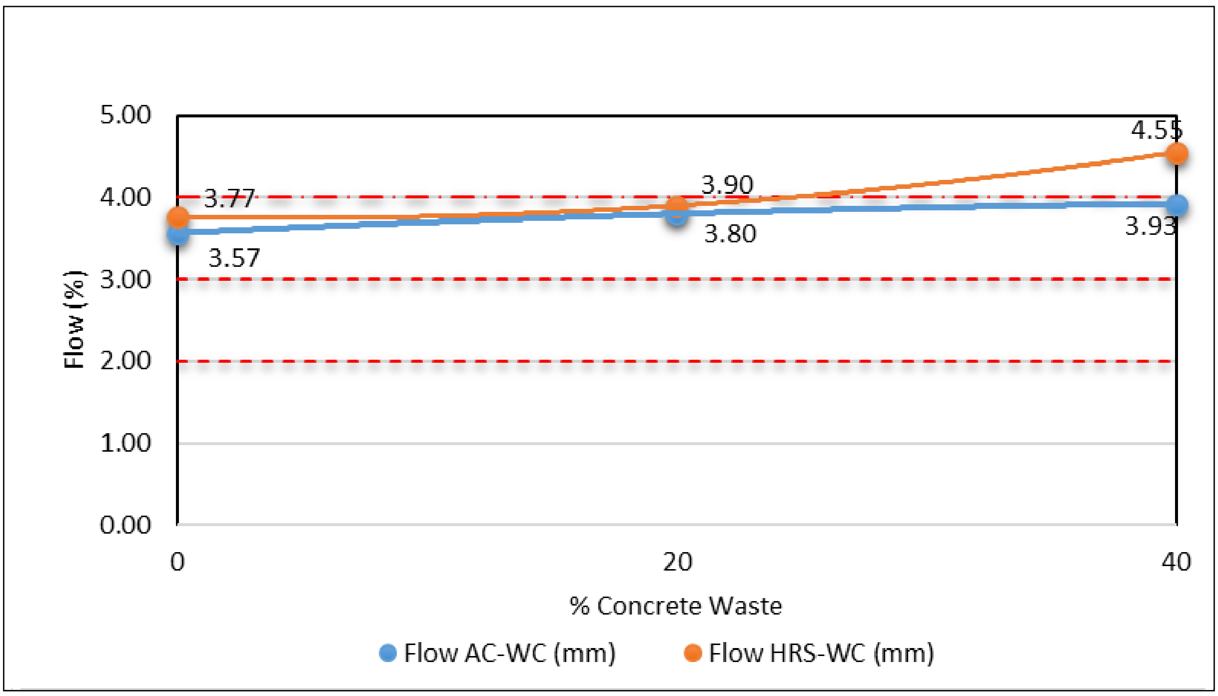

Figure 6. Comparison of AC-WC and HRS-WC Asphalt Mixture Flow with variation in concrete waste

3.1.3. Marshall Quotient

Marshall Quotient is ratio stability to flow and is expressed in kg/mm. The Marshall Quotient value is the indicator of potential flexibility to deformation. The Marshall Quotient value depends on the stability value, which is affected by the friction between the grains and gradation aggregate, as well as the flow influenced by the asphalt content, viscosity, materials gradation, and the number of collisions. General Specification of Bina Marga 2010 [22] states that the minimum value for Marshall Quotient is 250 kg/mm for both AC-WC and HRS-WC asphalt mixtures.

Based on Figure 7, it shows that Marshall Quotient value for each variation of concrete waste for the AC-WC asphalt mixture includes specifications, whereas in the

HRS-WC asphalt mixture of 40% concrete waste variation is not specified. Marshall Quotient value tended to decline in higher concrete content. It occurred due to concrete waste had a large abrasion value, which affected the density value of asphalt concrete mixture; in effect, it decreased stability and increased flow. Marshall Quotient value of AC-WC asphalt mixture was higher than HRS-WC asphalt mixture. The Marshall Quotient value was influenced by the ratio stability to flow. Asphalt mixture with low MQ value implies that the asphalt mixture is more flexible and more plastic so it can easily deform when it serves. While the mixture with high MQ value shows that the hot mix asphalt concrete is rigid and less flexible.

3.1.4. VIM (Void in the mix)

VIM (Void in the mix) is the ratio of void volume to solid mixture total volume or value that indicates the number of voids in mixture. Based on the General Specifications of Bina Marga 2010 [22], the VIM value of AC-WC asphalt mixture is 3% - 5%, whereas for HRS-WC asphalt mixture is 4% - 5%.

VIM for each variation of concrete waste in both AC-WC and HRS-WC asphalt mixture tended to increase as seen in Figure 8. It was caused by the air void filled with asphalt decreased during the inclusion of the variation of concrete waste since aggregate of crushed concrete waste was in presence at the time of collision. So, after the compression, there were many air voids in the mixture. Addition of 40% concrete waste in AC-WC and HRS-WC asphalt mixture did not meet the specifications. The maximum variation of concrete waste fitting the VIM value specification was 35% for AC-WC asphalt mixture and 29% for HRS-WC asphalt mixture. VIM value in AC-WC and HRS-WC mixtures experienced a significant increase for 40% concrete waste addition. The VIM value of HRS-WC mixture was higher than AC-WC mixture because AC-WC used well-graded aggregate to provide smaller voids in the asphalt mixture.

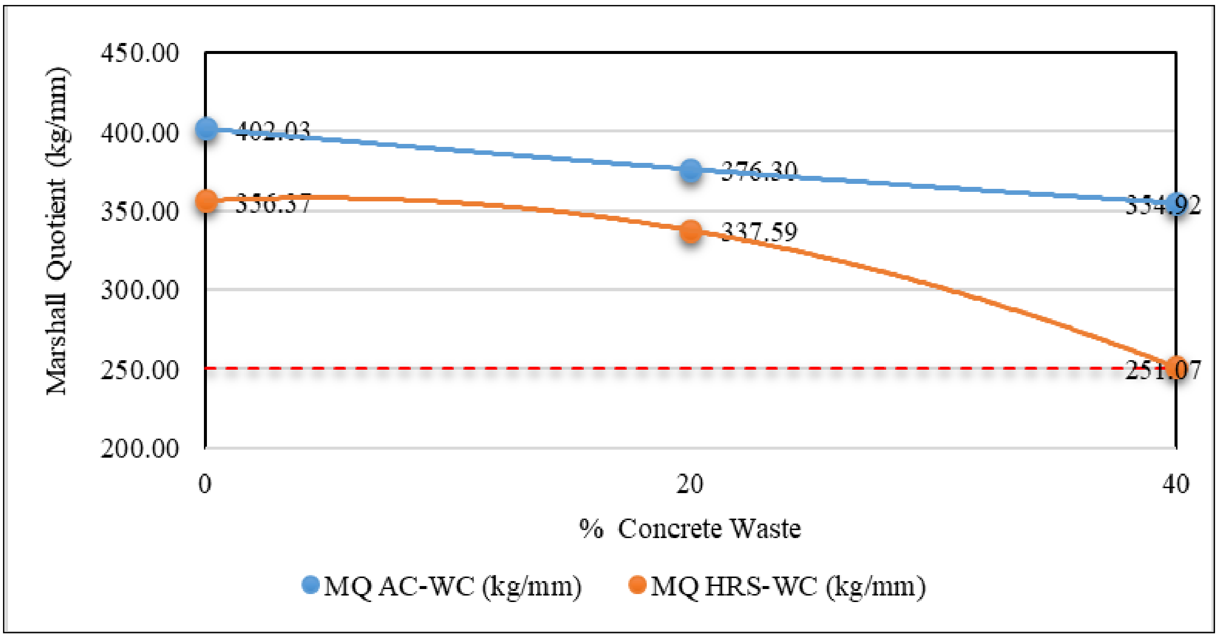

Figure 7. Comparison of Marshall Quotient of AC-WC and HRS-WC Asphalt Mixture with variation of concrete waste

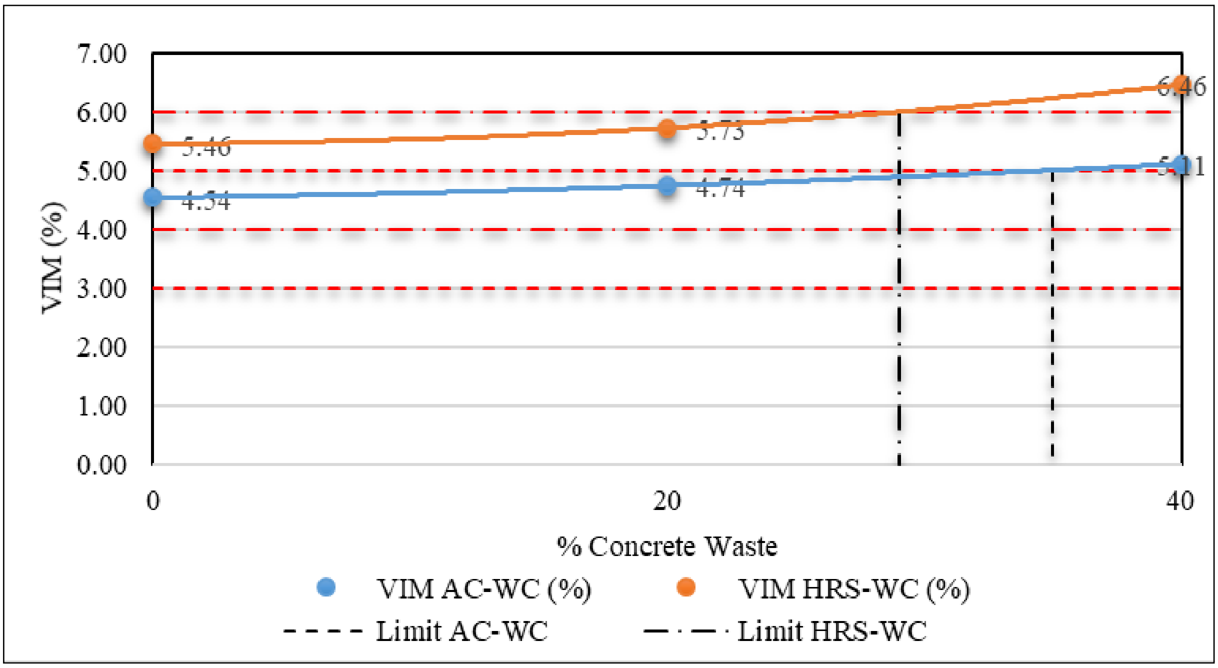

Figure 8. Comparison of VIM AC-WC and HRS-WC Asphalt Mixture with variations of concrete waste

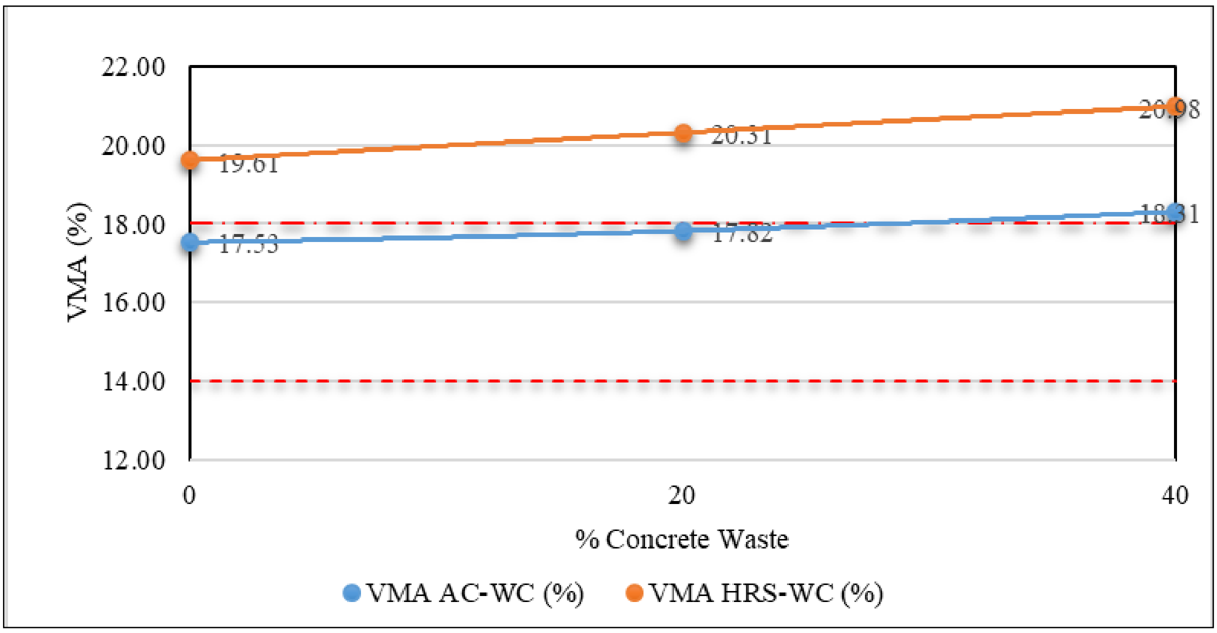

Figure 9. Comparison of VMA AC-WC and HRS-WC Asphalt Mixture with variation of concrete waste

3.1.5. VMA (Void in Mineral Aggregate)

VMA (Void in Mineral Aggregate) is air voids in a mixture of solid asphalt concrete with the absence of asphalt binder. General Specifications of Bina Marga 2010 [22] recommends that the minimum value for VMA is 14% for AC-WC asphalt mixture and 18% for HRS-WC asphalt mixture. The higher the value of the air voids between the aggregate grains is, the higher the value of the air voids in the asphalt mixture becomes.

The VMA value for each variation of concrete waste for AC-WC and HRS-WC asphalt mixture met the specifications, as presented in Figure 9. The VMA value increased with greater variations in concrete waste content. It was caused by the large value of the abrasion of concrete waste, and the aggregate of concrete waste was vulnerable during compaction, and thus, compaction became imperfect and resulted in greater air voids in the mixture. VMA values in AC-WC and HRS-WC mixture experienced insignificant increase in each addition of concrete waste. The VMA value of the HRS-WC asphalt mixture was higher than the AC-WC asphalt mixture because HRS-WC asphalt mixture had gradation, and the value of VMA was affected by the gradation of the materials.

3.1.6. VFWA (Void Filled With Asphalt)

VFWA (Void Filled with Asphalt) is value that indicates the number of voids filled with asphalt expressed in percentage (%). The percentage of voids filled with asphalt in compacted asphalt mixture is the ratio between the effective asphalt volume and the volume of void in mineral aggregate. General Specifications of Bina Marga 2010 [22] states that the minimum value of VFWA for AC-WC asphalt mixture is 65%, while for the HRS-WC asphalt mixture is 68%.

Based on Figure 10, the VFWA value of variations of AC-WC and HRS-WC asphalt concrete mixture was included in specification. VFWA value tended to decrease in greater variations of concrete waste content. It was due to asphalt filling the voids in the mixture absorbed by concrete waste, which had a higher absorption value than fresh aggregate. In addition, it was also influenced by the concrete waste crushed into fillers during the process of making specimens. VFWA value experienced significant decrease in HRS-WC asphalt mixture of 40% concrete waste variation. VFWA value of AC-WC asphalt mixture was higher than HRS-WC asphalt mixture because the AC-WC had small air void as it used well-graded aggregate compared to HRS-WC, which used gap graded aggregate. Pavement will be water-resistant and airtight when the VFWA value is higher.

3.2. Percentage of Concrete Waste that Qualifies Specifications of AC-WC and HRS-WC Asphalt Mixture Marshall Properties

Based on the Marshall test results presented in Table 5, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10, the values of AC-WC and HRS-WC, Marshall properties with the use of concrete waste 0%, 20%, and 40% are obtained.

Based on the analysis conducted on 20% concrete waste variation as the substitute for coarse aggregate, this might be used for AC-WC and HRS-WC asphalt mixtures. It is shown by all Marshall properties values: stability, flow, Marshall Quotient, VMA, VFWA, and VIM, which meet specifications up to 0% and 20% concrete waste addition.

The test results show that all Marshall properties values such as stability, flow, Marshall Quotient, VMA, VFWA, and VIM meet the specifications up to 35% concrete waste inclusion in AC-WC asphalt mixture. Thus, the maximum permissible use of concrete waste variation is 35% for AC-WC mixture and 29% for the HRS-WC mixture. Using concrete waste as a partial replacement for coarse aggregate with a certain level still meets the requirements for asphalt mixtures materials, and this is similar to the research conducted by Amir Khomeiny Ruslan et al. [30] which concluded that the smallest deflection is found to be with the panels with inclusion of 50% of the recycled concrete aggregate as partial sand replacement.

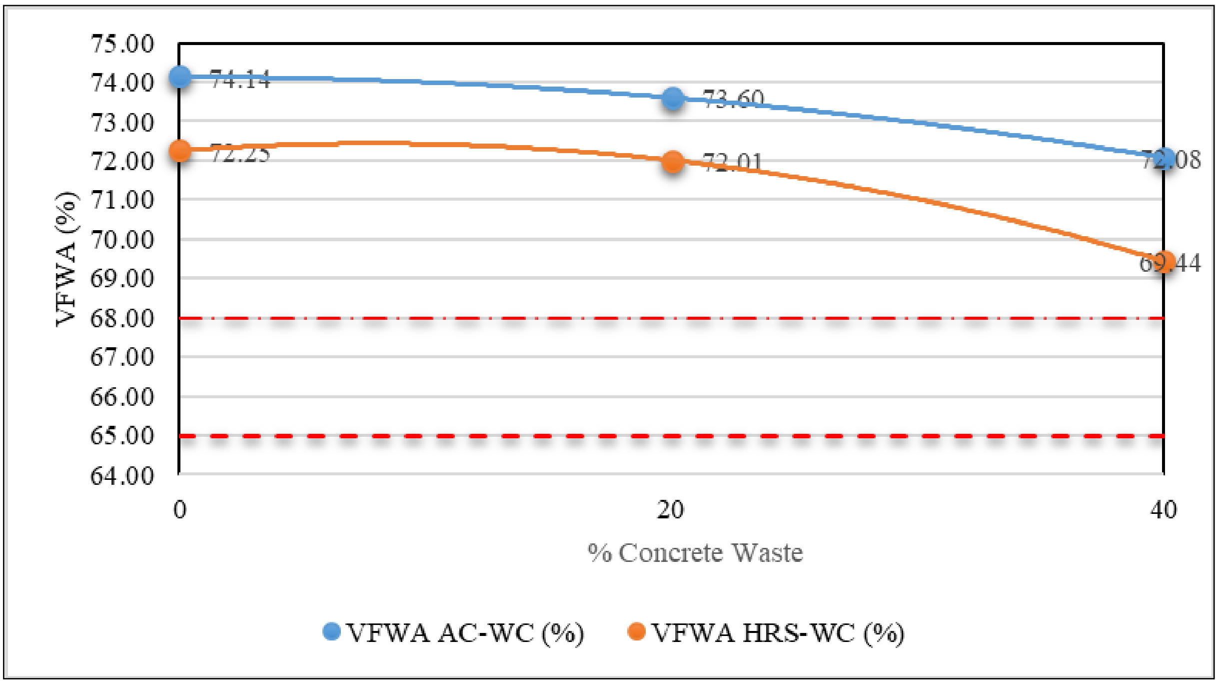

Figure 10. Comparison of VFWA AC-WC and HRS-WC Asphalt Mixture with variation of concrete waste

4. Conclusions

Based on the results of the study, conclusions drawn are as following: Marshall properties as the indicator of the performance of asphalt mixture, with the utilization of concrete waste by 0%, 20%, and 40%, the value of Stability, Marshall Quotient and VFWA experience decrease as the addition of concrete waste variations in of AC-WC and HRS-WC asphalt mixture is continued, while for the value of Flow, VIM, and VMA tends to increase. Utilization of up to 20% concrete waste as the substitute for coarse aggregate is acceptable for each of AC-WC and HRS-WC asphalt mixtures. The maximum permissible variation of concrete waste is 35% for AC-WC mixture and 29% for HRS-WC mixture. Waste concrete can be used to substitute coarse aggregate in asphalt mixtures, and this can reduce the amount of concrete waste and reduce the use of fresh aggregates, which can make a positive contribution to the environment.

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