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Numerical Simulation of the Effect of Variation in Subgrade CBR Values on Rigid Pavement

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Abstract: Filler material is a material that is utilized in the manufacture of pavement mixes with dimensions smaller than 0.075 mm or passing sieve no. 200 which can be in the form of limestone ash, dolomite, Portland cement. Therefore, with the limited natural resources, it is necessary to implement a program to reduce the use of natural resources and maximize the potential generated from unutilized waste. The types of waste that can be utilized as filler in AC-WC asphalt are rice husk ash waste obtained from Gunungsari Village, Malang Regency and sawdust ash waste obtained from H. Sulaiman Brick Factory, Malang Regency. The purpose of this research is to identify the chemical content values contained in rice husk ash and wood powder ash waste in AC-WC asphalt pavement mixtures by reviewing through Marshall parameters and the Residual Strength Index (IRS). The results of the utilization of rice husk ash filler in AC-WC asphalt mixtures can provide an increase in stability values until it finally decreases at 100% content, besides that it can provide an increase in the values of yield, VIM and VMA. However, it gives a decrease in the VFA value and produces an IRS of 90.6% and can meet the requirements of Bina Marga 2018 Revision 2. In the sawdust ash filler, it can give an increase in stability and yield values until the peak at 100%, but it can give a decrease in VIM and VMA values. However, it increases the VFA value and produces an IRS of 87.2% which does not meet the guidelines of Bina Marga 2018 Revision 2.

Keywords: *rice husk ash, sawdust ash, filler, Marshall parameters, residual strength index*

1. Introduction

Development in Indonesia is growing, this is shown by the increase in new road projects and the improvement of existing roads [1]. Roads are an important asset that plays a vital role in economic development, especially in the field of passenger and goods transportation. Roads have a significant influence on safety, convenience and cost, so it is important that roads remain in optimal condition [2].

Although road construction continues to advance, many roads in Indonesia deteriorate faster than they should. Causes include overly heavy vehicle loads, poor soil conditions, inadequate drainage, and poor-quality road layers. Based on the material, road pavement layers are divided into three types: flexible pavement (asphalt), rigid pavement (Portland cement), and composite pavement (a mixture of asphalt and Portland cement).

The use of coarse aggregate, fine aggregate, and filler in the asphalt mixture layer of highway pavement is a waste of limited natural resources [3]. Therefore, with these limited resources, a program is needed to reduce the use of natural resources and maximize the potential generated from unused waste. Rice husk ash waste and sawdust ash waste can be utilized as fillers in AC-WC asphalt mixtures.

The fertile land and tropical climate of Indonesia create perfect conditions for rice cultivation. Rice husk ash results from the burning of rice husks, which is often found in East Asia and Southeast Asia. According to data from the Central Bureau of Statistics, Indonesia experienced an increase in the level of rice production from 54.75 million tons of GKG in 2022, an increase of 1.01% from 2021. With the increase in the level of rice production, it will increase the by-products produced during the milling process by 20% [4]. The rice husk produced in Indonesia in 2022 was 15 million tons. If the amount of rice husk waste is burned, it will produce as much as 18% of rice husk ash waste [5]. So, if it is assumed that all rice husk waste is burned, it will produce as much as 2.7 million tons of rice husk ash waste in Indonesia in 2022.

Just like rice husk waste, wood utilization can create problems in the disposal of waste from unused wood [6]. Wood utilization in Indonesia alone according to the Central Bureau of Statistics reached 64.65 million cubic meters with the amount of powder produced around 8.87 million tons. If all the waste is burned, it will produce 532,200-887,000 tons of sawdust ash waste according to theory [7]. With these results, it is necessary to utilize the waste generated from wood processing in order to overcome the problem of waste disposal in vain [6]. Wood sawdust from industrial waste is a material that can give a positive impression to be used as filler and can be an alternative option in reducing the use of fly ash or lime, especially in rural areas [8]. Waste sawdust ash can replace half of the filler in asphalt mixtures used at low temperatures for local roads with moderate traffic levels [9].

Wood powder is a natural material obtained from processed wood, both wood cutting businesses, furniture businesses and others that will produce waste of various types and sizes [6]. The wood waste produced will be burned into ash or a form of pozzolana until it meets the criteria as a material that can be used as a filler in asphalt, which passes through sieve no. 200. The utilization of wood ash waste as a filler can increase the melting life of an asphalt and permanent deformation at varying temperatures [10]. Wood dust ash also produces better durability than coal ash. Test samples with 6% and 8% wood ash filler content produced stability values that met the Marshall testing criteria which can have a positive impact on asphalt mixtures [11].

This research was tested using references from SNI 06-2489-1991 and RSNI M-01-2003. Based on the 2018 General Specifications (Revision 2), this test produces asphalt mixture properties in the form of VIM, VFA, VMA, flow and stability values carried out by soaking the asphalt mixture to be tested. The Index of Residual Strength (IKS) test is carried out with the intention of describing the durability of the asphalt mixture against damage caused by water. One of the measures used to obtain the durability value of an asphalt mixture is IKS. IKS is a criterion set by the Directorate General of Highways 2018 Revision 2 by analyzing the stability value of asphalt after being soaked for 24 hours and 30 minutes.

Based on these problems, this research aims to identify the value of chemical content contained in rice husk ash waste and sawdust ash waste on the performance of AC-WC asphalt mixtures and describe the performance of AC-WC type asphalt pavement mixtures with rice husk ash waste filler substitutes and sawdust ash waste in terms of Marshall parameter values so that this research is needed in the hope of reducing the disposal of unutilized rice husk waste and wood waste and creating asphalt mixtures with stronger binding ability to withstand traffic loads properly.

2. Method

The initial stage carried out in this research is the inspection of materials which includes inspection of asphalt, coarse aggregate, fine aggregate and filler materials. The material inspection stage is carried out in order to identify the characteristics of each material in the study. The characteristics obtained will determine whether the material meets the specifications for use in mixing asphalt concrete. In the inspection of asphalt material itself passes 7 stages of testing including penetration testing, soft point testing, burn point and flash point, ductility testing, specific gravity testing and asphalt weight loss testing. Meanwhile, the aggregate itself will pass through sieve analysis testing, aggregate wear testing, aggregate specific gravity testing and finally aggregate water absorption testing.

The equipment used to support the implementation of this research consists of 1 set of sieves, Los Angeles machine, pycnometer, scales, oven, 1 set of penetration testing, 1 set of soft point testing, 1 set of flash point and burn point testing, 1 set of ductility testing, 1 set of asphalt specific gravity testing, 1 set of asphalt weight loss testing, 1 set of Marshall tools, waterbath, spatula, stove, thermometer and gloves. In this study, the mixtures were adjusted with reference to the 2018 General Specifications can be shown in Table 1.

Table 1. Aggregate Requirements for One Test Object

No. Filter	**Filter Size (mm)**	**Specification (%)**	**Aggregate (%) Passed Middle Grade C**	**Retained Aggregate (%)**	**Required Aggregate Weight (gr)**
A	B	C	D	E	F
3/4”	19	100	100	0	0
1/2"	12,5	90-100	95	5	60
3/8”	9,5	77-90	83,5	11,5	138
No. 4	4,75	53-69	61	22,5	270
No. 8	2,36	33-53	43	18	216
No. 16	1,18	21-40	30,5	12,5	150
No. 30	0,6	14-30	22	8,5	102
No. 50	0,3	9-22	15,5	6,5	78
No. 100	0,15	6-15	10,5	5	60
No. 200	0,075	4-9	6,5	4	48
Pan				6,5	78
		Total Weight of Aggregate			1200

Table 2. Variations in Filler Content and Number of Test Objects

No	**Sample Code**	**Asphalt Content (%)**	**Filler Cement Portland (%)**	**Filler Waste (%)**	**Number of Test Objects**
1	K. 5	5	100	-	3
2	K. 5,5	5,5	100	-	3
3	K. 6	6	100	-	3
4	K. 6,5	6,5	100	-	3
5	K. 7	7	100	-	3
6	ASP. 0	KAO	100	-	3
7	ASP. 25	KAO	75	25	3
8	ASP. 50	KAO	50	50	3
9	ASP. 75	KAO	25	75	3
10	ASP. 100	KAO	-	100	3
11	ASK. 0	KAO	100	-	3
12	ASK. 25	KAO	75	25	3
13	ASK. 50	KAO	50	50	3
14	ASK. 75	KAO	25	75	3
15	ASK. 100	KAO	-	100	3
16	IKS. ASP	KAO	-	KFO	6
17	IKS. ASK	KAO	-	KFO	6
18	IKS. PC	KAO	100	-	6

Total Sample	63

2.1 Plan Asphalt Content

The calculation of the planned asphalt content can be determined by the following Equation (1).

Pb = 0,035 (%CA)+0,045 (%FA)+0,18(%Filler)+K

Where:
Pb = Asphalt content design (%)
CA = Percentage of coarse aggregate that does not pass through sieve No. 4 (%)
FA = Percentage of fine aggregate that passes through sieve No. 4 (%)
Filler = Percentage of fine aggregate that passes through sieve No. 200 (%)
K = Constant value; use 0,5-1,0 for Laston (AC)
2,0-3,0 untuk Lataston (HRS)
Where:
CA: 39%
FA: 54,5%
Filler: 6,5%
Pb = 0,035 (%CA)+0,045 (%FA)+0,18 (%Filler) + K
= 0.035 (39%)+0,045 (54,5%)+0,18 (6,5%)+1,0
= 5,99 ~ 6,0

Based on the results of the above equation, it is found that the plan/middle asphalt content is 6.0% which will be the reference in making the test samples. To calculate the KAO, 5 variations of asphalt content were made. If the center plan asphalt content is α%, the test specimens are designed for asphalt contents of (α-1)%, (α-0.5)%, (α%), (α+0.5)%, and (α+1)%. Thus, the asphalt content variations used are 5%, 5.5%, 6%, 6.5%, and 7%.

3. Result and Discussion

3.1. Material Inspection

The inspection of asphalt materials is intended to identify the characteristics obtained from the asphalt in accordance with the 2018 General Specifications (Revision 2). The results of the asphalt material inspection can be shown in Table 3 below.

Table 3. Asphalt Material Inspection

No	Test Type	Results	Standard
1	Penetration (mm)	64,93	60-70
2	Flash Point (°C)	307	≥232
3	Burn Point (°C)	318	≥232
4	Burn Point (°C)	48,50	≥48
5	Ductility (cm)	142,47	≥100
6	Specific Gravity (gr/cc)	1,06	≥1,0
7	Weight Loss (%)	0,33	≤0,8

Based on Table 3 above, the use of asphalt that will be applied to the mixture as a whole has met the requirements of Bina Marga 2018 Revision 2, so it can be utilized for asphalt mixture using rice husk ash waste and sawdust ash waste. In addition to the inspection of asphalt materials, aggregates were also inspected in accordance with the standard Bina Marga Specification 2018 Revision 2. In Table 4 below, the results of the inspection of aggregate materials that have been carried out are shown.

Table 4. Inspection of Aggregate Materials

No	Testing	Result	Standard
1	Bj. Coarse Ag (gr/cc)	Bulk: 2,64 SSD: 2,70 Semu: 2,81	≥2,5
2	Bj. Fine Ag (gr/cc)	2,24	≤3
3	Gross Ag Absorption (%)	Bulk: 2,53 SSD: 2,58 Semu: 2,67	≥2,5
4	Fine Ag Absorption (%)	1,94	≤3
5	Aggregate Wear (%)	13,87	Maks. 40

3.2. Chemical Content Testing of Effluents

In this research, to obtain the chemical content values of rice husk ash waste and sawdust ash waste, X-Ray Fluorosence (XRF) testing was carried out with the aim of obtaining the oxide composition of the two materials. The results of the chemical content test for rice husk waste are described in Table 5 below.

Table 5. Chemical Composition of Rice Husk Ash

Compound	Composition (%)
SiO_2	86,10
P_2O_5	2,30
Fe_2O_3	1,18
CaO	3,63
MnO	0,35
K_2O	4,82
SO_3	1,30
TiO_2	0,08

The compound with the largest chemical composition found in rice husk ash waste is silica (SiO2). Silica is one of the compounds that has characteristics that make it effective as an insulator, such as low heat conductivity, high melting point, low density and small particle size [12].

The utilization of silica contained in rice husk ash can play a role in increasing the ability of asphalt to absorb water, so that asphalt has the ability to deal with variations in temperature and load on road pavements [13]. In addition, the utilization of silica in asphalt mixtures can improve the performance of asphalt mixtures [14].

Table 6. Chemical Composition of Wood Powder Ash

Compound	Composition (%)
SiO_2	7,00
SrO	1,10
Fe_2O_3	5,00
CaO	67,80
MnO	0,34
TiO_2	0,28
K_2O	10,50
P_2O_5	2,50
MoO_3	4,83

The compound with the largest composition in the wood powder ash waste is calcium oxide (CaO). Calcium oxide is a compound that is able to increase the hardening process and is able to absorb carbon dioxide from the air [15].

Calcium oxide (CaO) compounds have an important role in limestone and cement which are often used as filler substitutes in pavement mixtures. So, the more calcium oxide in the mixture, the better the performance of the mixture. Therefore, the use of sawdust ash can increase the melting life of an asphalt mixture and permanent deformation at several temperature variations [10].

3.3. Marshall Parameter KAO

Table 7. Marshall Parameters for KAO

Marshall	Asphalt Content (%)				
	5	5,5	6	6,5	7
Stability (kg)	1416	1465	1780	1611	1259
Flow(mm)	2,69	3,15	3,19	3,23	3,92
VIM(%)	8,79	7,64	5,75	5,24	4,89
VMA(%)	16,8	16,7	15,9	16,4	17,0
VFA(%)	47,8	54,4	64,5	68,1	71,3

Based on the graph above, it can be seen that the value of asphalt content that is in accordance with the provisions of several marshall parameter values is for the range of 6.85% and 7%. So for the calculation of the KAO value is:
KAO = (6,85%+7%)/2
KAO = 6,925%

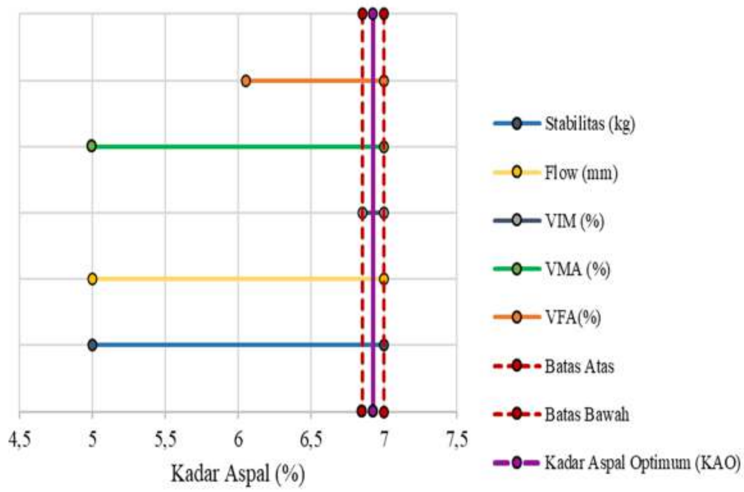

Fig 1. Optimum Asphalt Content Chart (KAO)

Fig 1 above, shows the sample results with values that are in line with the 2018 General Specifications (Revision 2). The appropriate asphalt content values are 6.85% and 7% for all Marshall parameter values, therefore, the KAO value obtained is 6.925% which is obtained from the middle value between the asphalt content of 6.85% and 7%.

3.4 Marshall Parameters of Rice Husk Ash Filler

Table 8. Marshall Parameters of Rice Husk Ash Filler

Marshall	**Filler Content (%)**				
	0	25	50	75	100
Stability (kg)	136 7	122 2	134 5	176 6	124 6
Flow(mm)	3,28	2,31	2,43	2,86	3,05
VIM(%)	4,95	4,45	4,68	4,91	5,15
VMA(%)	16,9	16,3	16,3	16,3	16,4
VFA(%)	70,7	72,7	71,3	69,9	68,6

Source: Research Results

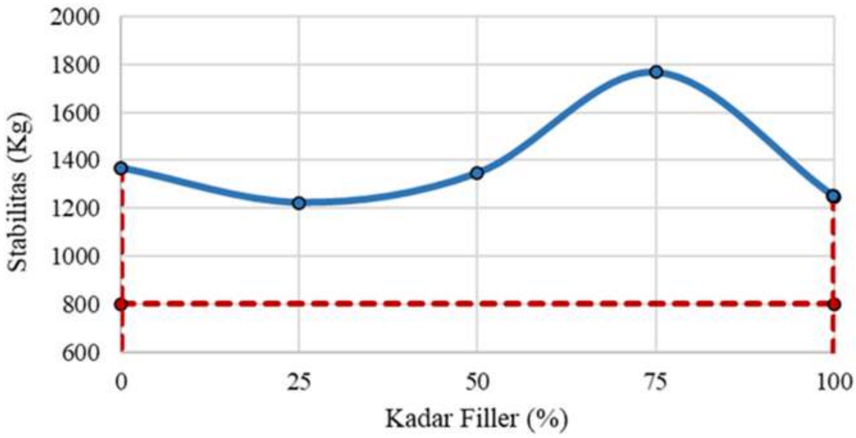

Fig 2. Relationship between Filler Content and Stability

Based on Fig. 2, it can be seen that the addition of rice husk ash filler at 25% level can decrease the stability value compared to 0% level. Then at 25% to 75%, the stability value increases from 1235.70 kg to 1749.69 kg and finally there is a decrease in the stability value at 100% with a stability value of 1253.20 kg.

Based on the research conducted [16], a similar thing happened where the provision of rice husk ash as filler can provide a high stability value until it will eventually decrease at certain levels. Rice husk ash as a filler in asphalt mixtures can close the gap better, but if too much, it can actually reduce stability. The more rice husk ash added, the less asphalt can cover the aggregates, so the asphalt adhesion decreases.

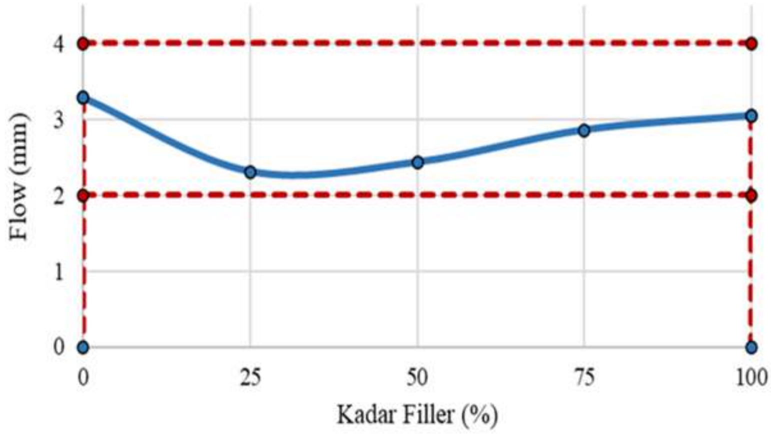

Fig 3. Relationship between Filler Content and Flow

Based on the graph shown in Fig 3 related to the flow of asphalt mixture with the addition of rice husk ash waste, the addition of rice husk ash waste at 0% level produces a flow value of 3.28 mm and at the next level, 25%, the asphalt mixture decreases in the flow value to 2.31 mm. However, the provision of rice husk ash at the next level increased to 100% with a flow value of 3.05 mm.

The results of this study are in accordance with [17], which found that the mixture will experience an increase in flow value with each addition of rice husk ash as filler, this is because the fine and slippery particles of rice husk ash can reduce friction between asphalt particles and aggregates, causing an increase in flow value.

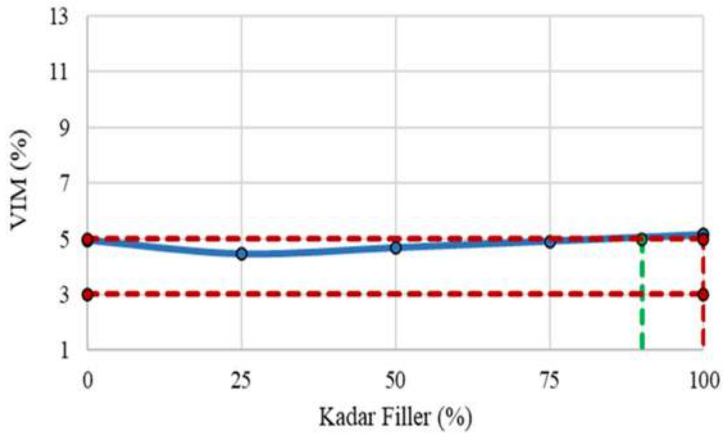

Fig 4. Relationship between Filler Levels and VIM

Based on the test results shown in Fig 4, the VIM value decreased from 0% to 25%. Then, the VIM value increased until finally at 100% content with a VIM value of 5.15%.

Based on previous research conducted by [18], the VIM value will decrease at the initial level until finally there is an increase in the VIM value along with the increase in the level of rice husk ash utilized. This is because the voids in the mixture will be filled by the given rice husk ash so that the mixture will be tighter.

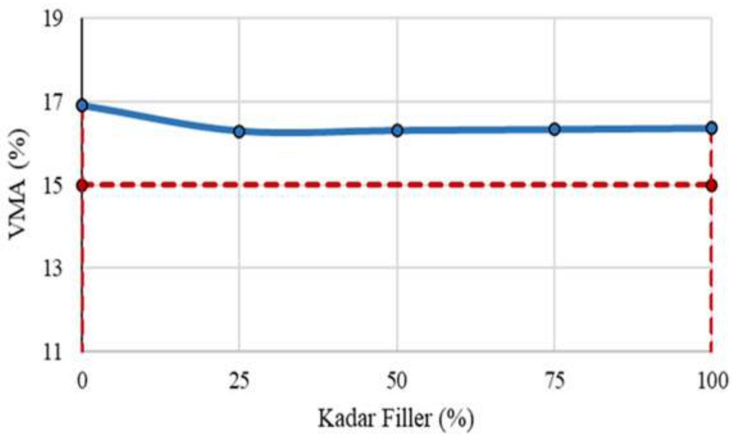

Fig 5. Relationship between Filler Levels and VMA

Based on the results of the VMA values shown in Fig. 5, the VMA values first decreased from 0-25% and then increased with each additional level of rice husk ash given to a mixture up to 100%. According to previous research conducted by [17], the same results were obtained regarding the VMA value. Along with the increase of rice husk ash content, it can increase the VMA value produced in the asphalt mixture.

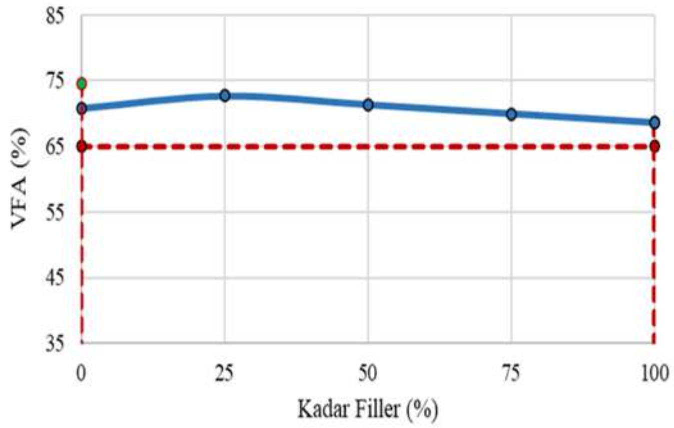

Fig 6. Relationship between Filler Levels and VFA

Based on Fig 6, the addition of rice husk ash at 0-25% level will increase the Void Filled with Asphalt (VFA) value, until finally the more rice husk ash is used, the VFA value drops to 100%. This is because the voids in the mixture will be filled by the rice husk ash so that the asphalt is unable to cover all the voids produced in the mixture.

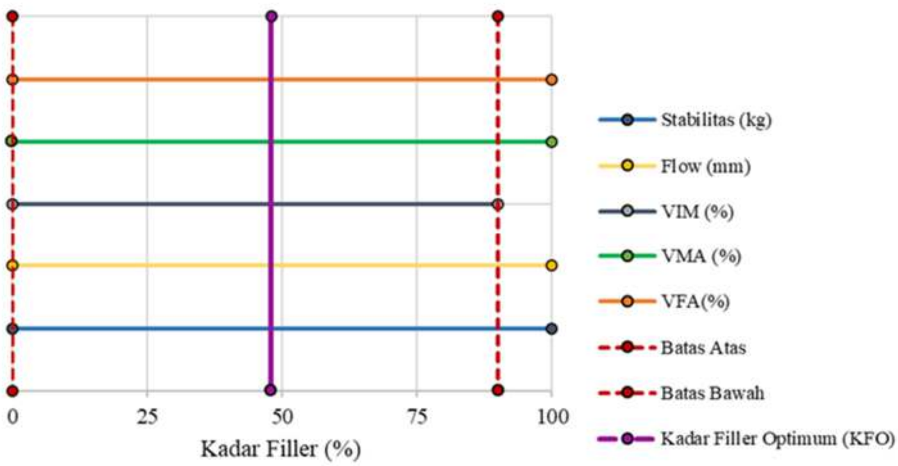

Fig 7. KFO graph of Rice Husk Ash

Based on Fig. 7, the KFO value of rice husk ash obtained from the Marshall test is in the range of 0% as the lower limit and 90% as the upper limit of adding rice husk ash as filler. These figures were obtained based on the Marshall tests that have been conducted by finding the middle value of the levels that can meet the requirements set by the 2018 General Specifications (Revision 2). Therefore, from the range of 0-90%, the Optimum Filler Content (KFO) of rice husk ash was found to be 48%.

3.5 Marshall Parameters Wood Powder Ash Filler

Table 9. Marshall Parameters Wood Powder Ash Filler

Marshall	Filler Content (%)				
	0	25	50	75	100
Stability (kg)	136 7	123 1	125 3	131 2	149 4
Flow(mm)	3,28	2,45	2,51	3,31	4,47
VIM(%)	4,95	5,18	4,63	4,31	4,06
VMA(%)	16,9	16,9	16,3	15,9	15,5
VFA(%)	70,7	69,5	71,6	72,8	73,7

Source: Research Results

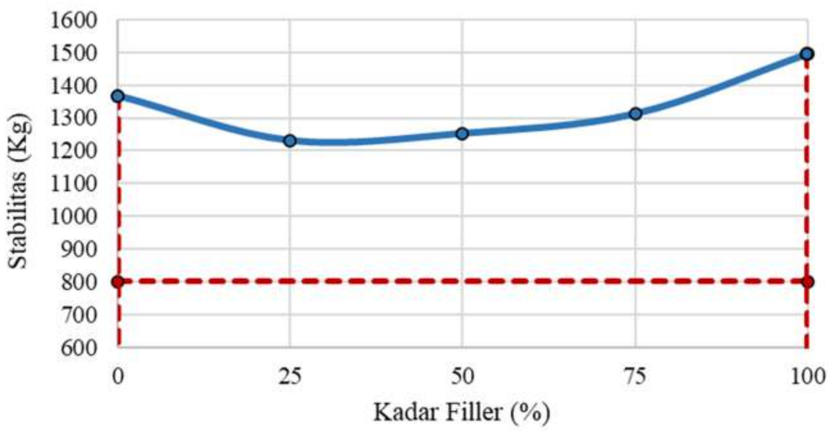

Fig 8. Relationship between Filler Content and Stability

Based on Fig. 8, the stability value increases with each addition of sawdust ash content applied to the mixture. However, at 0-25%, the stability value decreased first from 1379.26 kg to 1212.59 kg.

Based on research [19], the stability value will increase with the increase of sawdust ash content. This happens because sawdust can fill the voids in the asphalt mixture so that it can improve the load distribution given to the asphalt.

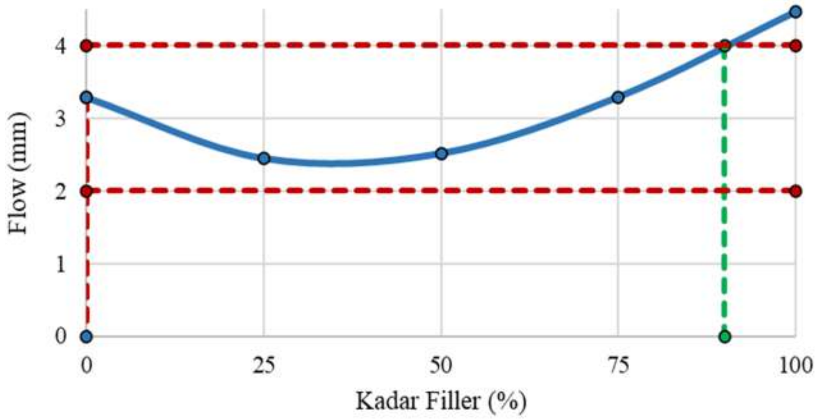

Fig 9. Relationship between Filler Content and Flow

Based on Fig. 9, the addition of sawdust ash to the asphalt mixture with 0-25% content has a decreasing impact on the flow value, but at 25% to 100% content, the flow value of the mixture will increase from 3.28 mm to 4.47 mm at 100% content.

Based on research [19], the higher the ash content of sawdust given, the higher the flow value. The greater the flow value shown, the more susceptible the asphalt mixture is to deformation, but the smaller the flow value, the more resistant the mixture is to deformation.

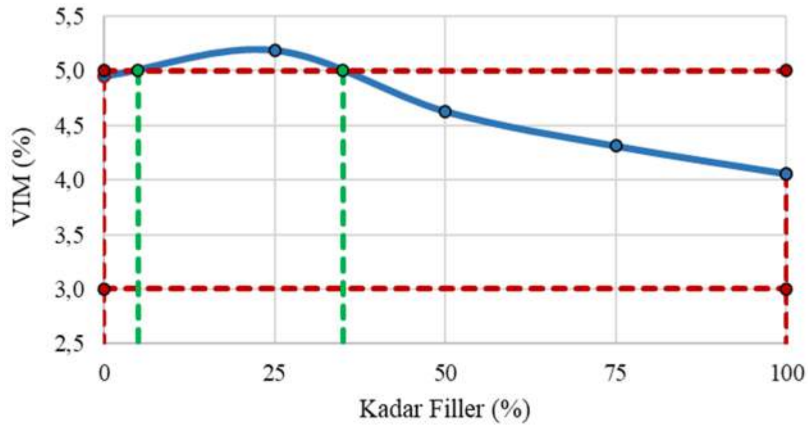

Fig 10. Relationship between Filler Levels and VIM

In Fig 10 related to the VIM value, the addition of sawdust ash content to the asphalt mixture will provide an increase first from 0-25% and decrease in the VIM value produced up to 100%. Based on this research, the lowest VIM value produced is 4.06%.

Based on previous research conducted by [19], similar results were obtained that the higher the level of sawdust ash given to the asphalt mixture, the lower the VIM value obtained. This is due to the large amount of sawdust ash added to the mixture, which reduces the volume of voids as the filler fills the existing space and affects the ability of the mixture to perform well.

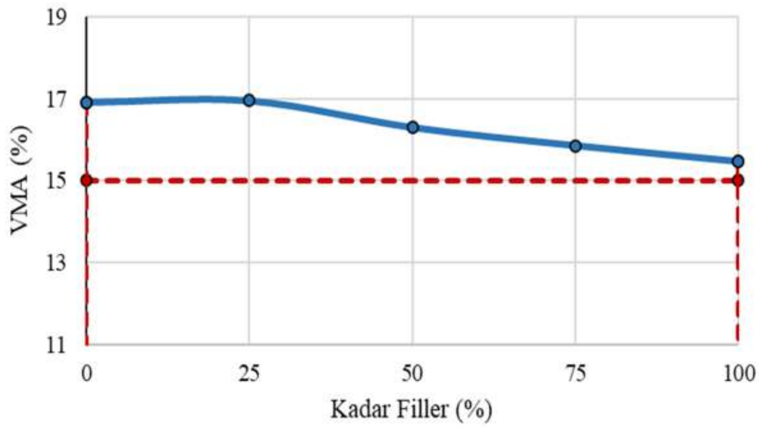

Fig 11. Relationship between Filler Levels and VMA

Based on the VMA result values shown in Fig 11, at 0-25% level, the VIM value increases until finally the higher the level of sawdust ash given to the asphalt mixture, there will be a decrease in the VMA value obtained in the mixture up to 100% level. This is proven by the decrease in the VMA value of the mixture until it finally reaches 15.46% at 100% level.

Based on research [19], it shows that the more wood powder ash content given to the asphalt mixture will further reduce the VMA value achieved. This will have an impact on the increase in the volume of asphalt that covers the aggregate surface and is absorbed by the sawdust ash.

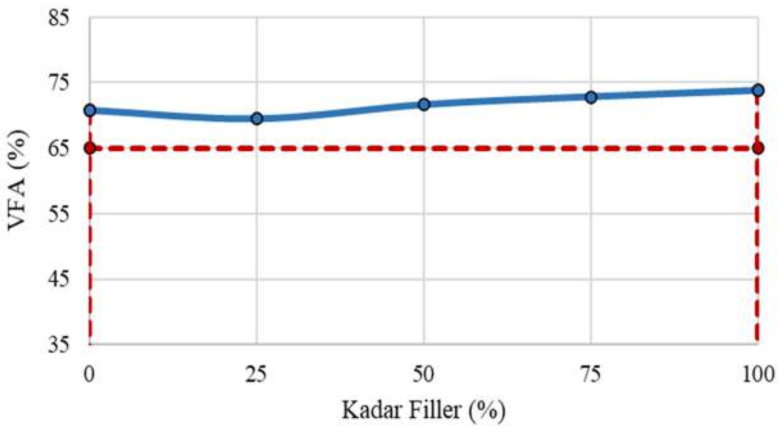

Fig 12. Relationship between Filler Levels and VMA

Based on Fig 12 graph, the greater the ash content of sawdust given to the asphalt mixture will experience a decrease first from the 0-25% level and get an increase at the next level. This is proven by the increase in VFA value that occurs from 25-100% asphalt content with the highest VFA value at 100% content with a VFA value of 73.74%.

Referring to research [19], the greater the value of the content given to the asphalt mixture can increase the resulting VFA value. This happens because sawdust contained in a mixture will help to close the cavity better so that it can increase the total volume contained in the mixture.

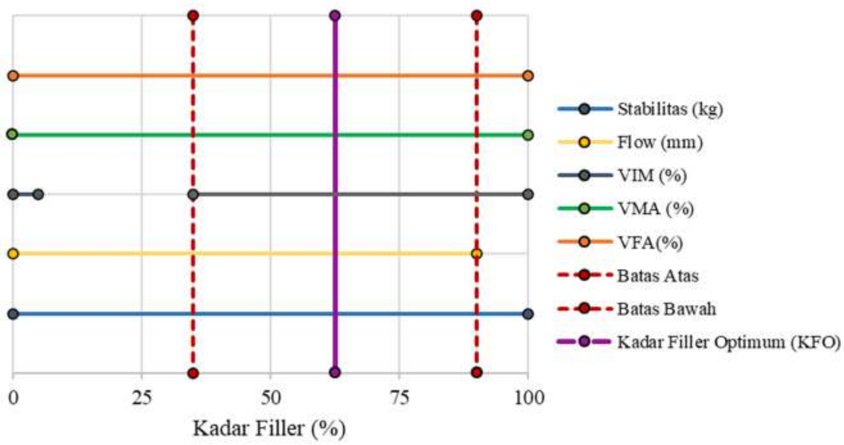

Fig 13. KFO Chart for Wood Powder Ash

Based on Fig 13, to obtain the Optimum Filler Content (KFO) value in the mixture, it is done by calculating the midpoint value of the variation in the addition of filler from sawdust ash waste with soaking for 30 minutes which is in accordance with the 2018 General Specifications (Revision 2).

Based on these tests, the results for the lower limit values obtained are in the range of 0-5% for the VIM value, with the upper limit value obtained which is 90% of the results of melting (flow). From the range of numbers, then the middle value is searched to obtain the KFO value of sawdust ash filler, which is 62.5%.

3.6 Residual Strength Index (IKS) Value

Table 10. Residual Strength Index (IKS) Value

Filler Type	Stability (kg)		IKS (%)
	30 Minute (a)	24 Hour (b)	c=b/a×100 %
Cement	1367,54	1297,56	94,9
Abu Paddy	1364,98	1236,08	90,6
Wood Ash	1385,87	1208,26	87,2

Based on Table 8, the stability value of the marshall test after soaking for 30 minutes and 24 hours is in accordance with the 2018 General Specifications (Revision 2) for AC-WC, the minimum stability value is 800 kg.

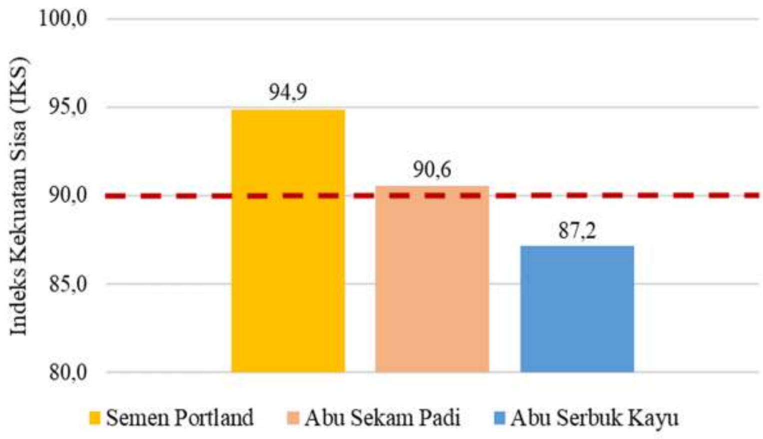

Fig 14. Residual Strength Index (IKS) Chart

Based on the graph in Fig 14, the IKS results for asphalt mixtures with the addition of rice husk ash waste as filler can meet the requirements set by the 2018 General Specifications (Revision 2). Meanwhile, the IKS results for asphalt mixtures with the addition of sawdust ash waste as filler cannot be met.

Based on the results of research [20] and [19], which states that the IKS results using wood ash filler mixtures do not meet the requirements due to the wood ash filler being quite susceptible to the influence exerted by water for a long time. In addition, this is because the calcium oxide (CaO) contained in wood powder ash will react with water that is able to seep in so that it will affect the strength of the resulting asphalt mixture [21].

4. Conclusion

Based on the results of the analysis that has been carried out related to the use of rice husk ash waste filler and sawdust ash waste, it can be concluded that the dominant chemical content value in rice husk ash waste is silica (SiO2) at 86.10%. The silica component has the characteristics of low density, small particle size and high adsorption power, so that a larger silica content will increase the binding capacity of asphalt as a carbon compound. The dominant chemical content value in sawdust ash waste is calcium oxide (CaO) with a level of 67.80%. This level has the ability to increase the hardening process and absorb carbon dioxide from the air so that it can provide good absorption and the more levels given, the higher the stability value.

The addition of rice husk ash filler, resulted in a decrease in stability value at 0-25% level until it increased to 75% level and finally decreased to 1246.39 kg at 100% level. As for the values of flow, VIM, and VMA, the addition of rice husk ash filler can result in a decrease up to 25% and an increase at the next level up to 100%. On the other hand, the higher the level added, the lower the VFA value obtained in a mixture.

The addition of sawdust ash filler, resulted in a decrease in stability andflow values from 0-25%, then increased to 100%. VIM and VMA values increase at 0-25% level until they continue to decrease at the next level up to 100%. Then in the VFA value, there is an increase in each provision of increasingly large levels until the maximum point at 73.74% at 100% level.

The IKS value with the addition of rice husk ash waste as filler at the Optimum Filler Content (KFO) level of 48%, gave positive results by obtaining an IKS value of 90.6%. Meanwhile, the addition of sawdust ash waste as filler at the Optimum Filler Content (KFO) of 62.5% obtained an IKS value of 87.2%. So that only rice husk ash waste filler can meet the provisions set by the 2018 Revision 2 Bina Marga Specification with a minimum IKS value of 90%.

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