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OPTIMIZATION OF OPTIMUM BITUMEN CONTENT AND MARSHALL CHARACTERISTICS OF AC-WC MIXTURES WITH RESIN GUM ADDITIVE

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ABSTRACT

Asphalt pavements in Indonesia are often found to suffer from damage such as cracks, plastic deformation (bumpy roads), and potholes on the surface. These damages are caused by errors in the road implementation, namely the determination of the type of bitumen used, the voids in the mixture, or the compaction temperature. The performance demands of asphalt pavements in serving the intensity of traffic loads and climate variability in Indonesia necessitates innovative approaches in modifying asphalt mixtures. Mastic gum is a viscoelastic natural resin that has the potential to be an alternative solution to improve the stability and mechanical properties of asphalt pavements, where its physical characteristics are very similar to asphalt, namely high viscosity and strong interparticle adhesivity. This research focuses on testing the marshall characteristics and optimising the optimum asphalt content of AC-WC mixtures using resin gum additives using the marshall testing method. The percentage variations of resin gum used were 0%, 5%, 7.5%, and 10%. Parameters tested included stability, *density*, *flow*, MQ, VMA, VIM, VFB, IRS, VIM_{PRD}, and KAO. The results of the marshall tests conducted showed that almost all parameters met the requirements of Bina Marga 2024 technical specifications, although there were still some of them that experienced an increase and decrease at certain mixture levels. Based on the analysis, the optimum resin substitution rate recommended for field application is 5%, which is by replacing 5.42% resin by weight of the asphalt used. This research contributes to the development of alternative materials in asphalt concrete mixtures with good performance results.

Keywords: Marshall testing, marshall characteristics, optimum bitumen content, AC-WC, and resin gum

ABSTRACT

Asphalt pavements in Indonesia are often found to suffer from damages such as cracking, plastic deformation, and potholes. These damages are caused by errors in road construction practices, including the selection of asphalt type and content, voids in the mixture, or compaction temperature. The demand for asphalt pavement performance in serving high traffic loads and the climatic variabilities in Indonesia highlights the need for innovative approaches in modifying asphalt mixtures. Damar resin, a natural viscoelastic resin, has the potential to serve as an alternative solution for improving the stability and mechanical quality of asphalt pavements, as it's physical characteristics are very similar to asphalt, namely high viscosity and strong particle adhesion. This research focuses on testing the marshall characteristics and optimising the optimum asphalt content (OAC) of AC-WC mixtures using damar resin additives with the marshall testing method. The variations of damar resin used were 0%, 5%, 7.5%, and 10%. The

parameters tested included stability, density, flow, MQ, VMA, VIM, VFB, IRS, VIM$_{PRD}$, and OAC. The marshall test results showed that all parameters met the 2024thBina Marga technical specifications, although some experienced increases and decreases at certain mixture levels. Based on the analysis, the optimal substitution level of damar resin recommended for field application is 5%, which corresponds to replacing 5.42% of the asphalt weight with damar resin. This study contributes to the development of alternative materials in asphalt concrete mixtures with promising performance results.

Keywords: Marshall test, marshall characteristics, optimum asphalt content, AC-WC, and resin.

1. INTRODUCTION

The condition of asphalt pavements in Indonesia varies greatly, ranging from structurally sound road segments to those that are severely damaged. This is due to differences in weather and climate, as well as the volume and load of vehicles travelling in each region. Common forms of damage are cracks caused by low asphalt binder quality, and plastic deformation or potholes on the surface due to construction errors or infiltration that damages the base layer of the pavement. A number of asphalt pavement failures are caused by errors in determining the type and grade of asphalt used, voids in the mix, and compaction temperature (Suroso, 2008). The demand for asphalt pavement performance in serving the intensity of traffic loads and climate variability has led to the need for innovative approaches in modifying asphalt mixes (Fitri *et.al.*, 2018).

Getah damar is a natural and local product that has the potential to improve the stability and mechanical properties of asphalt. This viscoelastic natural resin has the most similar physical characteristics to asphalt, namely high viscosity and strong interparticle adhesivity (Bahari *et.al.*, 2024). Research by Agustian & Agusmaniza (2022) showed that marshall testing of 4% resin gum as an additive material produced AC-BC mixtures that met the technical requirements of the Directorate General of Highways 2018, although there were substantial differences in the stability of the two types of mixtures. This indicates further studies using different percentages of resin content - different mixing methods, and the selection of other types of aston such as AC-WC or *AC-Base*.

This research focuses on testing marshall characteristics, namely stability, *density*, *flow*, MQ, VMA, VIM, VFB, IRS, VIM $_{PRD}$, and optimising the optimum asphalt content (KAO) of AC-WC with resin gum additives. The modification percentage variations used were 0%, 5%, 7.5%, and 10% by weight of asphalt. The research is expected to contribute to the development of alternative asphalt replacement materials that are relevant to the sustainable infrastructure development agenda based on the *circular economy* approach and energy efficiency.

2. THEORETICAL FOUNDATION

AC-WC (*Asphalt Concrete-Wearing Course*)

AC-WC is a type of laston (asphalt concrete layer) that functions to support traffic loads, protect the construction layer underneath, and provide a flat and smooth road surface. AC-WC is a mixture of asphalt and aggregate graded to a certain density at a heating temperature of 150^{o}C (Pomantow *et.al.*, 2019). The use of AC-WC requires heat-resistant asphalt characteristics to be resistant to plastic deformation (*bleeding*), waves (visual deformation of pavement markings), cracks or holes in the surface, and loose grains (loss of adhesion).

Resin

Mastic gum is a natural resin that is elastomeric and plastomeric like conventional bitumen by adjusting the ratio of ingredients and adhesion. It contains aromatic organic compounds that are viscoelastic with melting points ranging from 120ºC - 150$^{(o)}$ C, compatible with AC-WC mixing temperatures. The chemical composition allows good chemical and physical interactions with bitumen, such as the formation of polar bonds that can improve the binding force and flexibility of asphalt mixtures.

Mix Planning

The planning of AC-WC asphalt mixtures is done by considering the upper and middle limits of the weight percentage of aggregates passing the sieve. This is stated in the Bina Marga 2024 specification. The following is the formula for calculating the initial estimate of optimum asphalt content.

$$Pb = 0.035\ (\%CA) + 0.045\ (\%FA) + 0.18\ (\%Filler) + K$$

Description:

Pb = Middle (ideal) asphalt content, percentage by weight of the mixture
CA = Percentage of aggregate retained by sieve No.8 (2.36 mm)
FA = Percentage of aggregate passing sieve No.8 (2.36 mm) and retained on sieve No.200 (0.075 mm)
Filler = Percentage of aggregate at least 75% passing sieve No.200 (0.075 mm)
K = Constant (estimated to be 0.5 - 1.0 for asphalt concrete layers)

Marshall Testing

Marshall testing is performed to facilitate the determination of the optimal asphalt mix design. It was first introduced by Bruce Marshall, and later developed by the U.S. Corps of Engineers. Marshall testing involves analysing the density and pores of a cylindrical solid mixture. The marshall testing procedure includes preparation of test specimens; compaction with a marshall tool, which is a press equipped with a 3000 kg *proving ring*; and *stability-flow* testing (Afriyannoor *et.al.*, 2024). Mixture stability is directly proportional to *flow*. If the acquisition of both values is high, it indicates that the asphalt has strong durability. The following is the provision of laston mix properties based on Bina Marga 2024 technical specification.

Table 1. Properties of Laston Hot Mix Asphalt

Mixture Properties		Laston			
		Wear Layer		Intermediate Layer	Foundation
Number of impacts per plane		50	75	75	112
Ratio of particles passing 0.075 mm sieve with effective bitumen content	Min.			0,6	
	Max.			1,6	
Voids in the mix (%)	Min.			3,0	
	Max.			5,0	
Voids in aggregate (VMA) (%)	Min.	15		14	13
Asphalt filled voids (%)	Min.			65	
	Max.	78	75	75	75
Marshall stability (kg)	Min.	550	800	800	1800
Melt (mm)	Min.	2		2	3
	Max.	4		4	6
Residual marshall stability (%) after immersion for 24 hours, 60˚C	Min.			90	
Voids in mix (%) at refusal density	Min.			2	

Marshall characteristics

Marshall characteristics are important parameters in evaluating the performance of hot mix asphalt determined through marshall testing. These parameters include stability,

flow, *marshall quotient* (MQ), voids in the mixture (VIM), voids in mineral aggregates (VMA), and voids filled with asphalt (VFB). Stability is the ability of the mixture to withstand traffic loads without undergoing permanent deformation, while *flow* is the degree of yielding or plastic deformation of the mixture due to loading. The MQ value is obtained from the ratio of stability and *flow*, which is the level of stiffness of the mixture. Meanwhile, VIM, VMA, and VFB relate to volumetric conditions that affect the binding force, resistance to water damage, and durability of the pavement. Thus, marshall characteristics provide a comprehensive picture of the balance between strength, flexibility and durability of a pavement mix.

3. RESEARCH METHODS

Research Framework

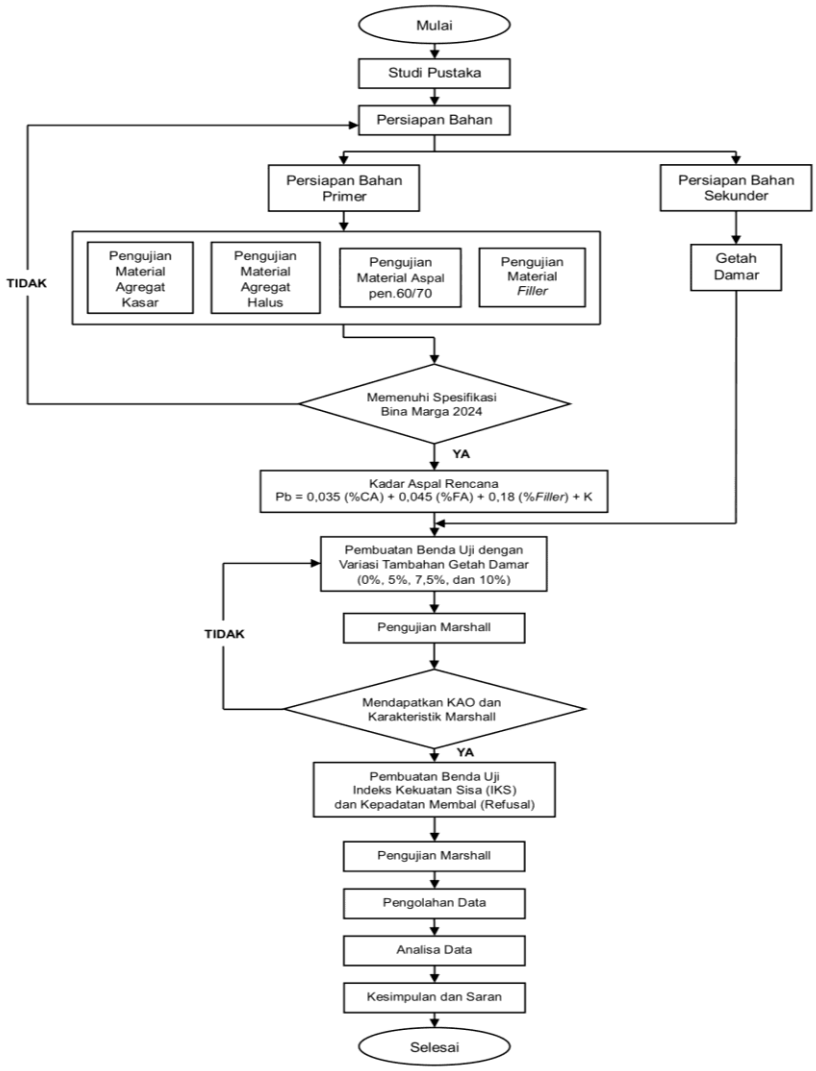


Figure 1 Flow Chart of Research Framework

Design of Test Objects

Based on the calculation of the Pb value (initial estimate of the optimum asphalt content) of 6%, the asphalt content used is 5%, 5.5%, 6%, 6.5%, and 7%, which is a calculation of +0.5 and -0.5 from the middle limit to obtain the upper limit and lower

limit. The following is the design of the number of test specimens for mixtures with additional resin gum at 0%, 5%, 7.5%, and 10%.

Table 2: Design of the number of test specimens

Test Item Code	Design Asphalt Content %	Substitution Rate (%)	Number of Samples
KD 0	5,0	0	15
	5,5		
	6,0		
	6,5		
	7,0		
KD 1	5,0	5,0	15
	5,5		
	6,0		
	6,5		
	7,0		
KD 2	5,0	7,5	15
	5,5		
	6,0		
	6,5		
	7,0		
KD 3	5,0	10,0	15
	5,5		
	6,0		
	6,5		
	7,0		
Total Sample			60

The following is the design of the number of test specimens for testing the residual strength index (IKS) and *refusal* density.

Table 3. Draft Number of Test Objects for Additional Testing

Name of Test Item	Asphalt Content (%)	Number of Samples
Refusal 1	KAO KD 0	3
Refusal 2	KAO KD 1	3
Refusal 3	KAO KD 2	3
Refusal 4	KAO KD 3	3
IKS 30 min and IKS 24 hours	KAO KD 0	4
IKS 30 min and IKS 24 Hours	KAO KD 1	4
IKS 30 min and IKS 24 hours	KAO KD 2	4
30 min IKS and IKS 24 hours	KAO KD 3	4
Total Sample		28

A total of 88 samples were prepared. The design of the number of specimens was determined based on the variation of asphalt content and the need for replication to obtain representative results. Generally, at least three specimens were made for each grade variation so that the data obtained could be statistically analysed and produce a curve of the relationship between marshall parameters and asphalt content. In addition, the number of ploughings, either 50, 75 or 100 per side, was adjusted according to the planned traffic level. The higher the traffic intensity, the greater the number of poundings applied to simulate compaction conditions in the field.

The following is the design composition of normal AC-WC mixtures using 5%, 7.5%, and 10% resin gum addition.

Table 4. Design of Modified AC-WC Mix Composition

Composition		Asphalt and resin content				
		5,0%	**5,5%**	**6,0%**	**6,5%**	**7,0%**
Asphalt (gr)	**5,0%**	60	66,35	72,77	79,25	85,81
	7,5%	58,42	64,6	70,85	77,17	83,55
	10,0%	56,84	62,86	68,94	75,08	81,29
Resin Gum (gr)	**0%**	63,16	69,83	76,6	83,42	90,32
	5,0%	3,16	3,49	3,83	4,17	4,52
	7,5%	4,74	5,24	5,74	6,26	6,77
	10,0%	6,32	6,98	7,66	8,34	9,03
Cold Bin I (gr)				480		
Cold Bin II (gr)				96		
Cold Bin III (gr)				480		
Cold Bin IV (gr)				120		
Filler (gr)				24		

4. RESULTS AND DISCUSSION

Marshall Characteristic Test Results

Based on the marshall test results, most of the parameters met the technical specifications of Bina Marga 2024. The data obtained is used to determine; optimum asphalt content (KAO), which is the best value of mixture performance according to specifications; and evaluate the effect of adding additives. The following are the results of marshall testing of AC-WC mixtures with added resin gum levels of 0%, 5%, 7.5%, and 10%.

Table 5. Marshall Testing Results

Relationship between Marshall Characteristics and Substitution Rate of Resin Gum

Characteristics	Spec. BM24	Resin Gum Content (%)	Asphalt Content (%)				
			5,0	**5,5**	**6,0**	**6,5**	**7,0**
Density (gr/cm^3)	-	**0**	2,3	2,33	2,33	2,33	2,33
		5	2,31	2,34	2,37	2,3	1,23
		7,5	2,32	2,33	2,33	2,34	2,34
		10,0	2,3	2,4	2,35	2,36	2,38
VIM (%)	3 - 5	**0**	6,54	4,89	4,18	3,32	2,65
		5,0	6,24	4,4	2,58	1,4	1,23
		7,5	5,88	4,83	3,84	3,13	2,82
		10,0	6,74	4,64	3,42	2,11	0,82
$VIM_{(PRD)(\%)}$	Min. 2	**5,0**	5,03	3,18	1,53	-	-
		7,5	4,86	3,85	2,83	-	-
		10,0	5,69	3,71	2,46	-	-
Stability (kg)	Min. 800	**0**	2212	2500,5	2395,7	2152,7	1804,8
		5,0	2012,74	2269,95	2311,77	2353,28	1837,15
		7,5	1711,29	2170,56	2239,71	2274,07	1899,82
		10,0	1801,57	2185	2254,01	2318,52	2027,41
Flow (mm)	2 - 4	**0**	2,41	2,81	3,05	3,41	3,94
		5,0	2,5	2,85	3,05	3,42	3,9
		7,5	2,19	2,77	2,98	3,28	4,06
		10,0	2,43	2,84	3,13	3,54	4,2
MQ (kg/mm)	-	**0**	925,8	906,42	785,26	636,97	472,95
		5,0	811,05	808,04	759,47	688,92	476,35
		7,5	787,35	784,89	750,56	695,37	499,62
		10,0	796,05	768,55	743,01	660,26	492,12
VMA (%)	Min. 15	**0**	16,73	16,3	16,73	17,01	17,46
		5,0	16,46	15,88	15,33	15,37	16,27
		7,5	16,14	16,26	16,43	16,85	17,61
		10,0	16,91	16,09	16,06	15,97	15,92
VFB (%)	Min. 65 Max. 75	**0**	60,89	70,03	75	80,49	84,85
		5,0	62,11	72,58	83,26	90,87	92,5
		7,5	63,65	70,27	77,28	81,46	83,97
		10,0	60,16	71,19	78,73	86,81	94,84

The following are the results of marshall testing of AC-WC mixtures with resin resin substitution presented in the form of relationship graphs.

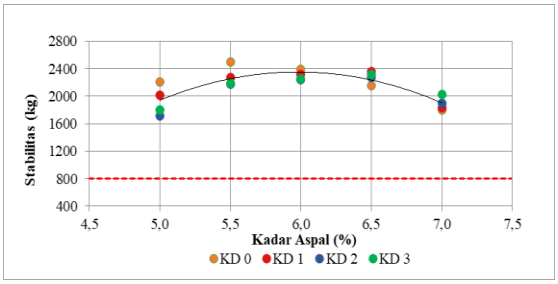


Figure 2. Stability

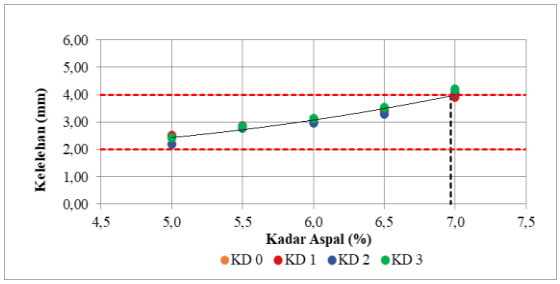


Figure 3. *Yield* (*Flow*)

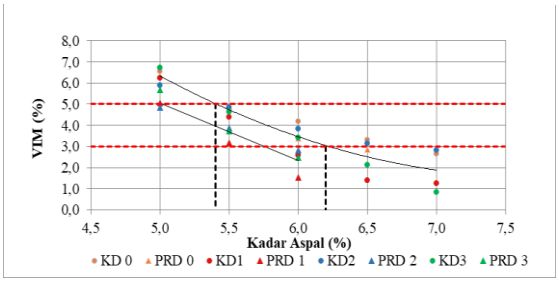


Figure 4. VIM (Voids in Mixture)

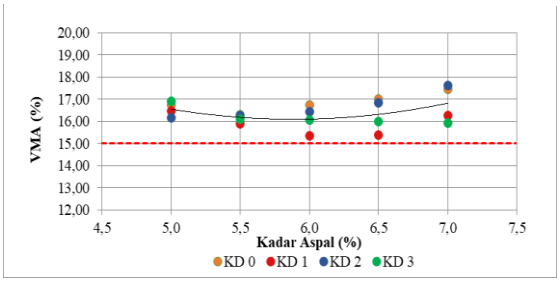


Figure 5. VMA (Voids in Aggregate)

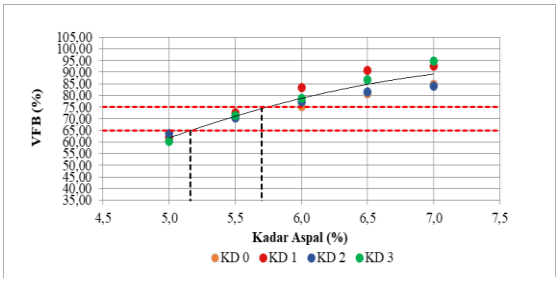


Figure 6. VFB (Asphalt Filled Voids)

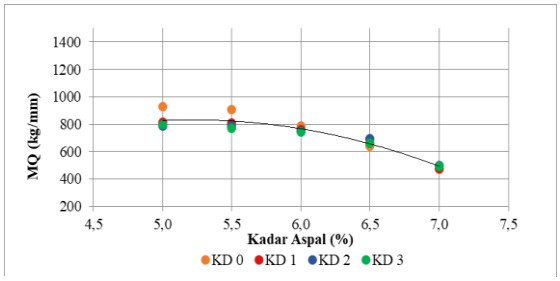


Figure 7. MQ (*Marshall Quotient*)

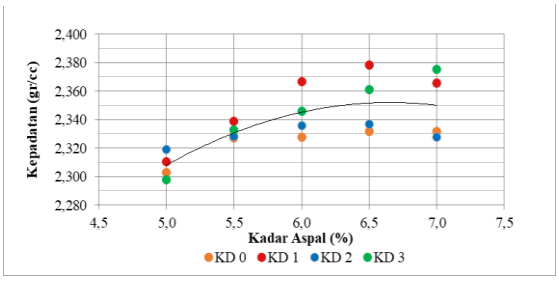


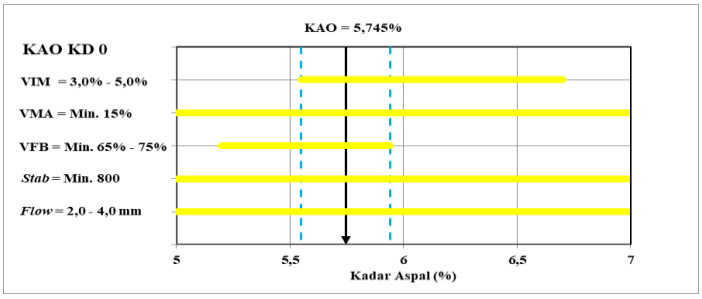
Figure 8. *Density*

Based on the graph above, it is shown that the stability value increases to the optimum point (5.5% - 6.0%), then tends to decrease. The stability value indicates that rosin resin plays a role in improving cohesion and bonding between aggregate particles, so that the durability of the mixture is strong against traffic loads. The *flow* values obtained increased as the asphalt content increased. This indicates better deformability without compromising stability. The VIM values obtained tend to decrease as the asphalt content increases. Technically, this condition does not have a major effect as long as it is within the specification range (3% - 5%), to avoid *bleeding*. In the VMA results, the value is relatively stable in the range of 14% - 16%, the VMA *trend* shown increases at high

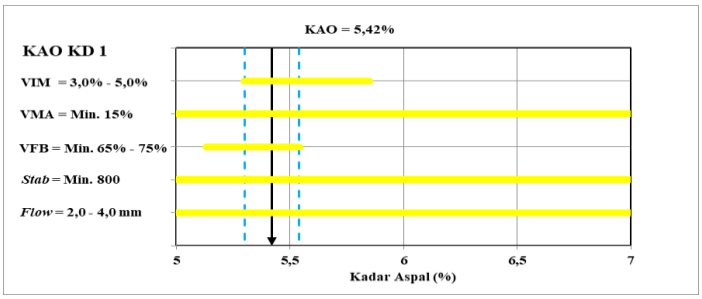
asphalt content, indicating the retention of voids in the aggregate is still maintained. Meanwhile, the VFB value increased in line with the increase in asphalt content. The VFB value was higher than the control, meaning that the ability to fill voids by asphalt also increased. The MQ value was indicated to decrease with increasing asphalt content, but in the resin resin-substituted mix, the MQ tended to be moderate. While the density value increases until it reaches the optimum asphalt content, then decreases again. With rosin resin substitution, the density tends to be higher due to better compaction efficiency.

Optimum Asphalt Content (KAO) Test Results

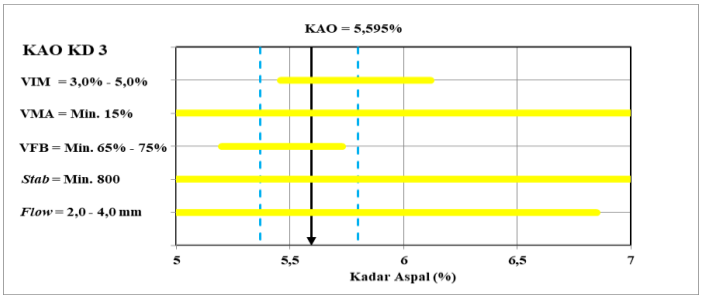
The optimum asphalt content is obtained through a series of marshall tests on several variations of asphalt content in the mixture. The determination process starts with making test specimens at a certain range of asphalt content, generally above and below the initial estimated content (plan content). The KAO value is determined by considering the intersection point or trend of the graph of the relationship between asphalt content and marshall parameters. The KAO is chosen as the asphalt content that provides the most balanced mix performance between stability, durability, and flexibility. The following is a graph of the test results of the optimum asphalt content of AC-WC mixtures with resin resin substitution.



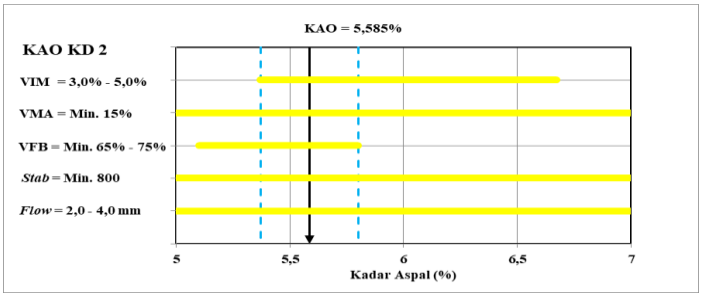
Optimum asphalt content at 0% resin content



Optimum asphalt content at 5% resin content



Optimum asphalt content at 7.5% resin content



Optimum asphalt content at 10% resin content

The results of the optimum asphalt content (KAO) test on asphalt mixtures with resin resin substitution show a variation in value which is influenced by the percentage of substitute material. In the mixture without substitution (0%), the KAO value was obtained at 5.745%. The addition of 5% resin gum resulted in a decrease in the KAO value to 5.42%, indicating that the mixture required less asphalt content to achieve optimal marshall characteristics. However, at 7.5% substitution rate there was a slight increase in the KAO to 5.585%, and at 10% substitution rate the KAO value was relatively stable at 5.595%. This pattern shows that the addition of a certain amount of resin can reduce the optimum asphalt demand, but at higher levels it tends to increase again. This is thought to be related to the chemical properties of rosin resin that affect adhesion and cohesion in the mix, thereby affecting the asphalt demand to achieve standardised mix performance.

Test Results *Index Retained Stability* (IRS) and *Refusal*

Index Retained Stability (IRS) is a parameter evaluating the resistance of asphalt mixtures to damage due to the influence of water, which is obtained from the comparison of the marshall stability value of the test specimen soaked for 24 hours with the stability of the test specimen soaked for 30 minutes. Meanwhile, the *refusal* test is carried out to determine the maximum density condition of the mixture with the *over-compaction* method, so that it can show the critical condition of the mixture against excess asphalt content. The following are the results of IRS and *refusal* tests of AC-WC mixtures with resin gum levels of 0%, 5%, 7.5%, and 10%.

Table 6. *Index Retained Stability* (IRS) Testing Results

Condition	Mastic Gum Substitution Rate (%)	Stability Value After Correction	Average Stability	Residual Stability (%)
Soaking 40 Minutes, Temperature 60°C	**0**	2479	2463,17	96,34
		2448		
	5,0	1917	2010,14	96,90
		2103		
	7,5	2524	2483,65	95,78
		2443		
	10,0	2630	2556,18	97,09
		2482		
24 Hours Soaking, Temperature 60°C	**0**	2358	2373,03	96,34
		2388		
	5,0	1897	1947,80	96,90
		1999		
	7,5	2338	2378,85	95,78
		2420		
	10,0	2523	2481,73	97,09
		2441		

Table 7. *Refusal* Testing Results

Test Item Code	Resin content (%)	VIM Refusal (%)	Specification
Refusal KD 0	0	3,38	Min. 2%
Refusal KD 1	5	3,18	
Refusal KD 2	7,5	3,85	
Refusal KD 3	10	3,71	

5. CONCLUSION

Most of the marshall characteristics obtained in this test have met the requirements of Bina Marga 2024 technical specifications, although at certain levels they have increased and decreased. Substitution of rosin gum up to 10% still gives good results on the performance of AC-WC asphalt mixtures. Based on the KAO value obtained, the optimal resin substitution level recommended for field application is in the range of 5% of the asphalt weight, which is 5.42%, to maintain the stability, flexibility, and durability of the mixture.

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