Engineering and Technology Journal e-ISSN: 2456-3358

Volume 08 Issue 11 November -2023, Page No. – 3103-3107

DOI: 10.47191/etj/v8i11.19, I.F. – 7.136

Analysis of Marshall Characteristics with Fly Ash Material for Stone Dust Substitution as Filler in HRS-WC Mixture

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ABSTRACT: Lataston asphalt mix is a thin layer of asphalt concrete that is often used on light-traffic roads because it produces roads with good flexibility and durability. An economical way of doing this is to vary the asphalt mix, especially by modifying fillers, to improve the quality of the road pavement and asphalt mix. So, an alternative was found, namely the use of fly ash, residue from the Asam-Asam PLTU. The filler material for fly ash which will be varied with the filler for stone dust, plays a role in filling the voids between aggregate grains in the Hot Rolled Sheet-Wearing Course (HRS-WC) mixture with each predetermined composition. This study aims to determine the characteristics of the HRS-WC asphalt mixture with respect to the utilization rate of rock dust and fly ash fillers. To find out the characteristics of a HRS-WC mixture with mixed variations of the two fillers, the method that will be used is the Marshall Test by analyzing each characteristic of the parameters to be obtained in accordance with the 2018 Revised Highways Specifications II Year 2018 to make the mixture hot asphalt. The bitumen content used in this study was 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%, with varying levels of fly ash and rock dust filler, namely 100%: 0%, 80%: 20%, 50%: 50%, 20%: 80%, and 0%: 100%. The results of the Marshall characteristic calculation analysis show that the asphalt mixture with lataston is very influential in the substitution of rock ash as a fly ash filler. Lataston asphalt mixture tends to be stiff and easily cracked because it has a high stability value of 1,615.38 kg and the lowest flow value of 4.10% in the 100% fly ash filler variation. At optimal asphalt content, the HRS-WC asphalt mixture for each variation in the range of fly ash and rock dust produces a decreased asphalt content because the water absorption capacity of rock dust is less than that of fly ash filler, so less asphalt is needed. In addition, the HRS-WC asphalt mixture also shows increasing durability, along with the replacement of rock dust filler with fly ash filler, which can be seen from the increased stability values, MQ values, and VFB values.

KEYWORDS: HRS-WC Mixture, Fly Ash Filler, Marshall Characteristics

I. INTRODUCTION

The development of pavement construction in Indonesia began to grow rapidly in 1970, when pavement construction was introduced in line with its function [1]. Engineers have continued to control the development of road construction with modern technology, and the impact of the available road length has resulted in new problems such as the deterioration of built road structures [2]. Road damage in Indonesia is usually caused by congestion due to improper road structure placement, leading to rapid road deterioration, environmental changes, and poor drainage function. Due to the inadequate quality of materials used in Design Mix Formula (DMF) production and improper field implementation procedures for Job Mix Formula (JMF), the production of asphalt concrete requires the use of higher-quality materials such as coarse aggregate and filler materials for asphalt mixtures, as well as asphalt as a binder [3]. Additionally, water stagnation, or water seeping into the pores of the road surface, is one of the factors causing road damage. Therefore, the top layer of the road is designed to maintain water resistance properties, in addition to an appropriate road drainage system. Water resistance is achieved through the use of binders and fillers in the gaps between aggregates such as asphalt or Portland cement [4]. Thus, the surface layer must be able to prevent water from entering to maintain the stability of the mixture. An elastic and flexible surface layer structure will enhance the strength of the pavement layer in bearing vehicle loads [5].

With this issue, the construction of new roads and road maintenance are required to improve the quality of roads, especially by enhancing the quality of the materials used in their mixture. Higher-quality roads will require increased funding. On the other hand, the allocation of funds for road infrastructure development is very limited [6]. Many researchers have innovated in testing asphalt mixture materials to make them more economical. These innovations aim to enhance the quality of existing asphalt, including modifying the physical and chemical properties of asphalt with various additives to obtain high-quality and affordable asphalt for future use in road infrastructure development. Good asphalt concrete should have properties that make it resistant to peeling and have a high, flexible pavement value. The commonly used type of flexible pavement is the HRS-WC asphalt layer, as it is resistant to weather changes, waterproof, highly stable, and easy to work with. HRS-WC asphalt is a hot mixture that uses both coarse and fine aggregates [7].

Lataston, or Hot-Rolled Sheet (HRS), is believed to produce roads with good flexibility and durability for light traffic. To enhance the performance of asphalt concrete mixtures, it can be done by modifying the mixture, especially by replacing the filler with other materials [8]. The construction of HRS consists of a mixture of coarse aggregates, fine aggregates, filler, and a binding material in the form of hotmix asphalt. The relatively high asphalt content in the mixture tends to increase flexibility, durability, and resistance to melting, and it is less prone to cracking [9]. To obtain a well-graded HRS-WC or HRS-Base, at least 80% should pass through sieve No. 8 (2.36 mm) and sieve No. 30 (0.600 mm) [10]. The purpose of producing HRS is to have a top or middle layer on the road surface, which enhances its load-bearing capacity and serves as a waterproof layer that protects the underlying structure [11].

In this study, the filler materials used for the asphalt concrete mixture are fly ash and stone dust filler to bind the aggregates in the asphalt mixture and make it denser. In principle, fly ash does not have binding properties, but with the presence of fine particles and the addition of water, the silica contained in fly ash causes a chemical reaction with the calcium hydroxide formed due to cement hydration. This process creates a substance with the ability to bind [12]. Fly ash is one of the solid wastes produced by industries that use coal as a fuel in their production processes. Fly ash possesses pozzolanic properties, meaning it contains silica or alumina but lacks adhesive properties. However, its fine particles are capable of chemically reacting with lime and water at normal temperatures to form an adhesive [13].

Pozzolan is a material containing silica or alumina compounds that, in its natural state, does not possess binding properties like cement. However, when in fine form and mixed with water, these compounds react with hydroxide compounds at normal temperatures to form calcium hydroxide compounds that act as binders [14]. The abundant coal waste in South Kalimantan Province, particularly in the form of fly ash used as a substitute for cement in road paving, shares similar pozzolanic properties with cement [15]. The characteristic of the filler material in road pavement mixtures is to serve as a gap filler, enhancing asphalt adhesion, improving mixture stability, and minimizing settlement [16]. To create a mixture that truly aligns, it must be designed according to specified standards, making the actual gap a crucial factor in the mixture. HRS-WC is suitable for use in Indonesia, where temperatures are relatively high, due to its high flexibility and resistance to melting [17]. The objective of this study is to ascertain the physical and mechanical properties of both filler materials, as well as to understand the characteristics of HRS-WC mixtures with variations in FA and DB filler contents.

II. METHOD

The research commenced with a literature review, followed by conducting laboratory work at the Transportation and Highway Laboratory of the Civil Engineering Program, Faculty of Engineering, Lambung Mangkurat University, Banjarbaru City, South Kalimantan Province. In this study, the materials used include coarse aggregate from Martadah mountain crushed stone, fine aggregate from Awang Bangkal sand, Asam-Asam Fly Ash (FA), and stone dust from the output of the Stone Crusher (DB). Then, each material was examined according to the 2018 Revised General Specification for Road Construction by the Directorate General of Highways, guiding the determination of the HRS-WC asphalt mixture. Once all materials met the requirements, the percentage retained for each material in the sieve was calculated, resulting in the weight proportion of each material to be mixed in the HRS-WC mixture. Subsequently, planning and calculation for the optimal asphalt content (OAC) will be carried out using Equation I [18].

$$Pb = 0{,}035(\%CA) + 0{,}045(\%FA) + 0{,}18(\%filler) + K \quad (1)$$

Explanation:

Pb = Asphalt content planning.

CA = Percentage of aggregate retained on sieve No. 8.

FA = Percentage of aggregate passing through sieve No. 8 and retained on sieve No. 200.

Filler = Percentage of aggregate passing through sieve No. 200.

K = Constant value (0.5–1.0 for asphalt concrete and rolled asphalt).

$Pb = 0{,}035(43{,}22\ \%) + 0{,}045(48{,}78\ \%) + 0{,}18(8\ \%) + 0{,}5$

$Pb = 5{,}65\ \%$

The calculation results indicate that the asphalt content used is 4.5%, 5.0%, 5.5%, 6.0%, and 6.5%, with variations in FA and DB filler content as follows: 100%:0%, 80%:20%, 50%:50%, 20%:80%, and 0%:100%. Parameters measured in the Hot Rolled Sheet-Wearing Course (HRS-WC) asphalt mixture include stability (load resistance received), flow (flexibility of a pavement), VIM (Void in Mix, which is the amount of air voids in the mixture), VMA (Void in Mineral Aggregate, which is the amount of voids between aggregate particles), VFB (Void Filled by Bitumen, which is the amount of voids filled with asphalt), MQ (Marshall Quotient, which is the division of stability value by flow value), and density

(density of a mixture). The planning design for each composition is shown in Table 1.

Table 1. Proportion of HRS-WC Design

Filler Proportion			Composition		Asphalt Content				
FA	:	DB			4,50%	5%	5,50%	6%	6,50%
100%	:	0%	Asphalt (gr)		54	60	66	72	78
			Percentage of Aggregate		95,50%	95,00%	94,50%	94,00%	93,50%
			Coarse Aggregate (gr)		495,30	492,71	490,11	487,52	484,93
			Fine Aggregate (gr)		559,02	556,09	553,17	550,24	547,31
			Filler (gr)	FA	91,68	91,20	90,72	90,24	89,76
				DB	0	0	0	0	0
Total					1200	1200	1200	1200	1200
80%	:	20%	Asphalt (gr)		54	60	66	72	78
			Percentage of Aggregate		95,50%	95,00%	94,50%	94,00%	93,50%
			Coarse Aggregate (gr)		495,30	492,71	490,11	487,52	484,93
			Fine Aggregate (gr)		559,02	556,09	553,17	550,24	547,31
			Filler (gr)	FA	73,34	72,96	72,58	72,19	71,81
				DB	18,34	18,24	18,14	18,05	17,95
Total					1200	1200	1200	1200	1200
50%	:	50%	Asphalt (gr)		54	60	66	72	78
			Percentage of Aggregate		95,50%	95,00%	94,50%	94,00%	93,50%
			Coarse Aggregate (gr)		495,30	492,71	490,11	487,52	484,93
			Fine Aggregate (gr)		559,02	556,09	553,17	550,24	547,31
			Filler (gr)	FA	45,84	45,6	45,36	45,12	44,88
				DB	45,84	45,6	45,36	45,12	44,88
Total					1200	1200	1200	1200	1200
20%	:	80%	Asphalt (gr)		54	60	66	72	78
			Percentage of Aggregate		95,50%	95,00%	94,50%	94,00%	93,50%
			Coarse Aggregate (gr)		495,30	492,71	490,11	487,52	484,93
			Fine Aggregate (gr)		559,02	556,09	553,17	550,24	547,31
			Filler(gr)	FA	18,34	18,24	18,14	18,05	17,95
				DB	73,34	72,96	72,58	72,19	71,81
Total					1200	1200	1200	1200	1200
0%	:	100%	Asphalt (gr)		54	60	66	72	78
			Percentage of Aggregate		95,50%	95,00%	94,50%	94,00%	93,50%
			Coarse Aggregate (gr)		495,30	492,71	490,11	487,52	484,93
			Fine Aggregate (gr)		559,02	556,09	553,17	550,24	547,31
			Filler (gr)	FA	0	0	0	0	0
				DB	91,68	91,2	90,72	90,24	89,76
Total					1200	1200	1200	1200	1200

In this study, 75 test specimens are required. After obtaining the OAC value, the Marshall value can then be observed for each effective variation ratio of filler content in the HRS-WC mixture. Figure 1 depicts the flowchart of the research.

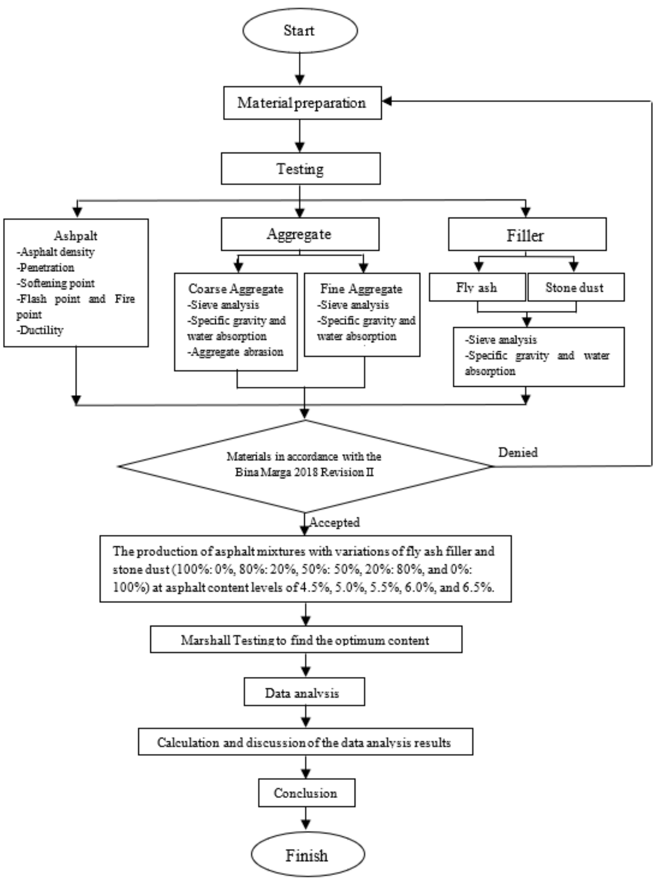


Figure 1: Research Flowchart

III. RESULTS AND DISCUSSION

The purpose of testing the materials is to determine the physical and material properties of the materials used. The results of the material testing are shown in Table 2.

Table 2. Material Testing Results

No.	Types of Testing	Testing Methods	Standard	Result	Notes
Coarse Aggregate Inspection Results					
1.	Water Absorption	SNI 1969:2016	< 3 %	1,88	Fulfilled
2.	Specific Gravity of Aggregate	SNI 1969:2016	> 2,1	2,68	Fulfilled
3.	Aggregate Abrasion with Los Angeles Machine	SNI 2417:2008	< 40 %	21,78	Fulfilled
Fine Aggregate Inspection Results					
1.	Water Absorption	SNI 1970:2016	< 3 %	2,55	Fulfilled
2.	Specific Gravity of Aggregate	SNI 1970:2016	> 2,1	2,25	Fulfilled
Ashpalt Inspection Results					
1.	Asphalt density	SNI 2441:2011	≥ 1,0	1,02	Fulfilled
2.	Penetration	SNI 2456:2011	60 – 70	62,80	Fulfilled
3.	Softening point	SNI 2434:2011	≥ 48	71,00	Fulfilled
4.	Flash point and Fire point	SNI 2433:2011	≥ 232	328	Fulfilled
5.	Ductility	SNI 2432:2011	≥ 100	100,00	Fulfilled
Filler Inspection Results					
1.	Water Absorption	SNI 1970:2016	-	10,57	-
2.	Specific Gravity of Filler	SNI 1970:2016	-	2,06	-

Based on Table 2, the test results for the properties of aggregates, asphalt, and filler to be used in the study have met the requirements of the 2018 Revised Bina Marga Specifications.

The summary of the optimum asphalt content for each mixture variation can be observed in Table 3.

Table 3. Recapitulation of OAC Results

Mixed Proportion	OAC (%)
100 % FA : 0 % DB	6,40
80 % FA : 20 % DB	6,30
50% FA : 50 % DB	6,25
20 % FA : 80 % DB	6,20
0 % FA : 100 % DB	6,15

Table 3 shows that the aggregate's water absorption directly influences the required asphalt content. The higher the water absorption value, the greater the need for asphalt in the asphalt mixture. In the mixture variation with 100% FA content and 0% DB content, it has a high asphalt proportion of 6.40% compared to the 0% FA:100% DB mixture, which has a lower asphalt content of 6.15%. This is because the water absorption capacity of DB filler is lower than that of FA filler, resulting in a reduced asphalt requirement in that variation. The HRS-WC stone mastic asphalt mixture with 100% FA filler has a lower volume, thus requiring more asphalt to cover the aggregate compared to the mixture with less stone dust filler.

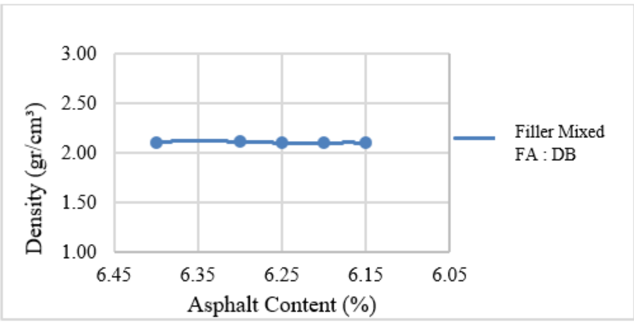
Below is the summary of Marshall characteristics for the OAC as shown in Table 4.

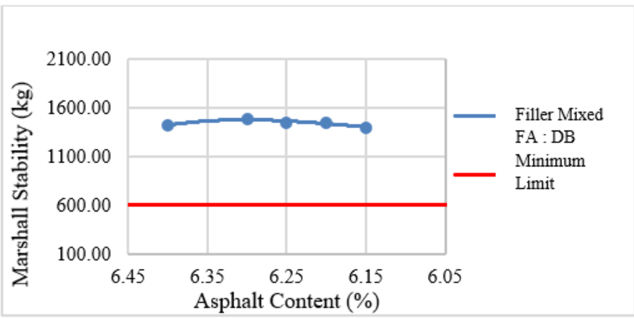
Table 4: Summary of Marshall Characteristics for OAC

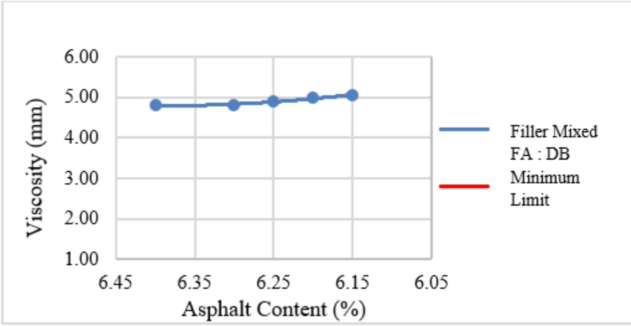
Mixture Varieties (%)		OAC	Stability	Flow	VIM	VMA	VFB	MQ	Density
		%	kg	mm	%	%	%	kg/mm	
100	0	6,40	1420,00	4,80	3,40	17,20	83,20	325,00	2,10
80	20	6,30	1485,00	4,80	3,60	17,20	82,50	317,00	2,11
50	50	6,25	1447,00	4,90	3,80	17,20	81,00	320,00	2,10
20	80	6,20	1450,00	5,00	4,00	17,20	79,00	310,00	2,10
0	100	6,15	1400,00	5,05	4,40	17,33	78,00	290,00	2,10
Requirment			> 600	> 3	3 - 5	> 17	> 68	> 250	-

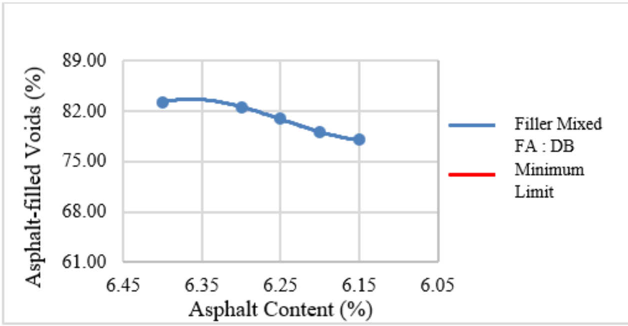
Based on Table 4, the obtained Marshall characteristic test results for the OAC meet the specified requirements. The use of FA filler instead of DB filler in asphalt mixtures has a significant impact. This is because the specific gravity of FA filler is lower than that of DB filler. The water absorption capacity of FA filler is higher compared to DB filler. For more detailed information, refer to the OAC test results for DB filler compared to FA filler shown in Figure 2.

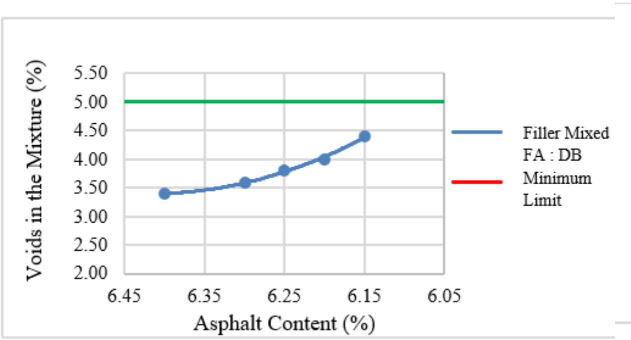
In Figure 2, the Marshall test shows that as the asphalt content increases to a certain point, the stability of the asphalt mixture improves. This happens with different levels of FA and DB filler. However, after reaching a peak, adding more asphalt can decrease stability as it changes from a binder to a lubricant. Subsequently, the stability value decreases due to the initial asphalt content, which initially acted as a binder, transforming into a lubricant. The more asphalt is added, the better the flexibility of the mixture. The flow value for the stone mastic asphalt mixture using 100% and 80% FA filler is low. FA has a smooth surface, which is characterized by its crystallinity and high-water absorption capacity. The increased MQ value is due to the 100% FA filler mixture variation having high stability and low flow values. Asphalt content increase leads to lower VIM and VMA values due to FA filler's higher density compared to DB filler. This results in less volume and smaller air pockets. The increasing VFB value with each replacement of DB filler with FA filler in the stone mastic asphalt mixture can reduce the air voids formed in the mixture. The density value in the stone-mastic asphalt mixture yields a stable value. This is because the specific gravity of FA filler is nearly the same as that of DB filler.

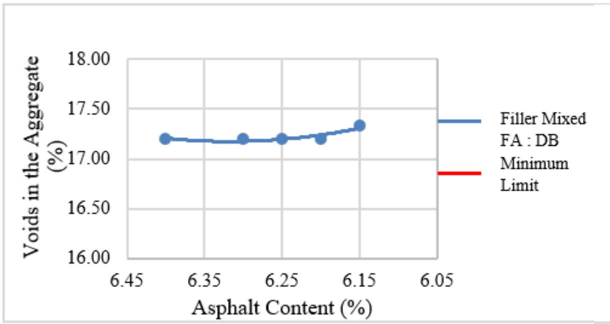


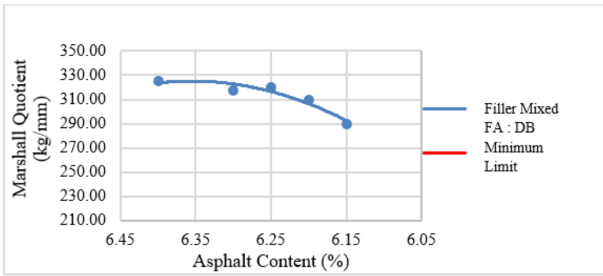












IV. CONCLUSION

The research confirms that the material inspection for the HRS-WC mixture meets the 2018 Revised Bina Marga specifications. Increasing the use of FA filler instead of DB filler in the asphalt mixture improves stability, VFB, and MQ values. This means that when using FA filler, the asphalt mixture becomes more durable and capable of bearing higher traffic loads compared to using DB filler. However, flow, VIM, and VMA values decrease because the volume weight of FA filler is greater than that of DB filler. Nevertheless, the density value indicates good compactness, as the mixture proportions of the two fillers have nearly the same specific gravity.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENT

The authors thank Universitas Lambung Mangkurat, under the Ministry of Education, Culture, Research, and Technology, provided research funding through the *Program Dosen Wajib Meneliti* (PDWM) for the year of 2023.

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