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Modification of High-Quality Porous Concrete Asphalt with Local Materials as an Alternative to Flexible Pavement

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ABSTRACT

Environmental issues and a lack of attention to open space as rainwater catchment areas cause flooding problems in urban areas. Constructing environmentally friendly roads with permeable capabilities is one way to prevent waterlogging along the road in the rainy season. This study evaluated the type of porous asphalt concrete called Open Graded Friction Course specification Japanese standard. This study modified porous asphalt concrete using bamboo fiber and hydrated lime. Stability testing is conducted by the Marshall method, and the volumetric mixture is analyzed. Stability testing is carried out by the Marshall method and analysis of the volumetry of the mixture is carried out. The results showed that adding bamboo fiber and hydrated lime increased stability and maintained the porosity of the porous asphalt concrete.

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1. INTRODUCTION

Asphalt concrete is a material that is widely used as a surface layer in this type of flexible pavement layer [1]. The asphalt concrete layer is designed as a watertight layer to protect the overall pavement structure, hoping water runoff will soon be channeled into existing drainage channels [2]. The problem in Indonesia is poor attention to the environment and drainage systems, lack of development arrangements that consider open space as a rainwater catchment area, and frequent floods during the rainy season. Rainwater puddles are not only a disaster but also trigger damage along the surface of the road layer.

This research participates in the Green Economy program, Green Construction. An innovation was carried out using the type of material that can be an alternative type of flexible pavement with high stability but can drain puddles. One way out that can be considered in this case is porous asphalt concrete.

Porous asphalt concrete is a mixture of asphalt concrete with open-graded aggregate, a large proportion of coarse aggregate, and a small proportion of fine aggregate, thus providing a large air cavity [3]. Large air cavities offer advantages to water flow so that the road surface is immediately accessible from puddles. The air void range of asphalt porous mixture can vary depending on the specific standard requirement, but usually, the recommended ranges from 18% to 25% after compaction [4]. Due to the high porosity and open aggregate gradation, the asphalt coating on the aggregate surface becomes more susceptible to external influences, ultraviolet rays, air, and water [5]. Raveling and pothole defects are major nuisances of porous asphalt pavements and will seriously affect the service life of roads[6]. In addition, in its application, porosity in the pavement will be reduced easily due to blockage by impurity materials carried by water flow.

Asphalt Porous concrete or the so-called Open Graded Friction Course (OGFC). In Indonesia, OGFC specifications have yet to be accommodated in regulations. Therefore, this study tried to design porous concrete asphalt with Japanese specification standards, which was modified using bamboo fiber to add porosity and maintain stability with added hydrated lime. Much research has been done on regulating aggregate gradation by comparing it with various regulations. In addition, efforts to replace aggregate materials with other types improve the physical characteristics/stability of the mixture [3][5][6][7][8][9][10]. Research using local aggregate materials [5] showed that the average stability reached a value of 1123.61 kg with an optimum asphalt content of 5% and an average VIM of 23.22 %. Research with modified porous asphalt recycles concrete material and Gilsonite [6] improved 8-10% marshall stability without decreasing permeability, stability value at 750 kg. Modification porous asphalt crushed stone and pyrophyllite compared with crushed stone and steel slag [7], the result of the research showed that the best performance on a mixture of crushed stone and steel slag with stability reached 430.8 kg and VIM reached 24.8%. Modifying porous asphalt with addive plastic [8] shows that adding plastic increases air void [VIM] but decreases stability. Stability without plastic is 690.35 kg, the stability becomes 193.75 kg with a 20 % plastic addition. The VIM value reaches 26 % with the addition of 20 % plastic. Two kinds of filler compared red mud and limestone on porous asphalt mix [9]. The research concludes that adding filler can increase the high-temperature performance of asphalt. If summarized, previous research shows that the highest stability is achieved at 1123.61 kg. VIM can reach 26% in modifications with plastics, but the stability value is low.

This study aims to modify porous concrete asphalt with a mixture of bamboo fiber and add hydrated lime to improve stability while maintaining porosity. The following objectives are met to achieve this goal: investigating the stability and volumetric properties of modified and unmodified OGFC. The following objectives are met to achieve this aim: investigating the stability and volumetric properties of modified and unmodified OGFC.

2. MATERIALS AND METHODS

This study used aggregates from Pasuruan, and the aggregate characteristics were tested through physical and mechanical tests described in Table 2. The asphalt used is 60/70. Penetration is presented in Table 3. As an additive material, bamboo fiber was used to increase stability and maintain the voids in the mixture. The research flow is shown on the flowchart in Figure 1

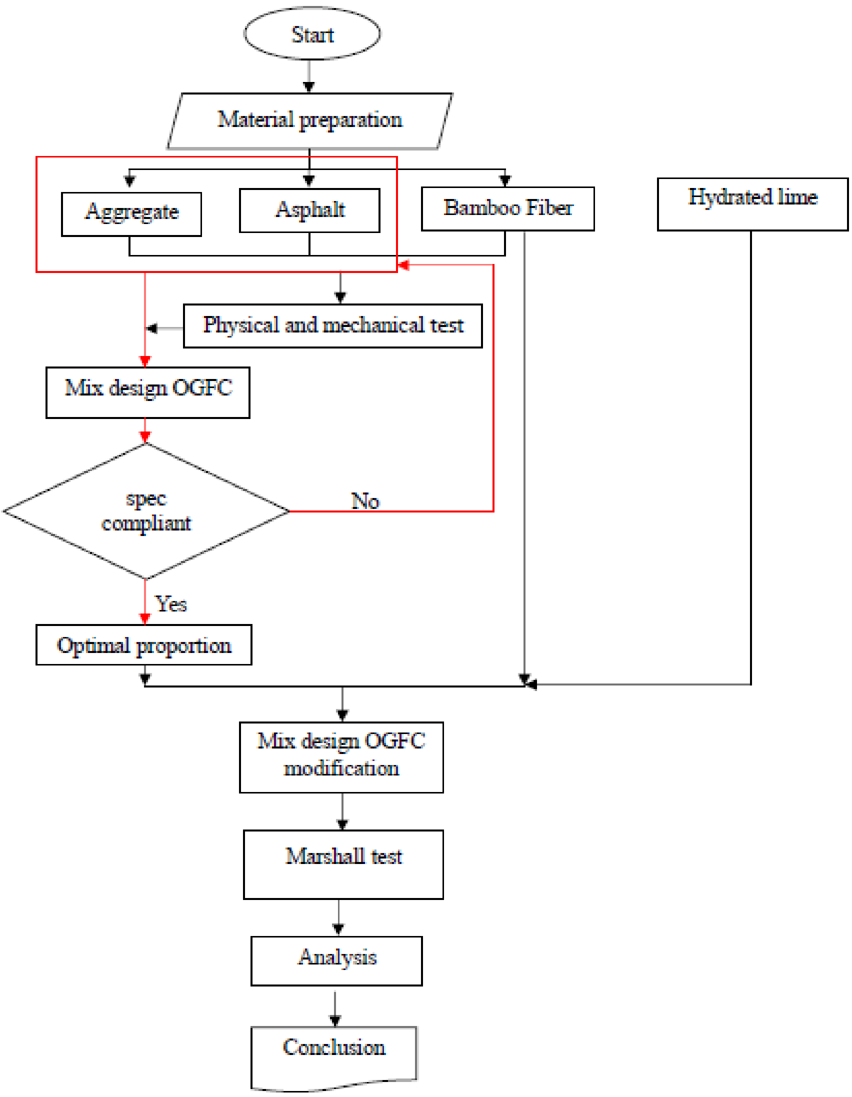

Figure 1. Research Flow Chart

The mechanical performance test method is carried out by Marshall testing. A Marshall test is performed on OGFC control specimens without modification and compared with OGFC specimens with modifications. The Marshall test is performed to obtain stability values. In addition, volumetric analysis (void in mix) is carried out to assess the ability of the mixture to escape the water and compare it with the standard design used. The OGFC blends used in the blend design using the Japanese standard are shown in Table 1.

Table 1. Specification of Japanese Standard Porous Asphalt Mixture

Mixture properties	Requirement
Stability	Min 500 kg
Flow	min 3 mm
Marshall Quotient	250 kg/mm
Void in mix (VIM)	15% - 25%
Void mix aggregate (VMA)	Min 15%

Sumber : Riyanto A, 2023 [11]

From the specifications above, it appears that the stability of OGFC is much lower than other types of Hot Mix Asphalt (HMA) and has a much larger VIM; this condition causes OGFC to have several weaknesses, including being prone to raveling, needs continuous repair, and being prone to moisture. The high air void content increases the potential for stripping. From this research, it is expected that the addition of hydrated lime will increase stability, and the addition of bamboo fiber will maintain the VIM value.

3. RESULTS AND DISCUSSION

3.1. Physic and Mechanical test

The study began by testing the characteristics of the material, namely coarse, medium, and fine aggregates, and asphalt. Coarse Aggregate (CA1) = 15-20 mm; (CA2) = 10-15 mm; Medium Aggregate (MA) = 5–10 mm; Fine Aggregate (FA) = 0–5 mm. The test results of aggregate characteristics are shown in Table 2, and the characteristics of asphalt are presented in Table 3. Furthermore, the manufacture of Open Graded Friction Course (OGFC) mixture test specimens with Japanese specifications was carried out. Moreover, testing of mixed volumetric stability and flow with the Marshall test. The OGFC specs are shown in Table 1.

Table 2. Material properties

Properties	CA1	CA2	MA	FA
Apparent specific gravity	2.738	2.890	2.889	2.708
Bulk specific gravity	2.624	2.722	2.703	2.587
Water absorption %	1.585	2.137	2.394	1.725
LA abrasion %	17.44 %			

Table 3. Asphalt properties

Properties	Asphalt specification Pen.60/70	Result	Method
Penetration 25^{O}C (0,1 mm)	60 - 70	64.3	SNI 2456:2011
The softening point, ^{O}C	≥ 48	53	SNI 2434:2011
Daktilitas 25^{O}C, cm	≥ 100	150	RSNI M-05-204

Testing the properties of aggregates and asphalt shows that the material is feasible as Open Graded Friction Course material. From these materials, a mixture is prepared to make test specimens.

3.2. Mix Design

Mixture design begins by conducting a sieve analysis of each type of aggregate used, namely Coarse Aggregate (CA), Medium Aggregate (MA), and Fine Aggregate (FA). The results of the sieve analysis can be seen in Table 4. Furthermore, specimens followed the Japanese Open Graded Friction Course (OGFC) gradation standard, as seen in Figure 1 with the proportion of aggregate used CA1 = 6 %; CA2 = 68 %, MA = 8 %; FA = 18 %;

Table 4. Gradation Distribution

Sieve		cumulative % pass			
ASTM	Mm	CA1	CA2	MA	FA
1"		100	100.0	100	100
¾"	19	39.10	100.0	100	100
½"	12.5	0.10	63.95	100	100
3/8"	9.5	0.10	20.40	100	100
# 4	4.75	0.10	1.05	98.7	100
# 8	2.36	0.10	0.20	22.9	82.4
# 16	1.18	0.10	0.20	1.85	62.7
# 30	0.6	0.10	0.20	0.30	49.3
# 50	0.3	0.10	0.20	0.30	43.7
# 100	0.15	0.10	0.15		33.0
# 200	0.075	0.10	0.15		27.6

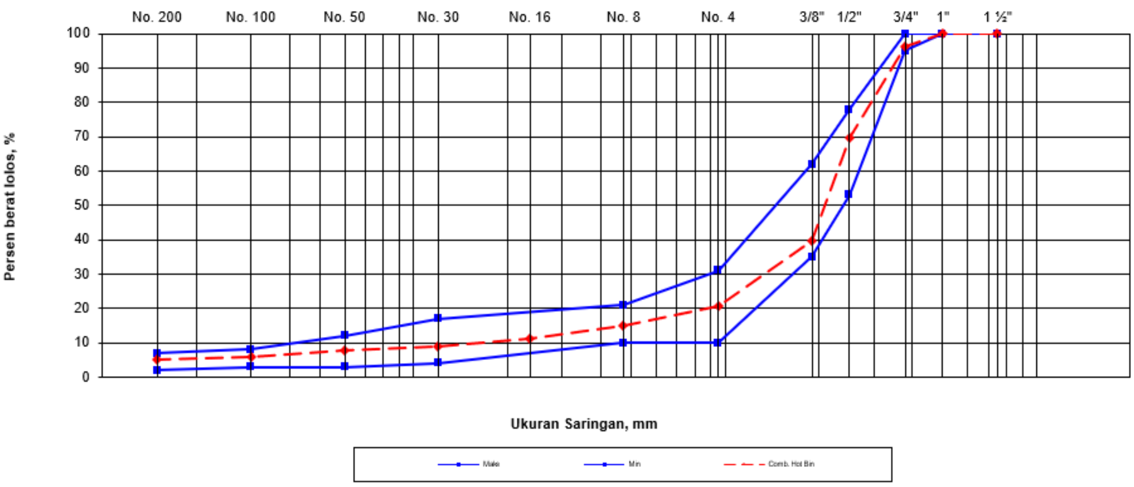

Figure 2. OGFC design gradation, percent passing

The proportion of gradation according to the target is selected, then the optimal asphalt content is estimated.

3.3. Determination of Optimal Asphalt Content

Before assigning a modified fiber mixture, the proportion of aggregate and asphalt grade that results in maximum stability is sought. Later the optimum asphalt content will be the control test object for the OGFC mixture. The optimum asphalt content (OAC) estimate with the gradation distribution of the selected grain size is 5.4 % asphalt content. This optimum asphalt content is sought to determine the optimum amount for the control test specimen. The variation in asphalt content made to obtain the OAC value is 4.4 %, 4.9 %, 5.4 %, 5.9 %, and 6.4 % of the total weight value of the test specimen of 1200 grams. Test specimens to obtain OAC can be seen in Figure 3.

In making OGFC test objects, because this mixture consists of aggregate granules with gap gradation when the asphalt content is raised, there is a time when it seems as if the aggregate is unable to absorb asphalt, so bleeding occurs. So, in this case, the fiber also functions as a stabilizer.

Figure 3. OGFC test specimens

3.4. Marshall Testing

Marshall testing is performed to test flow and stability and to determine the optimum asphalt content used in the research. The specimens were prepared with the mix by applying 50 blows on each side. Volumetric analysis measures the weight of test specimens in air, water, and saturated surface dry weight. The test results are shown in Table 5. The optimal asphalt content (OAC) ranges between 4.9 % and 5.4 %, but the VIM value still does not follow the specifications. Table 5 shows that VIM at asphalt content of 4.9% and 5.4% ranges from 9-11%.

Table 5. Marshall test result

Asphalt content	Specimen	VIM	VMA	Stability	Flow	MQ
%	-	%	%	Kg	Mm	kg/mm
4,4%	1	9.44	17.09	529.91	3.00	176.64
	2	11.28	18.77	431.32	3.50	123.23
	3	11.95	19.39	603.85	3.80	158.91
	Average	10.89	18.42	521.69	3.43	152.93
4,9%	1	9.08	17.85	639.87	3.00	213.29
	2	9.45	18.18	511.89	3.80	134.71
	3	10.78	19.38	563.08	3.80	148.18
	Average	9.77	18.47	571.62	3.53	165.39
5,4%	1	10.18	19.90	566.88	3.30	171.78
	2	10.51	20.19	677.79	3.00	225.93
	3	11.65	21.21	566.88	3.50	161.96
	Average	10.78	20.43	603.85	3.27	186,56

Asphalt content	Specimen	VIM	VMA	Stability	Flow	MQ
5,9%	1	9.48	20.32	492.94	3.50	140.84
	2	9.81	20.61	468.29	4.40	106.43
	3	10.97	21.63	554.55	4.50	123.23
	Average	10.09	20.85	505.26	4.13	123.50
6,4%	1	8.82	20.77	246.47	5.30	46.50
	2	8.63	20.61	369.70	4.50	82.16
	3	8.99	20.93	240.15	5.00	48.03
	Average	8.81	20.77	285.44	4.93	58.90

Figure 4. shows a graph of asphalt content versus stability, where the optimal percentage is at 5.4 % asphalt content with a stability value of 603.85 kg. However, based on consideration of VIM values, this proportion still needs to meet the requirements for OGFC blends.

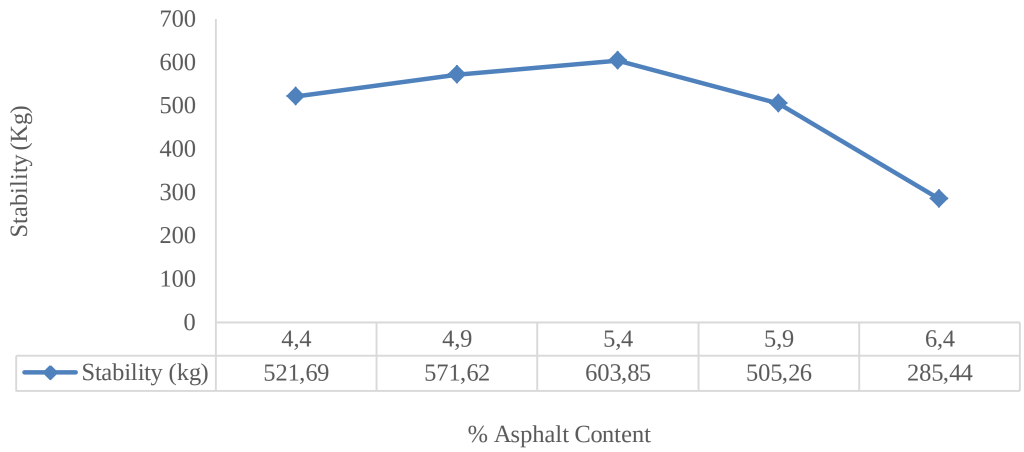

Figure 4. OGFC stability to get Optimal Asphal Content

The results of testing (Table 5), the characteristics of the specimens show that VIM tends to decrease with increasing asphalt content. In contrast, stability shows an upward pattern to 5.4 % asphalt content, and there is a gradual decrease and drastic decrease at 6.4 % asphalt content. At asphalt levels of 5.4 % and 6.4 %, when making asphalt, test specimens are added as if they cannot be absorbed into the mixture, so stability at 6.4 % levels drops to the extreme because much asphalt is lost, and the film is too high. The VIM target using the selected gradation distribution has yet to achieve the 18-25 % VIM target. With adding bamboo fiber, the VIM value is expected to increase to reach the target value.

3.5. Determination of OGFC modification with bamboo fiber

Next, OGFC test specimens were made with asphalt content values of 4.9 % and 5.4 % with fiber proportions of 0.25 %, 0.5 %, 0.75 % and 1%

Figure 5. OGFC test specimen with bamboo fiber modification

In OGFC, aggregates that are gap-graded of increasing asphalt cause asphalt not to be absorbed properly into the mixture and cause bleeding. The function of the fiber here is as a stabilizing agent that absorbs asphalt, which in turn can increase the stability of the mixture, in addition to aiming to increase the void in the mixture (VIM). Stabilizing agents are used in OGFC mixtures to minimize the drain down of the asphalt and increase the mixture's strength. Draindown is an issue in open-graded mixtures because, typically, there is little material passing the number 4 (4.76 mm) sieve and a relatively low P-200 compared to conventional dense-graded-mixtures.

The results of volumetric and mixed stability testing are presented in Table 6. The addition of bamboo fiber by 0.25 % as an additive to the OGFC mixture, at 4.9 % asphalt content there was an increase in VIM, but an increase in fiber content caused a decrease in stability. The addition of fiber to OGFC with a grade of 5.4 % showed a pattern of decreased stability and gradually rose again at a fiber content of 0.5 %. The addition of fiber could not increase stability at 5.4% asphalt content. At 4.9 % asphalt content and 1 % fiber, stability surpasses the original OGFC. However, the average VIM value increased according to the required specification (Table 1); the average VIM OGFC fiber modification was 17.21 – 21.18 %.

Table 6. Test result and Marshall analysis

Asphalt content	Specimen	Properties				
		VIM	VMA	Stabiliy	Flow	MQ
%	-	%	%	Kg	Mm	kg/mm
4,9% Fiber 0,25%	1	17.68	18.66	639.87	5.00	127.80
	2	17.06	18.05	554.55	4.00	138.64
	3	17.06	18.05	554.55	4.00	138.64
	Average	17.37	18.36	**597.21**	4.5	132.71
4,9% Fiber 0,5%	1	19.51	20.69	480.30	3.40	141.26
	2	19.14	20.32	480.30	4.00	120.07
	3	22.33	23.47	480.30	4.00	120.07
	Average	20.32	21.50	480.30	3.70	130.67
4,9% Fiber 0,75%	1	17.54	20.23	591,52	4,00	147.88
	2	16.88	20.66	447.91	5.00	89.588
	3	16.88	20.66	447.91	5.00	89.588
	Average	17.21	20.45	519.71	4.5	115.49

Asphalt content	Specimen	Properties				
		VIM	VMA	Stabiliy	Flow	MQ
%	-	%	%	Kg	Mm	kg/mm
4,9% Fiber 1%	1	19.36	20.32	720.44	4.50	160.10
	2	20.78	21.73	576.35	4.20	137,23
	3	21.72	22.65	456.28	4.10	111.29
	Average	20.62	21.57	584.36	4.27	136.20
5,4% Fiber 0,25%	1	17.54	19.74	518.90	5.00	103.78
	2	16.88	19.09	514.00	5.00	102.80
	3	16.88	19.09	514.00	5.00	102.80
	Average	17.21	19.42	516.45	5.00	103.29
5,4% Fiber 0,5%	1	19.51	21.56	624,38	4,20	148.66
	2	19.14	21.30	444.27	4.10	108.36
	3	22.33	21.13	396.24	4.20	94.34
	Average	20.33	21,33	488.30	4.17	117.12
5,4% Fiber 0,75%	1	17.54	20.34	480.61	4,00	129.15
	2	18.38	21.15	480.30	5.00	96.06
	3	17.54	20.34	480.61	4.00	129.15
	Average	17.96	20.74	480.46	4.50	106.77
5,4% Fiber 1%	1	20.90	23.00	369.70	3.30	112.03
	2	21.46	23.55	431.32	3.00	143.77
	3	21.18	23,28	739.40	3.50	211.26
	Average	21.18	23.28	513.47	3.27	155.69

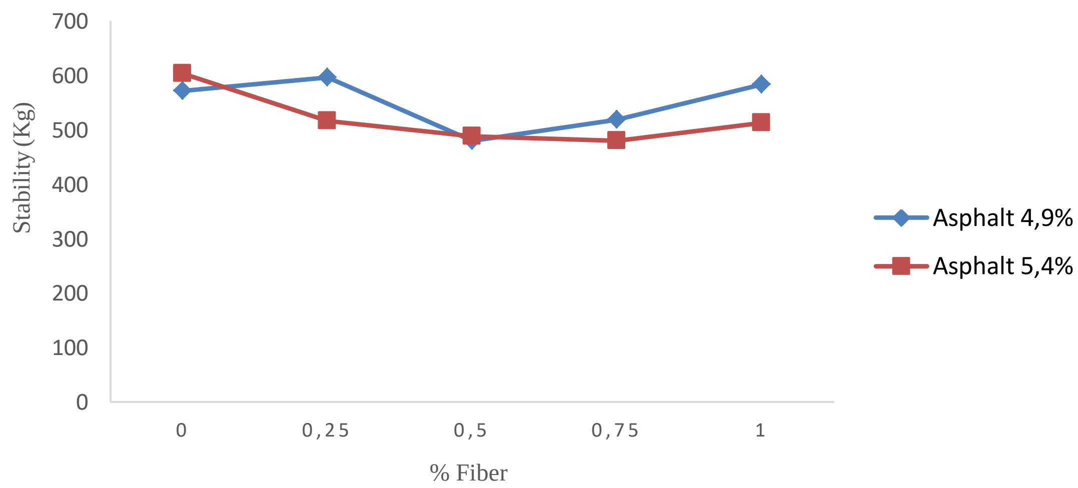

Figure 6. OGFC stability graph with modification of bamboo content variation at 4.9% and 5.4% asphalt content

The test results of porous concrete asphalt with modifications show that the addition of fiber results in an increase in VIM value but needs to be consistent in stability value. However, the best pattern of stability improvement is at 4.9 % asphalt content and achieves maximum value at 0.25 % bamboo fiber with 597.21 kg. At 5.4 % asphalt content with the same percentage of bamboo fiber, the stability value is below 4.9 % asphalt content. Adding fiber to the OGFC mixture causes the VIM value to rise to meet the specification target.

Furthermore, to improve the stability of the proportion of aggregate OGFC with asphalt content of 4.9% was selected to be modified with bamboo in variations of 0.25%, 0.50%, 0.75%, and 1%, and hydrated lime in variations of 0.5%, 1%, and 1.5%. The stability test results are shown in Table 7 and Figure 7. Based on the stability value, adding fiber without hydrated lime shows insignificant and random differences. The addition of hydrated lime tends to increase stability. The specimen with hydrated lime showed peak stability at all 0.5% fiber content, except at 1.5% hydrated lime content (purple color in Figure 7). The highest stability of 1511.60 kg is achieved at 0.5% fiber content and 0.5% hydrated lime. The minimum standard of stability according to the Specification of Japanese Standard Porous Asphalt Mixture is 500 kg; modifications made with bamboo fiber and lime far exceed the target. Compared to previous studies with various additives [5], [6], [7], [8], this study produced specimens with higher stability. In considering the optimum proportion of specimens assess stability and volumetric value, especially VIM value.

The results of VIM analysis are shown in Table 8 and Figure 8. The analysis of VIM showed that the fiber addition tends to increase the VIM value. The hydrated lime addition tends to decrease the VIM value, as shown in Figure 8, for each specimen with the same fiber content, but an increase in hydrated lime content tends to decrease VIM. The minimum value of VIM in the Specification of Japanese Standard Porous Asphalt Mixture is 15 %. The average fiber addition exceeded that value. The specimen's fiber and hydrated lime combined resulted in an average VIM value below the target. Specimens with 0.5% HL additives and 1% bamboo fiber can achieve VIM exceeding the target (Fig. 8, maroon color), but the stability value only reaches 939.54 kg.

The results of the VMA analysis are shown in Table 9 and Figure 9. Results showed that adding fiber increased the VMA value, and adding hydrated lime decreased the VMA value. The minimum value of VMA in the Specification of Japanese Standard Porous Asphalt Mixture is 15 %.

Based on the calculation and approach to the Stability and VIM values, the required value is the proportion of OGFC with an asphalt content of 4.9 %, fiber content of 0.5 %, and hydrated lime of 0.5 %. In this proportion, the stability value is a maximum of 1511.60 kg, and VIM achieves 12.30 %. VIM value could not reach the target but is close to the target value. The addition of hydrated lime is carried out to increase stability and bonding to the mixture. The test results are presented in Table 7.

Hydrated lime (HL) was added to OGFC bamboo fiber (BF) to increase stability, and stability and volumetric testing were carried out; the results can be seen in Tables 7 and 8.

Table 7. Stability of modification OGFC with bamboo fiber and hydrated lime

Asphalt content 4,9 %	Bamboo fiber (%)	Hydrated lime (%)			
		0	**0.5**	**1**	**1.5**
Stability (kg)	0	571.62	582.40	584.10	585.40
	0.25	597.21	1108.28	899.76	791.79
	0.50	480.30	**1511.60**	1410.89	953.75
	0.75	519.71	1238.83	1231.25	1170.00
	1	584.36	939.54	1116.34	1362.59

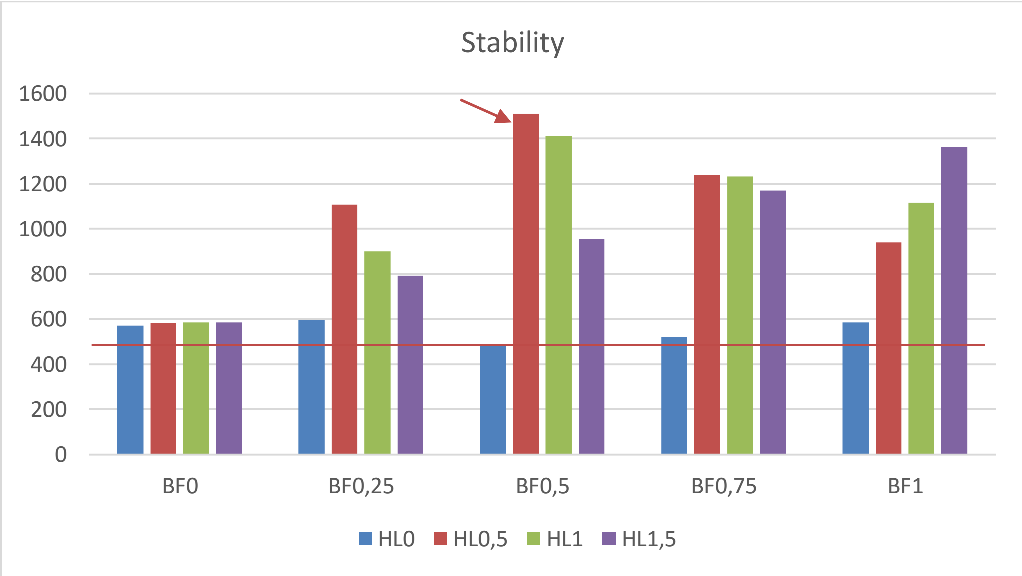

Fig 7. Stability OGFC in various bamboo fiber and hydrated lime

Table 8. VIM of modification OGFC with bamboo fiber and hydrated lime

Asphalt content 4,9 %	Bamboo fiber (%)	Hydrated lime (%) 0	0.5	1	1.5
VIM (%)	0	9.77	9.62	9.48	9.27
	0.25	17.37	10,53	11,50	11,26
	0.50	20.32	**12,30**	12,45	11,80
	0.75	17.21	13,51	14,41	12,49
	1	20.62	19,23	14,15	14,90

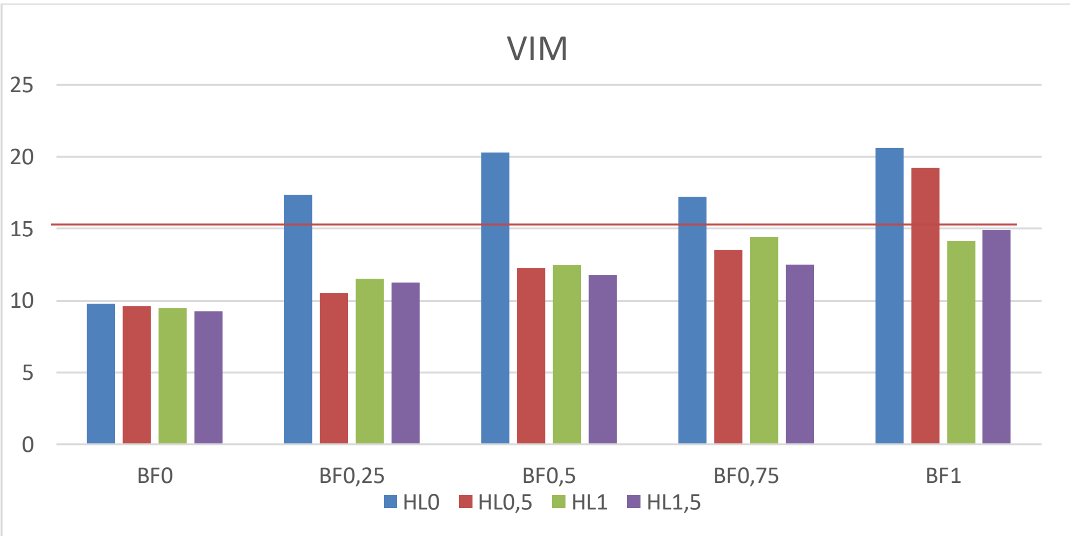

Fig. 8. VIM of OGFC in various bamboo fiber and hydrated lime

Table 9. VMA of Modification OGFC with bamboo fiber and hydrated lime

Asphalt content 4,9 %	Bamboo fiber (%)	Hydrated lime (%)			
		0	0.5	1	1.5
VMA (%)	0	9.77	7.52	6.70	4.88
	0.25	18.36	12.02	12.97	12,73
	0.50	21.50	13.76	13.91	13.27
	0.75	20.45	14.95	15.83	13.94
	1	21.57	20.57	15.57	16.31

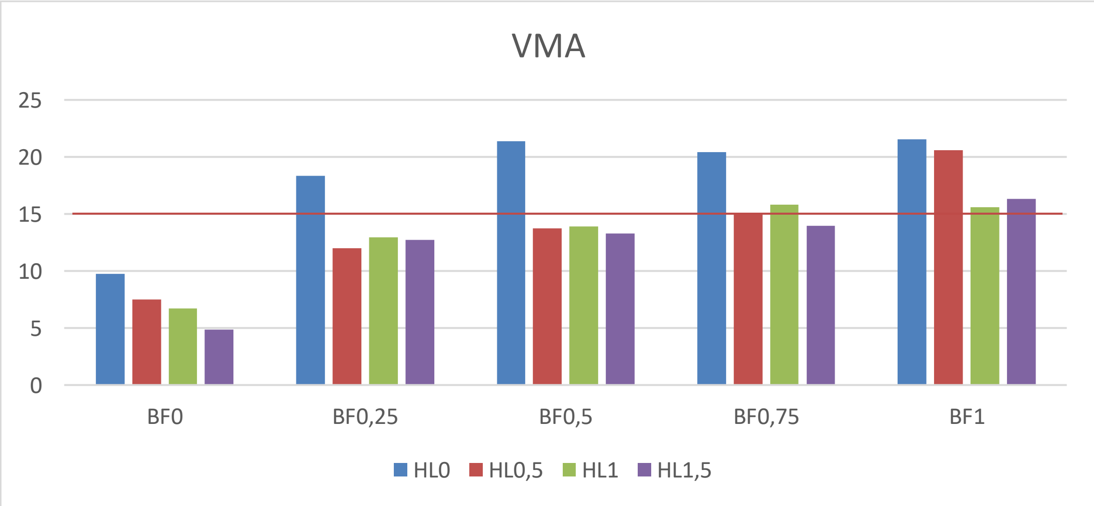

Fig. 9. VMA of OGFC in various bamboo fiber and hydrated lime

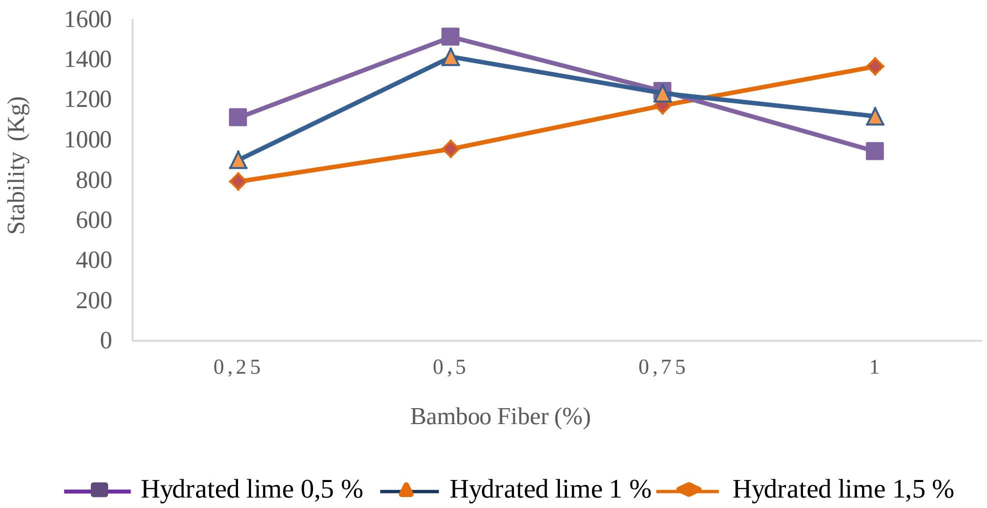

Figure 10. OGFC stability chart with bamboo and hydrated lime modifications

Hydrated lime can function as a filler material, which doubles as an anti-stripping agent to prevent moisture damage to the mixture [12]. The presence of hydrated lime causes the mixture to be more stable; this can be seen in Table 7. At the time of fiber addition of 0% with the addition of hydrated lime, there is a consistent increase in stability. Stability tests show that the average stability increases with the addition of hydrated lime content, in each fiber content. However, with the addition of more than 0.5 % fiber, there was a decrease in the stability of the OGFC mixture at hydrated lime levels of 0.5% and 1%. Excessive fiber addition causes the void to increase and stability to drop. Adding 1,5% hydrated lime stability rises consistently, but the VIM value decreases below the standard. Fiber additives can be incorporated into porous asphalt to improve performance in various ways, including increasing tensile strength, improving binder stability, reducing binder leakage, and increasing noise reduction.[13], [14], [15]. This research needs to be continued by trying different compositions; excessive fiber addition would be counterproductive to stability performance. Adding hydrated lime will function as a filler that fills the void, thereby increasing stability. Asphalt as a binder must be mixed with the right proportions to bond additional materials and increase stability because additive materials can decrease the cohesion force.

4. CONCLUSION

The conclusion of the research results on the effect of giving bamboo fiber additives and hydrated lime is as follows : 1). The addition of bamboo fiber to OGFC without hydrated lime improves stability with optimal concentrations at 4.9% asphalt content and 0.25% fiber; 2). At the proportion of asphalt content of 4.9% and fiber of 0.25%, the stability achieved is 597,21 and void in a mixture (VIM) of 17,37 ; 3). Adding hydrated lime to the OGFC mixture increases stability but decreases the VIM value. The optimum value was reached at the specimen with 0.5 % bamboo fiber and 0,5 % hydrated lime. The stability value achieved 1511.60 kg, 3 times higher, and the VIM value of 12.30 %, 30% lower than specimen stability without hydrated lime; 4). Adding bamboo fiber and hydrated lime increased stability and maintained the porosity of the open-graded friction course. However, the VIM value does not match the expected result.

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