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Optimizing the Use of Palm Fiber to Increase Stability and Deformation Resistance in Asphalt Concrete Mixes

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***Abstract*— Modifying asphalt binder materials with fiber reinforcement enhances the performance of asphalt concrete mixtures. This research evaluates the effect of optimal palm fiber concentration on mixture strength and rutting resistance. Specimens were prepared with varying palm fiber percentages (0%, 0.4%, 0.6%, 0.85%) and lengths (0.4 cm, 0.6 cm, 0.8 cm, 1.0 cm) using 6% optimum asphalt content. The Marshall Test assessed the asphalt concrete properties, while the rutting indicator was evaluated with a wheel tracking tool for palm fiber percentages at an optimal length of 0.8 cm. The Marshall test results showed a 6% increase in stability, with the highest stability at 0.6% palm fiber of 0.8 cm length (1210.45 kg), compared to 1142.59 kg for the normal mixture. VIM value decreased by 14%, and flexibility increased by 4% at the optimum fiber composition of 0.6% and 0.8 cm length. Wheel tracking test results indicated a 53% improvement in groove and rutting resistance with a total deformation value of 0.856 mm, dynamic stability of 5727 passes/mm, and deformation rate of 0.007/mm/minute. However, palm fiber is susceptible to damage at high mixing (150°C) and compaction (140°C) temperatures.**

Keywords*— *Marshall, Palm Fiber, SEM, Wheel Tracking

I. Introduction

In general, road construction in Indonesia experiences damage before reaching its planned lifespan due to increased vehicle loads and weather [1], various ways to improve the performance of asphalt pavement are increasingly being carried out by modifying the asphalt concrete mixture. One of these technologies uses fiber as reinforcement in the asphalt mixture, which comes from cement concrete fiber [2]. Various types of fibers are known to be used in this application, namely synthetic fibers (glass, carbon, polymer) and natural fibers (hemp, coir, hemp, sisal, hemp) [3]. the main function of fiber inserted into the asphalt mixture is to increase tensile strength, which can produce higher strain energy for crack resistance [4]. As a result, asphalt mixtures with added fiber tend to be more resistant to permanent deformation and have higher tensile strength, [5], especially for crack resistance at low temperatures.

The use of fiber in asphalt mixes is a concept that has been introduced previously. In 1984 [6], a report was published regarding synthetic fibers in asphalt mixtures. Ten different fiber types (synthetic and organic) were tested regarding Hveem and Marshall stability, endurance modulus, indirect tensile strength, fatigue, and deformation and rutting resistance. Rutting is common damage to asphalt pavement caused by vehicle wheels, and surface cracking due to these loads affects the service of asphalt [7].

In developing the use of fiber in asphalt mixtures, two types of fiber are applied to road pavement construction: 1) natural fibers such as plant fibers [8], [9] and mineral fibers [10]. In the research, the fibers used are alma fibers which are resistant to the effects of solar heat and cold weather, resistant to weathering, and easy to find in everyday life. In general, the use of fibers in asphalt concrete mixtures shows good performance, namely resistance to damage due to temperature and higher asphalt content in mixtures with added fiber. Another contribution was extending fatigue life and reducing crack propagation based on the results of field test analysis. Since then, several other experiments have been carried out using fiber in asphalt mixtures [11], [12].

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The nature of the asphalt mixture contains fiber

Fiber-reinforced asphalt mixtures in short or long sizes are used as asphalt mixtures and have long-lasting properties, improving the properties and characteristics of the mixture. Fibers act as reinforcements, helping to increase the stiffness, toughness, and fatigue resistance of asphalt mixtures. Shorter fiber lengths have good resistance to cracking and ruts, which are common pavement forms [13]. The addition of fiber increases the stability and durability of road pavement and reduces maintenance costs [14], [15], [16].

Some fibers have high tensile strength compared to asphalt mixtures, so it was found that fibers have the potential to increase the cohesive and tensile strength of asphalt mixtures. Fibers are believed to provide physical changes to the asphalt mixture through the phenomenon of strengthening and durability of the mixture. Reinforcement with high tensile strength can increase the strain energy absorbed during fatigue and damage processes in the mixture. Finely divided fibers also provide a high surface area per unit weight and behave like fillers. Fibers also tend to make the asphalt clump, so it cannot cover the aggregate during construction.

The performance improvement of asphalt mixtures reinforced by these fibers turns out to be small; depending on the characteristics of the fibers, the effect of adding fibers to asphalt concrete can be very different. For example, if the fibers are too long, this can cause a problem called "balling" (some of the fibers may clump together), break and break, and the fibers may not blend well with the asphalt mixture. If the fibers are too short, they may not provide any reinforcing effect and only serve as an expensive filler [4].

II. Research Methodology

A. Materials

Characteristics of Palm Fiber

The tensile strength of palm fiber depends on the diameter of the fiber; if the diameter is small, the tensile strength will be greater, while with a large diameter, the tensile strength will be smaller. Palm fiber has the following chemical composition, cellulose, hemicellulose, lignin, water, and ash, respectively 51.54%, 15.88%, 44.09%, 8.9%, and 2.54%. The percentage of cellulose and hemicellulose elements in fiber [17].

The average and standard deviation of the moisture content of natural formation and market formation are 16.54 ± 1.64% and 10.29 ± 1.39%, respectively. The physical properties of palm fiber, such as density and grammage, also vary slightly according to the source (natural or market). Natural formation fibers have an average density and grammage of 1.001 g/cm^3 and 472.663 g/m^2, respectively, while market formation fibers have an average density and grammage of 0.997 g/cm^3 and 484.587 g/m^2, respectively. The lower ratio of sheet grammage value and fiber density in the natural formation indicates that the fibers of the natural formation are more compact compared to the market [18].

The palm fiber used in this research is palm fiber that has been separated from trees, such as in Figure 1.

Figure 1. Palm fiber from selection

The method for preparing palm fiber samples is to take them randomly using multi-dimensional sizes, starting from fiber sizes with a small diameter (fine) to a maximum large diameter of 0.3 mm. This is to avoid the occurrence of clusters in asphalt mixtures with finer diameter fibers.

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Figure 2. Palm fiber samples with varying lengths

Finer and shorter fibers will be difficult to distribute evenly in the asphalt mixture and tend to stick together to form lumps. Next, the palm fiber is cut into four length variations with sizes of 0.4 cm, 0.6 cm, 0.8 cm, and 1.0 cm with percentages of 0.4%, 0.6%, and 0.9% as in Figure 2 fiber sample fibers are made according to the size of each percentage.

Aggregate

Coarse aggregate is crushed stone that meets the requirements for a coarse aggregate fraction with a nominal size of 1-2 cm and 0.5-1 cm, which is retained on sieve No. 8 (2.36 mm), has a 90/95 breaking area, is clean, hard and free from clay. Meanwhile, fine aggregate is used as ash from crushed stone sieves that pass-through sieve No. 4 (4.75mm). All materials must meet the road construction requirements set out in the Bina Marga specifications. Material testing and inspection methods are based on Indonesian National Standards (SNI). Each aggregate physical properties inspection includes sieve analysis, specific gravity and absorption, wear, sand equivalent (SE), soundness test, and aggregate adhesion to asphalt. The results of testing the physical properties of coarse aggregate and stone ash are in Table 3.

Asphalt Binder

Even though asphalt is only a small part of the components of the asphalt mixture, it is crucial in providing a durable bond and keeping the mixture in an elastic, viscous condition. As for several qualities, asphalt must guarantee satisfactory performance: rheology, cohesion, adhesion, and durability. Testing and checking asphalt characteristics based on Indonesian National Standards [19], ductility, and specific gravity. Recap the results of testing the physical properties of asphalt in Table 3.

B. Mixed Planning

Determination of the composition of the mixture

Determination of the mixture composition to determine the percentage of the composition of each aggregate fraction using the trial and error method by carrying out several experiments on the percentage of each aggregate fraction that meets the mixture gradation with the required gradation limits according to the provisions in Table 1. The composition of the asphalt concrete mixture consists of a combination of coarse aggregate, stone ash, and asphalt that meet the requirements for the properties of asphalt concrete mixtures based on specifications in Table 2.

Determination of planned asphalt content

The estimated asphalt content is based on the percentage composition of the coarse aggregate fraction, fine aggregate fraction and minimum filler percentage that passes sieve No. 200 75 % and calculated based on equation 1:

$$Pb = 0{,}035\ (\%\ CA) + 0{,}045\ (\%\ FA) + 0.18\ (\%FF) + K \quad (1)$$

Where :
CA = percent of aggregate retained on sieve No. 8,
FA = percent of aggregate passing sieve No. 8 and retained on sieve No. 200,
filler = percent aggregate of at least 75% passing No. 200,
K = constant = 0.5-1.0 for lastonf = 2.0-3.0 for lataston

To obtain the optimum asphalt content, test specimens were first made with 5 variations of asphalt content, each of which differed by 0.5. The asphalt content selected results from calculations from the Pb value, then two asphalt levels are taken less than the middle asphalt content value, and three asphalt content values are greater than the middle asphalt content value.

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The planned asphalt content is Pb%, so a mixture design is made for the test object at asphalt content (Pb-1)%, (Pb-0.5)%, Pb%, (Pb+0.5)%, (Pb+1)%. Each variation uses 3 test objects.

C. Test Method

Marshall test

The basic principle of the Marshall method is checking stability and melting (flow), as well as density and pore analysis of the solid mixture formed. In this case, test objects or briquettes of solid asphalt concrete mixture are formed from mixed aggregate gradations obtained from the results of gradation tests according to the mixture specifications. Marshall testing for stability and flow follows the SNI 06-2489-1991 or AASHTO T245-90 procedures. The optimum asphalt content will be determined from the relationship between asphalt content and Marshall parameters.

Marshall testing is carried out in two stages. The first testing stage was to determine the optimum asphalt content with five variations, namely 4.5%, 5%, 5.5%, 6%, and 6.5%. Three test objects were made for each percentage of asphalt content. Next, the second stage of testing was using the optimum asphalt content for the asphalt concrete mixture with variations in the percentage and length of the fiber.

Wheel Tracking test rutting resistance

Rutting is a longitudinal groove in asphalt pavement due to wheel loading, which is one of the main sources of pavement damage at high-temperature conditions [20], [21], [22]. Permanent deformation is mainly caused by vehicle loads when the asphalt pavement temperature is above 40 C, and the influencing factors mainly involve the construction asphalt mixture (asphalt, aggregate, and gradation) and the environment (climate and loading) [23]. In several studies, the addition of synthetic fibers reduces crack paths due to forming a three-dimensional fiber network in the asphalt concrete mixture [24].

The Wheel Tracking test is an experimental method commonly used to determine the deformation resistance of asphalt mixtures. The heated asphalt mixture is put into a mold of 300 mm, 300 mm, and 50 mm and compacted 75 times according to the mixture requirements. The specimen was placed at room temperature for 24 hours and then tested on a load wheel with 42 cycles/minute and a pressure of 0.7 MPa. The specimen was loaded for 60 minutes. Wheel Tracking testing is a simulation where the wheel load moves back and forth across the test object. The deformation resistance of a predetermined test object can be measured by looking at the results obtained from the groove depth (Rut Depth) after passing several passes or the Deformation Rate (RD) in mm/minute. Dynamic stability (DS) is calculated based on equation 2 to estimate the flow resistance of the asphalt mixture and the deformation rate (RD) in equation 3.
[25].

$$DS = 21\ x\ 2\ x\ \frac{(t2-t1)}{(d2-d1)}\ x\ C1\ x\ C2 \quad (2)$$

$$RD = \frac{(d2-d1)}{(t2-t1)} \quad (3)$$

Where :
DS = Dynamic Stability (trajectories/mm)
RD = Deformation Rate (mm/min)
d1 = Deformation at 45 minutes test (mm)
d2 = Deformation at 60 minutes test (mm)
C1 = Equipment correction factor is 1.0
C2 = Specimen correction r factor is 1.0
t_1 = 45 minutes
t_2 = 60 minutes

In Figure 3, the rutting resistance test is set up using wheel - tracking tool

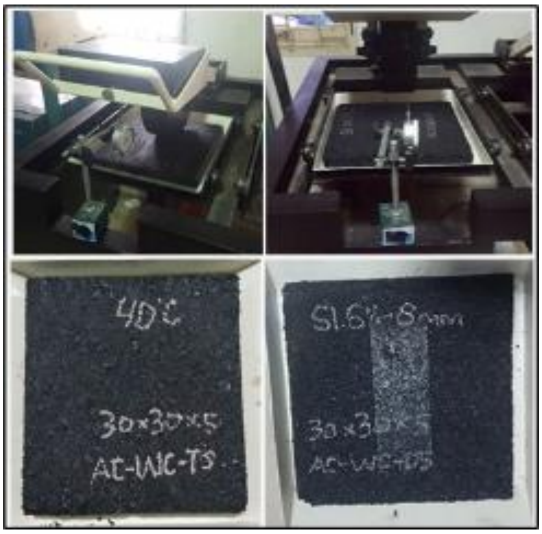

Figure 3. Test set up and test objects before and after testing

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Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) testing was carried out to determine the morphological structure of the palm fiber after mixing and compacting the mixture. Scanning Electron Microscope (SEM) is an electron microscope that produces images of samples by scanning a surface with a focused electron beam at a magnification up to a certain scale. The electrons interact with atoms in the sample, producing various signals containing information about the sample's surface topography and composition.

An electron gun generates a beam of electrons at the top of the microscope. The electron beam follows a vertical path through the microscope, which is kept in a vacuum. The beam travels through an electromagnetic field and a lens, focusing the beam towards the sample. After the light hits the sample, electrons, and X-rays are ejected from the sample. The main advantage of an SEM is its ability to magnify a sample millions of times, allowing users to see very small details of the sample, such as surface structure, topography, and chemical composition. The SEM device is shown in Figure 4.

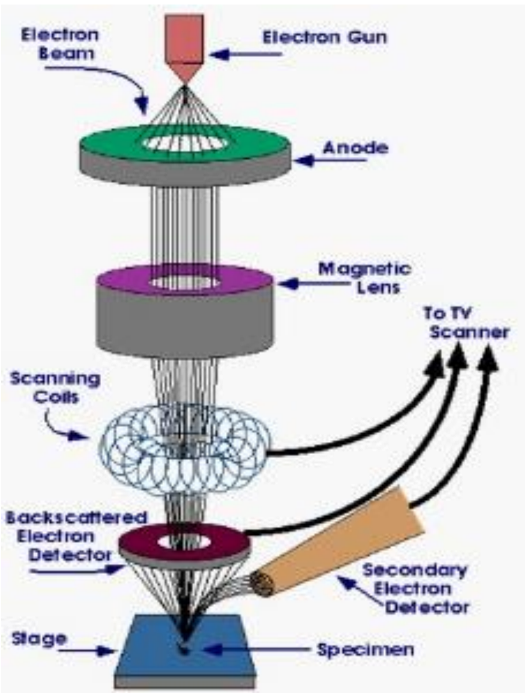

Figure 4. SEM device (Purdu University)

III. Results and Discussion

A. Standard Marshall test

The results of evaluating the characteristics of the concrete mixture in Table 4 show that the asphalt content in the range of 4.5% to 5% does not meet the VIM value. This is because the percentage of asphalt to cover all the aggregates still needs to be increased, and he interlocking between the aggregates and asphalt has low adhesion so that the mixture is not dense and has increased air voids in the mixture. At asphalt content ranging from 5.5% to 6.5%, all Marshall parameters, including stability, flow, Marshall Quotient (MQ), Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), and density, have appropriate Marshall characteristic values. Figure 5 shows that the composition of the mixture of asphalt concrete wearing course (AC-WC) with asphalt oil pen 60/70 with KAO 6% can be stated to meet the specifications for Marshall characteristics [26]. The optimum asphalt content is obtained in the asphalt content range that meets the minimum mixture properties of 5.5% and a maximum of 6.5%. The average value of the asphalt content is obtained as the optimum asphalt content.

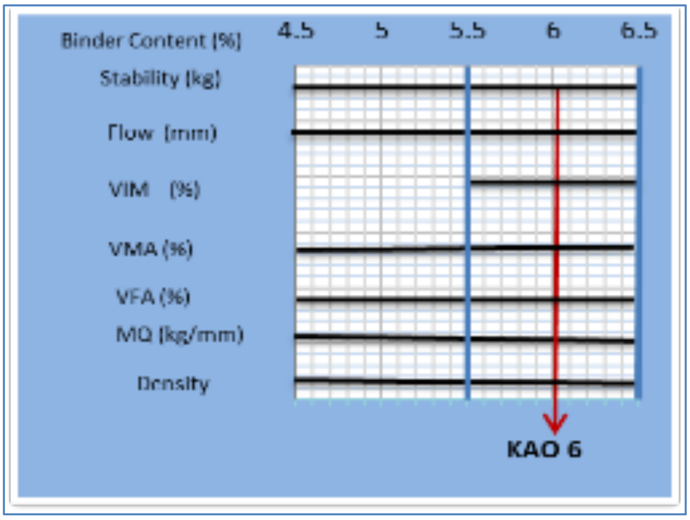

Figure 5. Graph for determining 0ptimum asphalt content (KAO)

Based on Table 5, the Marshall test results on asphalt concrete mixtures reinforced with palm fiber with four variations in length and three variations in fiber percentage show that the stability value meets the minimum requirement specifications of 800 kg with the

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highest stability value in the mixture composition with a percentage of 0.6% with a length of 1 cm of 1210,45 kg.

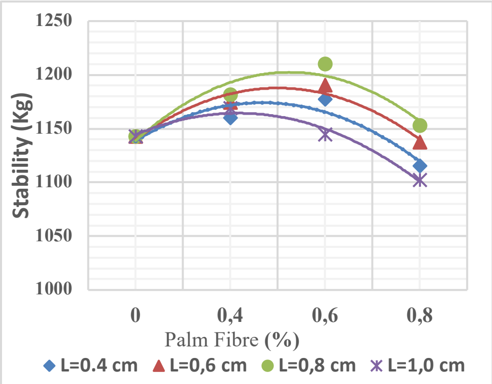

Figure 6. Graph of the relationship between stability and the percentage of palm fiber.

In Figure 6, the stability value decreased by adding a percentage of 0.6% to 0.8% with four variations in fiber length. Increasing the percentage of fiber in the mixture increases the melting index value. The lower it causes the stability value and Marshall Quotient (MQ) to be greater, the mixture becomes stiffer and more plastic. Fiber fibers with surface roughness increase adhesion properties with good interlocking so that the density of the mixture with low air voids increases. Figure 7 shows the increase in the percentage and length of palm fiber, the flow index value increases, and the mixture shows high flexibility. For fibers with a longer size, the density of the mixture decreases with increasing VIM values in the mixture, as in Figure 8. The mixture with a fiber length of 1.0 cm has a large VIM value and increases with each fiber percentage.

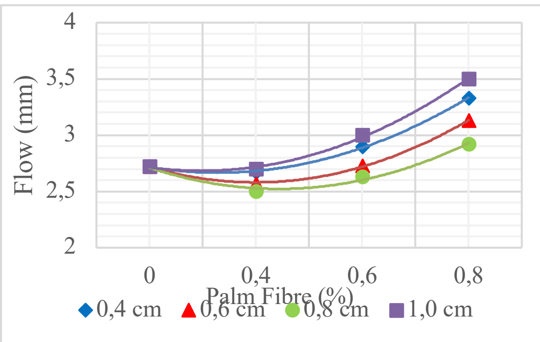

Figure 7. Graph of the relationship between flow and palm fiber

The addition of palm fiber to asphalt concrete mixtures provides better performance compared to normal mixtures; this is indicated by lower VIM values, resulting in mixture properties with higher flexibility and stability. Apart from that, the fibers in the mixture are evenly distributed with good homogeneity, thus providing a strong bond between the aggregate and asphalt.

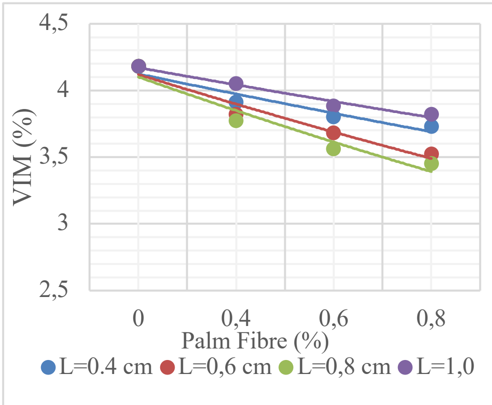

Figure 8. Graph of the relationship between VIM and palm fiber

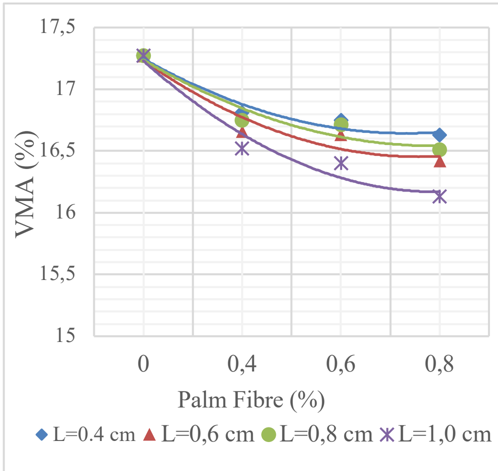

Figure 9. Graph of the relationship between VMA and palm fiber

Voids in the mineral aggregate are voids between aggregate particles in a compacted mixture, including voids containing asphalt expressed as a percent of the total volume. In Figure 9, with the addition of palm fibers to the mixture, the percentage of VMA values tends to decrease. This results in fibers with a longer size, protecting the absorption of asphalt and filling the voids

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between aggregate particles optimally. Compared to fibers with long sizes, the percentage of VMA values is greater, whereas fibers with short sizes are homogeneously integrated with aggregate and asphalt to fill the voids available in the mixture.

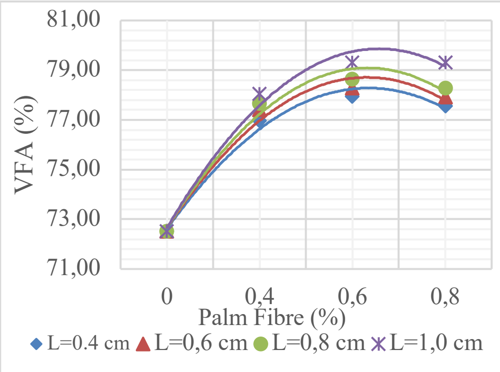

Figure 10. Graph of the relationship between VFA and palm fiber

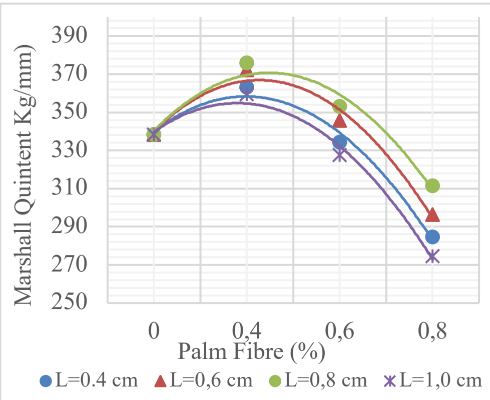

Figure 11. Graph of the relationship between Marshall Quotient and palm fiber

The VMA value indicates the space available in the mixture to accommodate the effective volume of asphalt except that which aggregate particles absorb. A VMA value that is too small causes the pavement layer to have a thin asphalt layer so that it easily comes off and is not watertight, which causes the pavement layer to be easily damaged. Meanwhile, adding palm fiber up to 0.6% in all length variations increases the VFA value, as in Figure 10. Using optimum asphalt content effectively covers the entire surface of the aggregate, and palm fiber fills the voids in the mixture within the optimum limit of using 0.6% palm fiber with length variations of 0.4 cm, 0.6 cm, 0.8 cm, and 1.0 cm. Palm fiber fills the voids in the mixture well with optimal absorption of asphalt and reduces the risk of the mixture experiencing bleeding and sagging.

A graph of MQ values for various variations in percentage and fiber length is shown in Figure 11. The stiffness of the mixture increases with the addition of a fiber percentage of 0.4% for all variations in length; then the MQ value decreases along with the addition of palm fiber to the length of the fiber. This shows that the increase in palm fiber in the mixture causes the flow index value to increase and stiffness and flexibility to decrease. The graph depicts the composition of the mixture with the highest flexibility, with an MQ value of 375.85 kg/mm at a percentage of 0.4%.

B. Wheel Tracking Test

For the deformation resistance performance of the mixture, three parameters were reviewed: total deformation in mm units, rate of deformation in mm/minute units, and dynamic stability in path units/mm. Based on Table 6 above, there are differences in the values produced after adding palm fiber content of 0%, 0.4%, 0.6%, and 0.8%. Asphalt concrete mixture with a palm fiber content of 0.6% has the lowest deformation with a deformation rate of 0.007 mm/minute with a total deformation for 60 minutes of 0.856 mm, lower than a normal mixture with a deformation rate of 0.015 mm/minute with a total deformation of 1.83 mm. Figure 12 shows that the normal mixture has high deformation compared to three variations in palm fiber content with an optimum fiber length of 0.8 cm. An increase in palm fiber content of 0.8% is a mixture composition with a greater total deformation, 1.46 mm, with a deformation rate of 0.012 mm. Adding fibers that exceed the optimum limit reduces adhesion properties with a lower mixture density so that the yield index increases and decreased fatigue resistance due to increased load results in the potential for greater deformation. The test results showed that the mixture with the addition of palm fiber contributed to resisting the potential for deformation by 53%, or the average of three variations in the percentage of palm fiber compared to the normal mixture..

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C. Scanning electron microscopy (SEM) Test

The Scanning Electron Microscopy (SEM) test results in Figure 13 show the morphology of the fiber fibers with a diameter of 0.3 mm, length of 6 mm, 8 mm, and 1.0 mm after mixing and compacting, showing that the fibers are damaged and broken. Meanwhile, Figure 14 shows the texture morphology of the surface of the palm fiber, which has fractured in part (a), and damage to the fiber stem in part (b) and part (c). The white color is a waxy substance, one of the chemical elements contained in palm fiber (SI), which has changed its properties due to temperature during the mixing process.

The impact of the mixing and compaction process results in damage caused by several factors, namely loading and the heating temperature during the mixing process, causing the fiber to experience changes in properties and characteristics where the fiber experiences stiffness and becomes brittle so that the fiber fibers experience a decrease in tensile strain when receiving a load during the compaction process. The high loading frequency due to compaction hammers causes the fiber surface structure to be damaged and experience tensile failure due to decreased flexibility and tensile strength. This condition shows that the palm fibers are not strong enough to withstand heat due to the mixing temperature of 150ºC and the compaction temperature of 140ºC. The fiber distribution pattern in the mixture with a greater shear angle causes a very large risk of damage and fracture due to increased load during the compaction process.

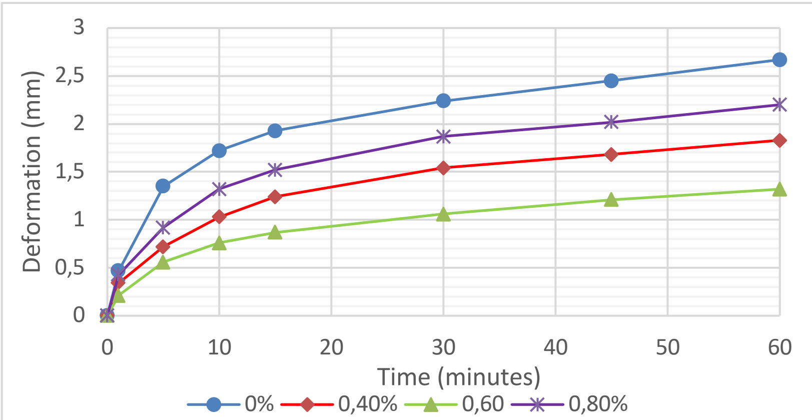

Figure 12. Graph of the relationship between deformation and testing time

Table 1 Aggregate gradation of the Laston mixture

Sieve Size		Laston (AC)		
ASTM	(mm)	WC	BC	Base
1/2”	37,5			100
1”	25		100	90 - 100
¾”	19	100	90 - 100	76 – 90
½”	12,5	90 – 100	75 – 90	60 -78
3/8”	9,5	77 – 90	66 -82	52 – 71
No.4	4,75	53 – 69	46 – 64	35 – 54
No.8	2,36	33 – 53	30 -49	23 – 41
No.16	1,180	21 – 40	18 -38	13 – 30
No.30	0,600	14 – 30	12 – 28	10 – 22
No.50	0,300	9 – 22	7 – 20	6 – 15
No.100	0,150	6 -15	5 – 13	4 – 10
No.200	0,075	4 -9	4 - 8	3 - 7

Source: Bina Marga Specifications, 2018

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Table 2 Conditions for the properties of the Laston mixture

Properties of Mixtures		Laston		
		Wear Layer	Layer Between	Foundations
Number of Tumbukab per field		75		112
The ratio of particles passing through the sieve is 0.075 mm with effective asphalt content	Min		0,6	
	Maks.		1,2	
Voids in mixture (%)	Min		3,0	
	Maks.		5,0	
Voids in Aggregate (VMA) (%)	Min	15	14	13
Asphalt Filled Voids (%)	Min	65	65	65
Marshall Stability (kg)	Min	800		1800
Melting (mm)	Min	2		3
	Maks.	4		6
Residual Marshall Stability (%) after immersion for 24 hours at 600C	Min	90		
Voids in mixture (%) at Refusal density	Min	2		

Source: Bina Marga Specifications, 2018

Table 3 Results of inspection of coarse aggregate, stone ash and asphalt

No.	Type of Examiner	crushed stone		Rock ash	Asphalt	Specifications
		1 – 2	0,5 – 1			
1	Berat Jenis Agregat a. Bulk b. SSD c. Apparent d. Absorption	 2.61 2.67 2.77 2.20	 2.49 2.56 2.68 2.88	 2.58 2.70 2.51 2.89		 2.4 – 2.9 2.4 – 2.9 2.4 – 2.9 ≤ 3 %
2	Sand Equipalent ba Before loading (%) bb After Loading (%)	 - -	 - -	 82.20 79.74		 ≥ 60 %
4	Soundness Test (%)	0.66	0.66	-		≤ 12 %
5	Aggregate adhesiveness to bitumen (%)				96	≥ 95 %
6	Penetration 25ºC; 100 gr; 5 seconds; 0.1mm				65.2	60 – 79
7	Asphalt Specific Gravity				1.055	1.0 – 1.16
8	Asphalt Softening Point (°C)				51	≥ 48
9	Ductility, 25ºC; cm				137	≥ 100
10	Flash Point (°C)				265	> 200
11	Burn Point (°C)				275	> 200

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Table 4. Characteristics of the AC-WC mixture from the Marshall test

characteristic Mixture	Test result					Specifications
Asphalt Content	4,5	5	5,5	6	6,5	
Density	2.41	2.39	2.38	2.36	2.34	≥2.2 kg/mm^3
VIM; %	5.93	5.13	4.72	4.27	3.798	3-5%
VMA; %	15.65	15.98	16.65	17.27	17.88	Min. 15%
VFA; %	65.14	68.10	71.66	75.32	78.77	Min. 63%
Stability; kg	901.46	968.86	1009.97	991.11	955.31	Min. 800 kg
Flow; mm	3.60	2.60	2.40	2.70	3.80	2-4 mm
MQ; kg / mm	250.67	375.59	421.41	368.78	256.08	Min 250 kg/mm

Table 5. Characteristics of AC-WC mixture with the addition of palm fiber (SI)

Testing	Palm Fiber Content %	Fiber Length (cm)				Specifications
		0,4	0,6	0,8	1	
Density	0	2.36				≥ 2,2 gr/cm^3
	0,4	2.268	2.27	2.272	2.27	
	0,6	2.273	2.275	2.277	2.268	
	0,8	2.267	2.27	2.272	2.266	
VIM	0	4.27				3-5 %
	0,4	3.91	3.82	3.77	4.05	
	0,6	3.8	3.68	3.56	3.88	
	0,8	3.73	3.52	3.45	3.82	
VMA	0	17.27				Min. 15 %
	0,4	16.81	16.66	16.75	16.52	
	0,6	16.75	16.63	16.71	16.4	
	0,8	16.63	16.42	16.51	16.13	
VFA	0	75.32				Min. 65 %
	0,4	76.95	77.39	77.65	78.03	
	0,6	77.93	78.26	78.64	79.31	
	0,8	77.56	77.92	78.26	79.3	
Stability	0	909.32				Min. 800 kg
	0,4	1160.12	1174.25	1181.57	1169.34	
	0,6	1177.14	1190.6	1210.45	1144.71	
	0,8	1115.61	1137.35	1153.17	1102.51	
Flow	0	2.70				Min. 3
	0,4	2.67	2.57	2.5	2.7	
	0,6	2.9	2.73	2.63	3	
	0,8	3.33	3.13	2.92	3.5	
MQ	0	338.30				Min 250 kg/mm
	0,4	363.16	372.2	375.85	359.44	
	0,6	334.37	345.61	352.99	327.41	
	0,8	284.49	296.34	311.38	274.41	

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Table 6 Test results with Wheel Tracking

Time	Number of Cycles	Deformation (mm)			
		0%	0.40%	0.60%	0.80%
0	0	0	0	0	0
1	42	0.47	0.34	0.21	0.43
5	210	1.35	0.72	0.56	0.92
10	420	1.72	1.03	0.76	1.32
15	630	1.93	1.24	0.87	1.52
30	1260	2.24	1.54	1.06	1.87
45	1890	2.45	1.68	1.21	2.02
60	2520	2.67	1.83	1.32	2.2
Total Deformation (DO) (mm)		1.833	1.197	0.856	1.469
Dynamic Stabilit (DS) (trajectories/mm)		2864	4200	5727	3500
Deformation Rate (RD) (mm/min)		0.015	0.010	0.007	0.012

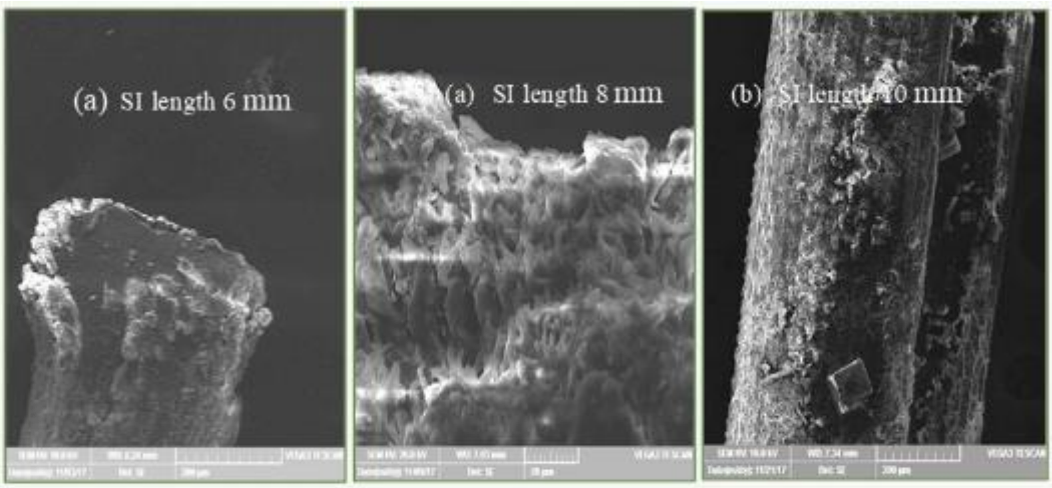

Figure 13. Morphology of fiber structure damaged and broken (a) SI length 6 mm, (b) SI length 8 mm, and (c) SI length 10 mm

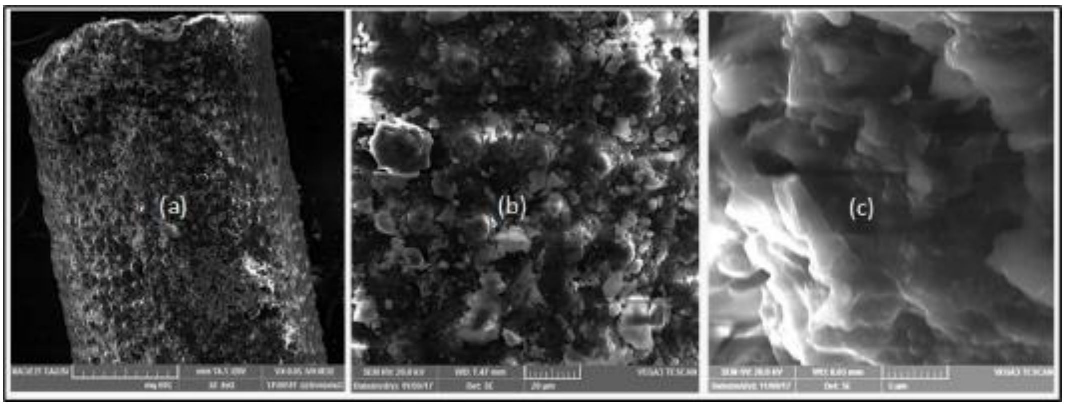

Figure 14. Morphology of palm fiber structure after mixing and compaction (a) fracture damage to SI, (b) fractured surface morphology of SI, and (c) wax elements that experience changes in properties.

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IV. Conclusion

a. The research analyzed the influence of several factors on mixture characteristics, including stability, flow, Marshall Quotient (MQ), Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), and density and deformation resistance in asphalt concrete mixtures with the addition of palm fiber. From the research results, several findings were obtained and concluded:
b. Asphalt concrete mixture with the addition of palm fiber, and the resulting mixture's properties and characteristics meet all Marshall parameters based on the 2018 Bina Marga specifications.
c. The stability of palm fiber in the asphalt concrete mixture increases with each additional fiber percentage of 6%, with the highest stability at a palm fiber percentage of 0.6% with a length of 0.8 cm, higher than the normal mixture.
d. The VIM and VMA values decreased with each additional fiber percentage of 14%, with the lowest VIM at a percentage of 0.8% and a 0.8 cm palm fiber length of 3.45% compared to the normal mixture. In contrast, the VFA value increased with each mixture composition with palm fiber added.
e. Marshall Quotient MQ value (MQ as an indicator of the level of flexibility. The MQ value increases and is highest at a percentage of 0.4%, 0.8 cm long, amounting to 375.85 kg/mm, with the mixture being stiff and plastic. Furthermore, the stiffness or flexibility of the concrete mixture asphalt experienced a decrease in all palm fiber percentages.
f. Asphalt concrete mixture with a palm fiber content of 0.6% has the lowest deformation with a deformation rate of 0.007 mm/minute with a total deformation for 60 minutes of 0.856 mm, lower than a normal mixture with a deformation rate of 0.015 mm/minute with a total deformation of 1. 83 mm.
g. The use of palm fiber contributes to resisting the potential for deformation by 53% or the average of a normal mixture.
h. Palm fiber contributes to avoiding the formation and propagation of cracks and increasing the cohesive strength of the asphalt mixture.
i. Palm fiber is not strong enough to withstand heat due to a mixing temperature of 150ºC and a compaction temperature of 140ºC, with a higher risk of fiber damage

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