UDC 625
DOI: 10.15587/1729-4061.2024.309733

IDENTIFYING THE EFFECT OF ADDING COCONUT COIR ON THE CHARACTERISTICS OF THE TOP LAYER OF PURE NATURAL BUTON ASPHALT CONCRETE WEARING COURSE (AC-WC)

Muhammad Zainul Arifin
Doctor, Ingenieur (Engineer), Master of Science*
Achmad Wicaksono
Corresponding Author
Ingenieur (Engineer), Master of Engineering, Philosophy of Doctor*
E-mail: wicaksono68@ub.ac.id
Hendi Bowoputro
Ingenieur (Engineer), Master of Science*
Raden Rayhan Ghufron
Bachelor of Engineering*
Muhammad Yusuf Abdurrahman
Bachelor of Engineering*
*Department of Civil Engineering
Brawijaya University
MT Haryono str., 167, Malang, Indonesia, 65145

Buton Asphalt is natural asphalt originating from Buton Island (Indonesia), with the potential deposit amount reaching up to 662 million tons. This substantial domestic mining potential must be utilized for domestic road needs and to boost the country's economy. However, Buton asphalt's utilization is minimal compared with imported oil asphalt, which reached a usage rate of up to 94 % in 2022. Therefore, as a form of a solution-oriented policy, Buton asphalt is included as one of the 21 commodities in the Strategic Roadmap for Downstream Investment in Indonesia, followed by various supportive regulations for developing this Buton asphalt product. One of the leading products the government targets is natural pure Buton asphalt. This product consists of >99 % bitumen content after extraction, also called Pure Buton Asphalt. The idea was to modify pure Buton asphalt with coconut coir to increase the Marshall Stability and Dynamic Stability values to make the asphalt mixture more resistant to vehicle loads and rutting. The tests were conducted to determine the optimum asphalt content (OAC) of the mixtures, Marshall's Stability comparison, and the dynamic stability test using a Wheel Tracking Machine to identify the comparison of permanent deformation. This study analyzed the Marshall characteristics and dynamic stability characteristics with variations in coconut coir content of 0.5 %, 0.75 %, and 1 % by weight of asphalt and variations in coconut coir length of 0.5 cm, 1 cm, and 1.5 cm. Based on the results of this study, the optimum asphalt content in this study is 6.76 %, where pure Buton Asphalt modified with coconut coir has an increase in Marshall's stability value and dynamic stability value compared to pure Buton asphalt without additional coconut coir

Keywords: pure Buton asphalt, rutting, dynamic stability, coconut coir, Marshall stability, wheel tracking machine

Received date 27.05.2024
Accepted date 05.08.2024
Published date 30.08.2024

How to Cite: *Arifin, M. Z., Wicaksono, A., Bowoputro, H., Ghufran, R. R., Abdurrahman, M. Y. (2024). Identifying the effect of adding coconut coir on the characteristics of the top layer of pure natural buton asphalt concrete wearing course (AC-WC). Eastern-European Journal of Enterprise Technologies, 4 (6 (130)), 59–68. https://doi.org/10.15587/1729-4061.2024.309733*

1. Introduction

Our study focuses on Buton Asphalt, natural asphalt from Buton Island (Indonesia), with a potential deposit of up to 662 million tons. This significant domestic mining potential holds a promising future for domestic road construction and the country's economy. Previous research has been done on natural asphalt [1, 2]. In this study, the researcher specifically investigated one of the products of natural asphalt, called pure Buton asphalt, which is equivalent to PG 70 asphalt with a bitumen content of >99 %. As traffic volume increases over time, the road's service life decreases. Therefore, our study aims to explore the use of pure Buton asphalt, believed to be of higher quality than oil asphalt, and the enhancement of its quality by adding modified materials in the form of coconut coir.

Coconut coir has been a popular choice among researchers as a modification material [3–6]. Its use has been shown to significantly improve the stability of asphalt and fill the voids in the asphalt mixture. These findings have direct implications for the construction industry, offering a more sustainable and cost-effective solution for road construction. Previous research has shown that coconut coir can increase the tensile strength of asphalt, thereby enhancing its resistance to cracking. When used to modify asphalt, coconut coir can reinforce the material, reduce the risk of cracks in the mixture, and bolster the mixture's resistance to permanent deformation. Furthermore, studies suggest that coconut coir can be combined with other modified materials such as rubber, plastic, face masks, and cigarette butts for asphalt mixtures.

Observing the rapid growth of goods vehicles on world highways, an innovative and efficient solution is needed to strengthen the road pavement against cracks and rutting deformation. In addition, Indonesia has abundant resources of natural asphalt in Buton Island, where research is still needed to utilize it for the Asphalt Concrete Wearing Course (AC-WC). In practice, this research is expected to contribute to:

a) increasing the use of Pure Buton Asphalt as one of the natural, high-quality asphalt that can be used as a mixture in flexible pavement (AC-WC);

b) increasing the use of Pure Buton Asphalt that has been modified with coconut coir in order to invent the mixture with low voids;

c) increasing awareness of natural resources and the environment using domestic products.

Therefore, the study on Pure Buton Asphalt is important research on reducing oil-based asphalt, and the use of coconut coir (beneficial to research on reducing waste from coconut-based production) was devoted to recent pavement research that is scientifically relevant.

2. Literature review and problem statement

This research is based on some results of previous research on pure Buton asphalt and the use of coconut coir as a modification material. Previous research on the use of coconut coir to improve the quality of pavement for highways using oil-based asphalt has been conducted, and it states that the addition of coconut coir significantly increases all the values of Marshall test parameters, especially Marshall stability, by 41.8 % compared to asphalt mixture without coir [7]. However, in their study, natural asphalt has not been used.

Research on using coconut coir and other coconut derivative materials has been carried out, such as natural fiber, ripe coconut coir, basalt fiber, and nano-charcoal coconut shell ash as modifiers of bituminous mixes. Research also reported that natural fiber reinforcement improves fatigue life, increases the mixture's stability, and improves structural resistance to distress in the flexible pavement due to traffic loads [8]. Adding ripe coconut coir generally increases the unit weight value and mixture stability, reducing the air voids and flow value. Satisfying all the Marshall test criteria, it is observed that adding 0.3 % ripe coconut coir is enough to improve Marshall's characteristics [9] substantially. Including basalt fiber in Buton rock asphalt significantly increases pavement performance and indicates that basalt fiber improves asphalt mixture quality effectively [10]. Adding a nano-charcoal coconut shell increases the mixture's internal resistance to cracking and allows asphalt to recover its original form after being loaded [11]. From the results of research on the utilization of natural and synthetic fibers in asphalt mixtures, fibers can be used as a stabilizer, reducing asphalt leakage and increasing the strength of binder content in the mix [12]. However, further research is needed to determine this study's optimum coconut coir content and length variations.

For pure Buton asphalt, a study compares the characteristics of pure Buton asphalt with P60 oil asphalt and B50/30 Buton asphalt, which is reviewed from the Marshall characteristics and dynamic stability characteristics. Pure Buton asphalt has the best Marshall stability and dynamic stability value compared to P60 oil and B50/30 Buton asphalt [2]. However, their study added no coconut coir as a modification material, so research related to modified pure Buton asphalt with coconut coir was needed. The dynamic stability value of pure Buton asphalt has not reached the standard provisions of the 2018 Indonesia Highway Department specification [13].

Based on previous research, coconut coir functions as a binding agent in asphalt mixture materials, especially in strengthening the bonds between aggregates, which can increase the strength and durability of asphalt against vehicle wheel loads. Coconut coir can increase the resistance of asphalt mixtures to cracking and deformation caused by loads and environmental temperature by providing a stronger bond between pavement materials, so it is necessary to carry out a dynamic stability test to find out how much influence coconut coir has on permanent deformation resistance. However, please note that the proportion of grade and length of coconut coir used must be in accordance with the needs of the type of pavement and material used. Suppose the level and length of coconut coir used do not match the needs. In that case, adding coconut coir can negatively impact the Marshall characteristic value of the asphalt mixture, such as decreasing the VFB, Marshall Quotient, and stability values. Therefore, in this study, further deepening was carried out by using coconut coir in pure Buton asphalt to determine the level of coir and the optimum coir length reviewed from the Marshall characteristics; we added the dynamic stability test to identify permanent deformation.

In conclusion, the results of previous research [7–13] show the performance of pure Buton asphalt, and there is some research on coconut coir as an additive for asphalt mixture done separately. In Indonesia, Buton asphalt and coconut coir are available in abundance. Both of these materials are natural resources that have not been utilized optimally, and there is a need to research how to use this type of highway pavement for a better sustainable environment. There were unresolved issues related to the use of pure Buton asphalt and coconut coir as a modifier combined into an asphalt concrete mixture. This allows us to state that there is a need to study the characteristics of asphalt mixture using pure Buton asphalt and combined with coconut coir.

3. The aim and objectives of the study

The study aims to identify the effect of adding coconut fiber to pure Buton asphalt on the characteristics of asphalt concrete (AC-WC). This process will utilize several tests to identify the characteristics of Pure Buton Asphalt concrete regarding stability, optimum coconut coir content and length, and deformation resistance.

To achieve this aim, the following objectives are accomplished:

– to determine the Optimum Asphalt Content (OAC) of pure Buton asphalt;

– to determine the effect of coconut coir content and length on Buton asphalt mixtures;

– to determine the Road Deformation (RD) of modified Buton asphalt with coconut coir.

4. Materials and methods

4. 1. Object and hypothesis of the study

Pure Buton asphalt and coconut coir were used as the research objects. The asphalt has performance grade 70 (PG-70) extracted from natural asphalt originating from Buton with >99 % purity and has the same quality as modified asphalt. Coconut coir was collected as unused or unutilized waste.

The object of this study is the effect of adding coconut coir on the characteristics of pure Buton asphalt. This study focused on Marshall testing, which includes stability value, VIM (Void in Mix) value, VMA (Void Mix Aggregate) value, VFB (Void Filled with Bitumen) value, flow, and MQ (Marshall Quotient) value.

This study's main hypothesis is that adding coconut coir to the asphalt mixture will improve the quality and performance of Marshall characteristics and dynamic stability, thereby reducing the fragility of the mixture. It is assumed that coconut coir could be a binder between aggregates and a filler between voids so that it could reduce VIM value, thereby increasing stability.

Coconut coir is assumed to become a binding material between aggregate and asphalt due to its strong and flexible coir structure. It can absorb asphalt well so that it reinforces cracks and deformation. With an effective size, coconut coir can act as a filler in the voids of the asphalt mixture. It can reduce the voids and increase the stability of the asphalt mixture. In this study, simplification is made by making a coir length of no less than 0.5 cm. It was used to facilitate easy cutting of the coir so that the length of the coir can be uniform and valid for conducting research in the laboratory.

4. 2. Research design

Asphalt concrete (AC-WC) is the top layer of flexible pavement construction directly related to vehicle loads and weather. Therefore, it is very important to plan the AC-WC asphalt concrete design mix formula according to applicable specifications or rules so that asphalt concrete can withstand various conditions and become good quality.

The variation of asphalt content applied in this research is 5.5 %, 6 %, 6.5 %, and 7% of the total aggregate weight, using coconut coir as an independent variable. The variation of coir content used is 0.5 %, 0.75 %, and 1 % of asphalt weight, and the variation of coir length is 0.5 cm, 1 cm, and 1.5 cm, as shown in Table 1. As a control, samples were also made without using coconut coir modifiers.

Table 1

Number of Design Specimens

Coconut Coir Length	Asphalt content+coconut coir content		
	OAC+0.5 %	OAC+0.75 %	OAC+1 %
0.5 cm	3	3	3
1 cm	3	3	3
1.5 cm	3	3	3
Subtotal	9	9	9
Total	27		

Based on Table 1, this study consisted of 9 treatments with 27 samples. After obtaining the optimum asphalt content (OAC), the dynamic stability characteristics test was carried out using the optimum asphalt content and control variables without using coconut coir to determine the effect of coconut coir. The mixture's gradation and the material's weight used in this study have been adjusted to the Indonesian Highway Department specifications. They are listed in the Job Mix Formula (JMF) with various treatments.

4. 3. Mixing method

The method used in this study is to mix coconut coir into the asphalt mixture while the asphalt and aggregate are mixed evenly, which is usually called the wet mixing method. This method of mixing asphalt is based on previous research related to the performance of the effect of coconut coir on the mixture. Mixing coconut coir when the asphalt is being stirred evenly is intended so that the coconut coir can be mixed evenly. Also, the stirring must be done quickly and carefully considering the more effective way of controlling its temperature.

4. 4. Analysis method

The analytical method used to find the optimum asphalt content (OAC) for each variation of coir content and coir length was the Marshall Test, which used Response Surface Methodology (RSM) to produce 3D graphics. In optimizing a process with RSM, it is necessary to determine the lower and upper limits of the variables. In this method, all variables are examined together [14]. The Wheel Track Machine was used to analyze dynamic stability to get the deformation.

5. Results of the study for determining the effect of adding coconut coir on pure natural Buton asphalt

5. 1. Determining the optimum asphalt content (OAC) of pure Buton asphalt

Determining OAC is done by doing the Marshall test of pure Buton asphalt for the top layer of asphalt concrete mixture (AC-WC) with variations in levels of 5.5 %, 6 %, 6.5 %, and 7 % without additional coconut coir. Table 2 shows the study's design, and Fig. 1 shows the results of the Marshall test on pure Buton asphalt.

The asphalt content that meets all Marshall test requirements is between 6.5 % and 7 %; the OAC figure is determined from that value. Based on Fig. 1, these test results obtained the optimum asphalt content of pure Buton asphalt at 6.76 %. Then, it was used to find the stability value of pure Buton asphalt, which is shown in Table 3.

The three samples underwent rigorous testing, yielding different results. The highest stability value, 1263.003 kg, and the lowest, 1065.894 kg, demonstrate the thoroughness of our testing process. The average of these three values, 1174.682, is the stability value of pure Buton asphalt.

Table 2

Marshall testing of pure Buton asphalt for the top layer of asphalt concrete mixture (AC-WC) without additional coconut coir

Asphalt content (%)	Coconut coir content	VMA (%)	VIM (%)	VFB (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
5.5	0	14.630	6.350	58.865	1291.719	4.600	280.808
5.5	0	14.715	6.442	55.866	1091.467	4.700	232.227
5.5	0	14.713	6.440	53.465	1186.902	4.100	289.488
6	0	14.918	5.616	58.689	1019.754	3.500	291.358
6	0	15.142	5.865	58.736	1044.871	3.900	267.916
6	0	14.952	5.654	59.234	1143.671	3.900	293.249
6.5	0	15.238	4.927	68.336	1006.114	3.500	287.461
6.5	0	15.160	4.839	68.080	1014.872	3.800	267.072
6.5	0	15.153	4.832	68.115	1017.858	3.750	271.429
7	0	16.147	4.913	75.406	1018.953	3.100	328.694
7	0	16.175	4.944	75.441	1038.560	3.100	335.019
7	0	16.174	4.943	75.429	1015.163	3.000	338.388

Table 3

Marshall test results for pure Buton asphalt mixture by using an optimum asphalt content of 6.76 %

Sample	Asphalt content	Void (%)			Stability (kg)	Flow (mm)	MQ (kg/mm)
		VMA	VIM	VFB			
1	6.76 %	15.698	4.902	68.773	1263.003	3.000	421.001
2	6.76 %	15.680	4.882	68.865	1065.894	2.800	380.676
3	6.76 %	15.678	4.880	68.876	1195.148	2.800	426.839
Average		15.470	4.888	68.838	1174.682	2.867	409.505

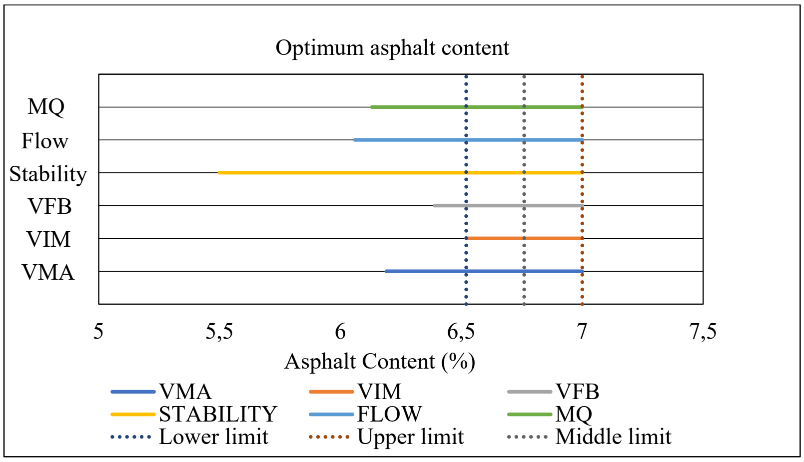

Fig. 1. Graphic of Marshall test to determine optimum asphalt content (OAC)

From the results of the regression equation of the relationship between asphalt content and coir content and coir length to determine the optimum asphalt content and coir content and optimum coir length, the optimum coir content of 0.5 % and optimum coir length of 0.81 cm were obtained. The Marshall characteristics of the mixture are shown in Table 7.

Table 7 shows a higher stability value at the optimum coconut coir of 0.5 % and the optimum coconut coir length of 0.81 cm. It produces VIM of 4.64 %, VMA of 15.47 %, FVB value of 69.96 %, stability value of 1213.58 kg, flow of 2.68 mm, and MQ value of 482.49 kg/mm.

5. 2. Determining the effects of adding coconut coir content and length to pure Buton asphalt mixtures

Table 4 shows the results of the Marshall test for the top layer of asphalt concrete AC-WC mixture, which consists of 6.76 % pure Buton asphalt and the addition of 0.5 % Coconut Coir. Then Table 5 shows the results of the Marshall test for the top layer of asphalt concrete AC-WC mixture, which consists of 6.76 % pure Buton asphalt and 0.75 % Coconut Coir. Table 6 shows the results of the Marshall test for the top layer of asphalt concrete AC-WC mixture, which consists of 6.76 % pure Buton asphalt and the addition of 1 % Coconut Coir.

Table 6

Marshall test results with the addition of 1 % coconut coir

Asphalt Content (%)	Coco Fiber Content (%)	Coco Fiber Length (cm)	VMA (%)	VIM (%)	VFB (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
6.76	1	0.5	16.666	5.993	64.037	1251.880	2.600	481.492
6.76	1	0.5	16.719	6.054	63.791	1146.971	2.400	477.905
6.76	1	0.5	16.648	5.974	64.117	1214.972	2.800	433.918
6.76	1	1	17.010	6.382	62.481	1274.723	3.300	386.280
6.76	1	1	17.056	6.434	62.277	1086.700	3.300	329.303
6.76	1	1	16.994	6.364	62.550	1226.313	3.400	360.680
6.76	1	1.5	17.237	6.638	61.491	981.631	3.400	288.715
6.76	1	1.5	17.209	6.607	61.610	1023.945	3.500	292.556
6.76	1	1.5	17.200	6.596	61.649	975.869	3.300	295.718

Table 4

Marshall test results with the addition of 0.5 % coconut coir

Asphalt Content (%)	Coco Fiber Content (%)	Coco Fiber Length (cm)	VMA (%)	VIM (%)	VFB (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
6.76	0.5	0.5	15.432	4.602	70.179	1117.873	2.900	385.473
6.76	0.5	0.5	15.475	4.650	69.951	1314.537	3.000	438.179
6.76	0.5	0.5	15.479	4.655	69.927	1193.784	2.600	459.148
6.76	0.5	1	15.629	4.824	69.132	1174.318	3.000	391.439
6.76	0.5	1	15.603	4.794	69.272	1228.164	3.200	383.801
6.76	0.5	1	15.625	4.819	69.156	1179.941	2.800	421.407
6.76	0.5	1.5	16.600	5.919	64.341	1013.425	3.100	326.911
6.76	0.5	1.5	16.532	5.842	64.659	1099.129	3.300	333.069
6.76	0.5	1.5	16.565	5.880	64.502	1071.271	3.300	324.627

Table 5

Marshall test results with the addition of 0.75 % coconut coir

Asphalt Content (%)	Coco Fiber Content (%)	Coco Fiber Length (cm)	VMA (%)	VIM (%)	VFB (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
6.76	0.75	0.5	16.156	5.419	66.461	1090.361	2.200	495.619
6.76	0.75	0.5	16.373	5.663	65.411	1101.104	2.300	478.741
6.76	0.75	0.5	16.514	5.823	64.742	1049.668	2.000	524.834
6.76	0.75	1	16.947	6.311	62.762	1069.587	2.800	381.995
6.76	0.75	1	16.892	6.248	63.009	1081.743	2.800	386.337
6.76	0.75	1	16.870	6.224	63.107	1210.981	3.000	403.660
6.76	0.75	1.5	17.090	6.472	62.128	1153.386	3.500	329.539
6.76	0.75	1.5	17.123	6.509	61.986	1156.567	3.700	312.586
6.76	0.75	1.5	17.124	6.510	61.981	1184.836	3.400	348.481

Upon completion of the Marshall testing, the results will be subjected to the powerful Response Surface Methodology. This method is instrumental in producing 3D graphical representations and regression equations. In these equations, the X value represents the coir content, while the Y value represents the coir length. The output variables of this test include crucial Marshall characteristics such as stability value, MQ value, flow value, VFB, VMA, and VIM, as depicted in Fig. 1–8 below.

Fig. 2 shows the relationship between the content of coconut coir and the length of coconut coir that gains the VIM value. Along with the graphics, the equation to get VIM was also obtained:

$$Z=-1.052+13.505X+1.416Y-1.277XY-6.514X^2+0.223Y^2. \quad (1)$$

Fig. 3 shows the relationship between the content and length of coconut coir that gains the VMA value. Along with the graphics, the equation to get VMA was also obtained:

$$Z=10.420+11.972X+1.255Y-1.132XY-5.775X^2+0.198Y^2. \quad (2)$$

Table 7

Characteristics of optimum coir content and length

Variable	Unit	Value	Indonesian Highway Department Specs	Description
VIM	%	4.64	3–5	Qualified
VMA	%	15.47	>15	Qualified
VFB	%	69.96	>65	Qualified
Stability	kg	1213.58	>1,000	Qualified
Flow	mm	2.68	2–4	Qualified
MQ	kg/mm	482.49	>250	Qualified

Fig. 4 shows the relationship between the content of coconut coir and the length of coconut coir that gains the CFB value. Along with the graphics, the equation to get VFB was also obtained:

$$Z=94.987-59.312X-6.474Y+ +6.240XY+28.401X^2-1.007Y^2. \quad (3)$$

Fig. 5 shows the relationship between the content and length of coconut coir that gains stability. Along with the graphics, the equation to get the stability value was also obtained:

$$Z=1171.587-425.173X-414.320Y+ +126.672XY+336.869X^2-205.274Y^2. \quad (4)$$

Fig. 6 shows the relationship between the content of coconut coir and the length of coconut coir that gains the flow value. Along with the graphics, the equation to get the flow value was also obtained:

$$Z=4.015-5.689X+1.100Y+0.800XY+ +3.378X^2-0.422Y^2. \quad (5)$$

Fig. 7 shows the relationship between the content and length of coconut coir that gains the Marshall Quotient (MQ) value. Along with the graphics, the equation to get the MQ value was also obtained:

$$Z=233.412+803.262X-99.146Y- -145.423XY-455.965X^2+30.601Y^2. \quad (6)$$

From all the 3D Graphs of Marshall characteristics, an overlay graph with rainbow-colored areas will be made. The combination of coconut coir content and length that meets Indonesian Highway Department specifications on asphalt mixture is presented in Fig. 8.

Based on the 3D Response Surface Methodology graphical method, the output is obtained as recommendations for the optimum coir content and length accompanied by the value of Marshall characteristics, as in Table 8.

Our study reveals that the most optimal variation, meeting the Indonesian Highway Department specification, is achieved when the coir content is 0.5 % and the coir length is 0.63 cm. As shown in Table 8, this variation produces the highest stability value. This finding is significant as it provides a clear guideline for future asphalt mixtures. Table 9 further compares the Marshall Test characteristics between the pure Buton asphalt mixture and the modified Buton asphalt with coconut coir.

Table 9 provides a comprehensive and detailed comparison of the Marshall Test characteristics between the pure Buton asphalt mixture and the modified Buton asphalt with coconut coir. It is evident that adding coconut coir decreases VIM, VMA, and flow values while increasing VFB, stability, and MQ. This thorough comparison instills confidence in the validity of our results.

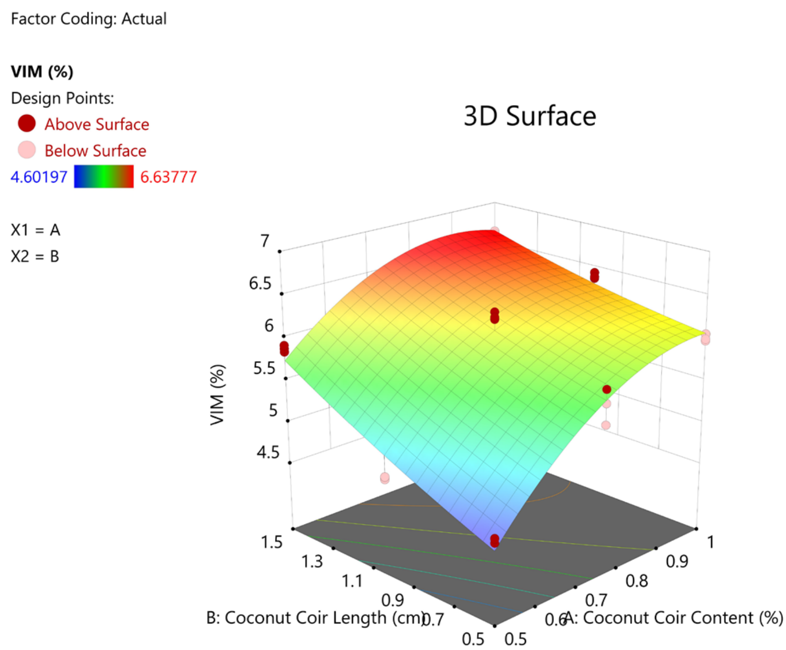

Fig. 2. 3D graph of the relationship between the content of coconut coir and the length of coconut coir with VIM values

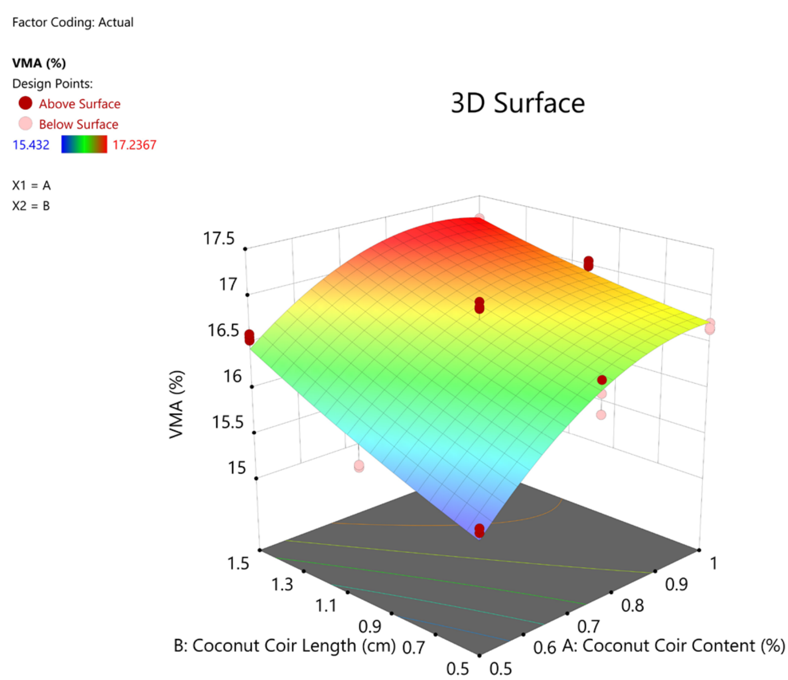

Fig. 3. 3D graph of the relationship between the content of coconut coir and the length of coconut coir with VMA values

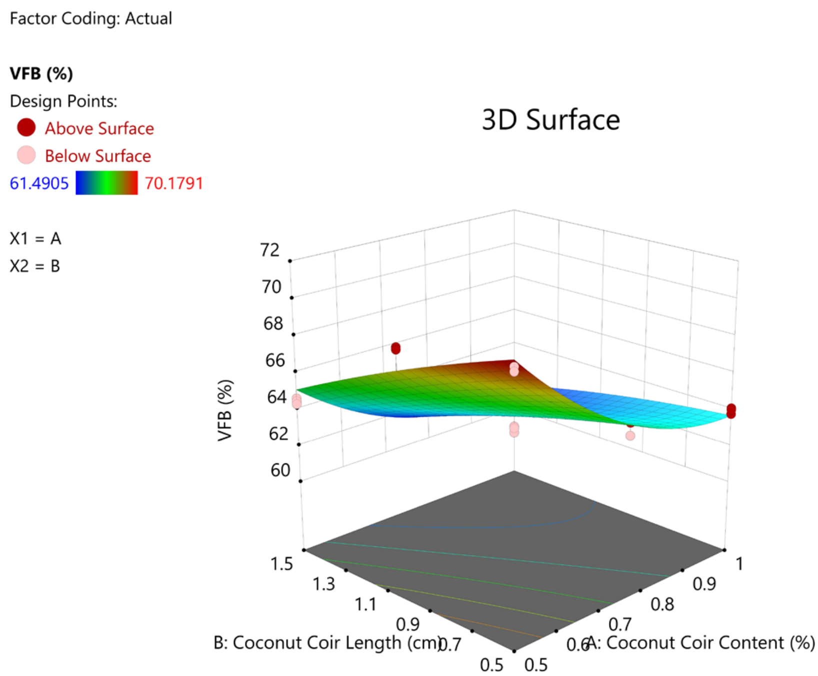

Fig. 4. 3D graph of the relationship between the content of coconut coir and the length of coconut coir with VFB values

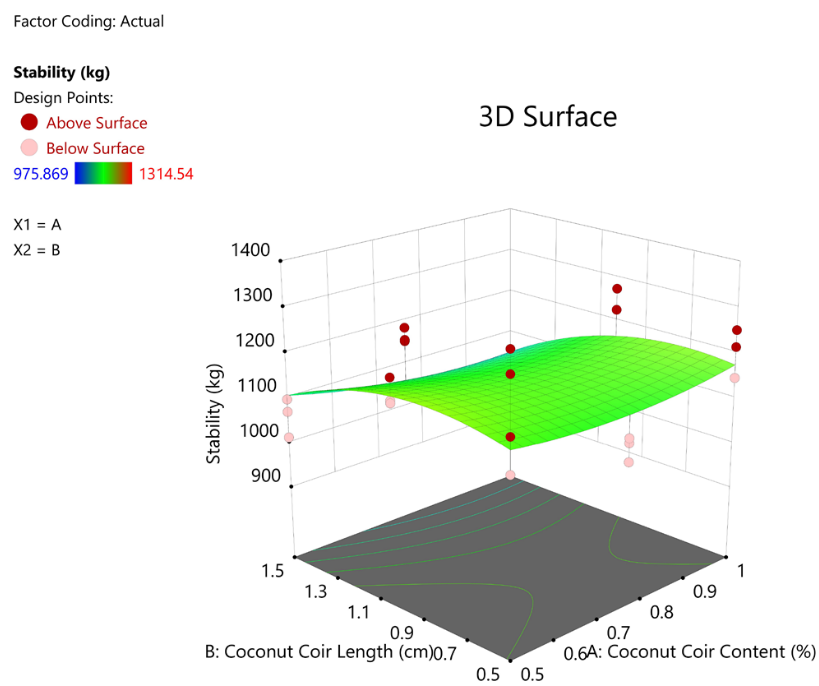

Fig. 5. 3D graph of the relationship between the content of coconut coir and the length of coconut coir with stability

Table 8

Optimum coir content based on the 3D Response Surface Methodology

Number	Content	Length	VMA	VIM	VFB	Stability	Flow	MQ
1	2	3	4	5	6	7	8	9
1	0.500	0.630	15.475	4.650	69.919	1182.852	2.792	424.946
2	0.501	0.623	15.475	4.650	69.919	1181.998	2.783	426.183
3	0.503	0.613	15.475	4.650	69.919	1180.771	2.771	427.926
4	0.504	0.605	15.475	4.650	69.919	1179.712	2.760	429.401
5	0.505	0.601	15.475	4.650	69.919	1179.246	2.755	430.041
6	0.506	0.593	15.475	4.650	69.919	1178.166	2.745	431.505
7	0.508	0.585	15.475	4.650	69.919	1177.112	2.734	432.911

Continuation of Table 8

1	2	3	4	5	6	7	8	9
8	0.509	0.579	15.475	4.650	69.919	1176.226	2.726	434.073
9	0.510	0.571	15.475	4.650	69.919	1175.205	2.716	435.394
10	0.512	0.557	15.475	4.650	69.919	1173.133	2.697	438.016
11	0.513	0.551	15.475	4.650	69.918	1172.235	2.689	439.130
12	0.515	0.543	15.475	4.650	69.918	1171.027	2.678	440.608
13	0.517	0.529	15.475	4.650	69.918	1168.927	2.659	443.124
14	0.521	0.505	15.475	4.650	69.917	1165.170	2.627	447.472
15	0.522	0.500	15.475	4.650	69.917	1164.301	2.620	448.453

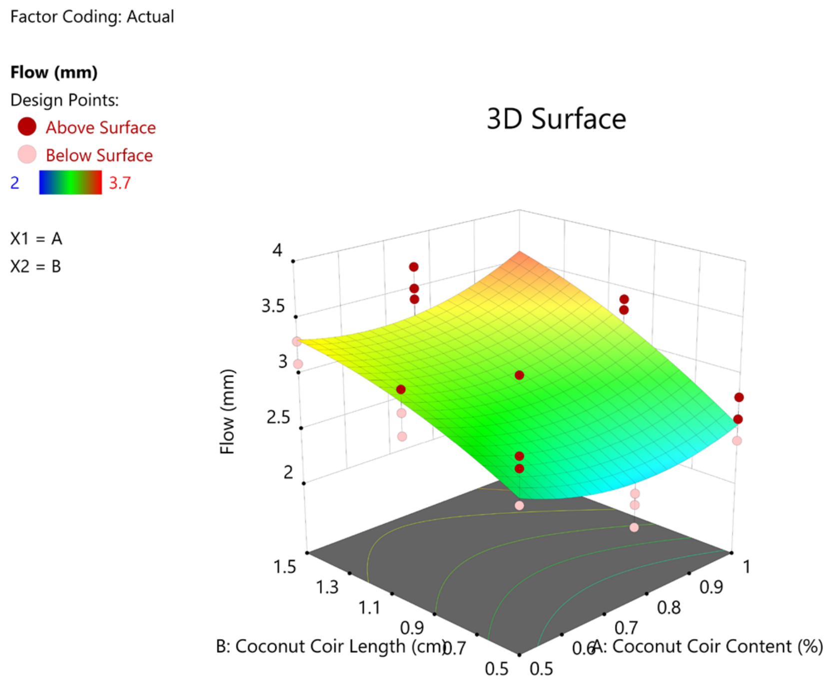

Fig. 6. 3D graph of the relationship between the content of coconut coir and the length of coconut coir with flow values

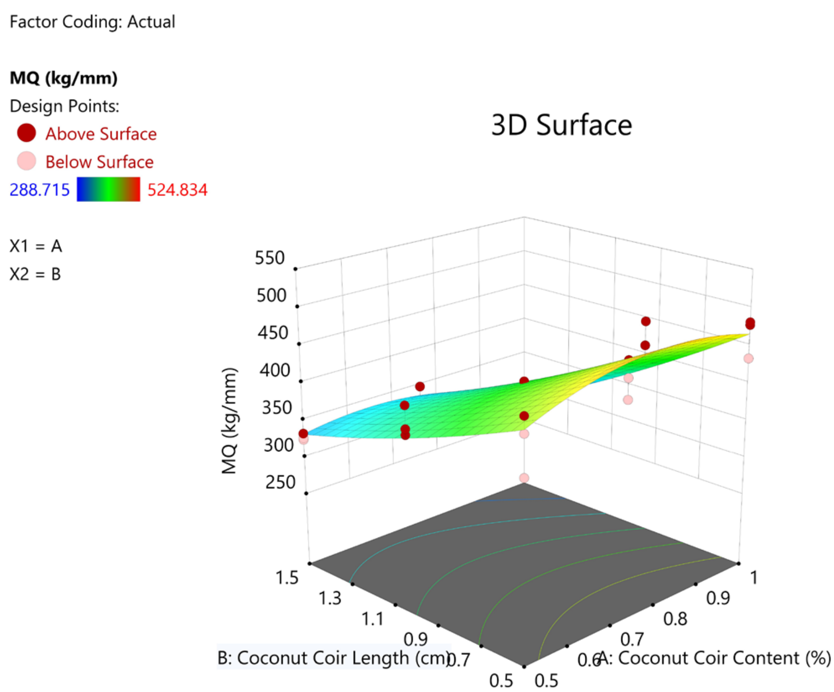

Fig. 7. 3D graph of the relationship between the content of coconut coir and the length of coconut coir with Marshall Quotient (MQ) values

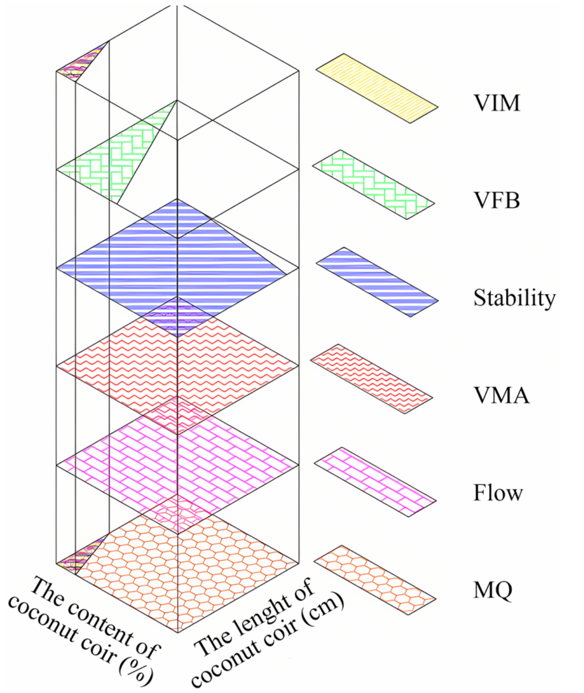

Fig. 8. 3D overlay graph of Marshall's characteristics that meet Indonesian Highway Department specification

Table 9

Comparison of Marshall Test characteristics between the pure Buton asphalt mixture and modified Buton asphalt with coconut coir

Marshall characteristics	OAC+coconut coir	OAC	Indonesian highway department specs
Optimum coir content	0.5 %	–	
Optimum coir length	0.81 cm	–	
VIM	4.64 %	4.89 %	3–5 %
VMA	15.47 %	15.69 %	>15 %
VFB	69.96 %	68.43 %	>65 %
Stability	1213.58 kg	1174.68 kg	>1,000 kg
Flow	2.68 mm	2.87 mm	2–4 mm
MQ	482.49 kg/mm	409.51 kg/mm	>250 kg/mm

5. 3. Determining the road deformation (RD) of modified Buton asphalt with coconut coir

The dynamic stability test, conducted in accordance with the Japan Road Association standard (Pavement Survey and Test Method Handbook B003), is a crucial part of our study. It aims to determine the road deformation when coconut coir is added to the Pure Buton Asphalt Concrete-Wearing Course (AC-WC) mixture. The results of these tests are shown in Table 10, while Fig. 9 compares the deformation as a result of dynamic stability tests using the Wheel Tracking Machine.

Interpreting the Wheel Tracking Machine test results, we can affirm that the pure Buton asphalt mixture, enriched with coconut coir, demonstrates a notably higher dynamic stability value of 2357.14 passes/mm. This surpasses the dynamic stability value of the pure Buton asphalt mixture, which stands at 2065.20 passes/mm without the coconut coir addition. This increase in dynamic stability is significant as it indicates the potential for improved pavement performance. These findings carry direct implications for the design and construction of pavement materials, suggesting that coconut coir and pure Buton Asphalt have significantly enhanced pavement performance.

Table 10

Deformation and dynamic stability mixture results

Deformation Data for the OAC sample and OAC+Coco coir sample				
Minute	Passes	Deformation (mm)		Unit
		OAC	OAC+Coco coir	
0	0	0	0	mm
5	275	5.54	4.68	mm
10	550	6.83	5.79	mm
15	825	8.2	6.62	mm
20	1,100	9.5	7.58	mm
25	1,375	10.38	8.31	mm
30	1,650	11.05	8.89	mm
35	1,925	11.52	9.48	mm
40	2,200	11.78	9.97	mm
45	2,475	11.98	10.25	mm
50	2,750	12.15	10.37	mm
55	3,025	12.27	10.49	mm
60	3,300	12.38	10.60	mm
Dynamic Stability		2062.50	2357.14	passes/mm
Rate of Deformation		0.02667	0.02333	passes/mm

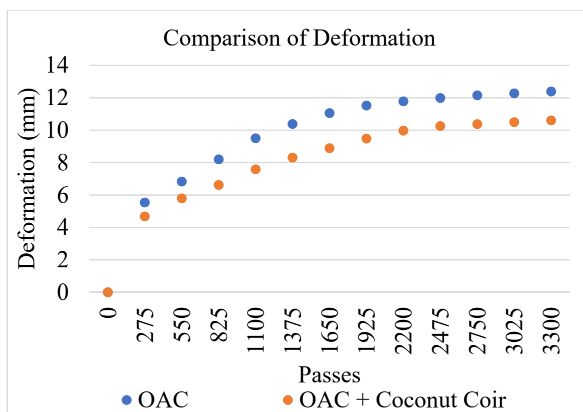

Fig. 9. Comparison of deformation between the optimum asphalt content (OAC) sample and the optimum asphalt content (OAC)+coconut coir sample

6. Discussion of experimental results of the study on the effect of adding coconut coir on the pure Buton asphalt

This study began by finding the optimum asphalt content using variations of 5.5 %, 6 %, 6.5 %, and 7 % without any addition, where the most optimum Marshall results were between 6.5 % and 7 % (Table 1). Unlike a previous study [2], which found that the optimum asphalt content of pure Buton asphalt is 6.1 %, our study's results show that the optimum asphalt content of pure Buton asphalt is between 6.5 % and 7 %, at precisely 6.76 % (Fig. 1). This is made possible by the differences in aggregate quality. By using an optimum asphalt content of 6.7 %, the Marshall characteristics of pure Buton asphalt without addition were obtained (Table 3). The results are VMA 15.470 %, VIM 4.888 %, VFB 68.838 %, stability value 1174.682 kg, flow value 2.867 mm, and MQ value 409.505 kg/mm. The study then proceeded to investigate the impact of adding coconut coir to the pure Buton asphalt, which is the focus of this report.

Unlike others, our research focuses on adding coconut coir to pure Buton asphalt, a novel approach that has not been extensively explored. In this study, the variation of coconut coir content was carried out with variations of 0.5 %, 0.75 %, and 1 %, while the length variations are 0.5 cm, 1 cm, and 1.5 cm (Tables 4–6). Using regression of the relationship between asphalt content and coconut coir, the optimum coconut coir content is 0.5 %, and the length is 0.81 cm. The mixture produces Marshall characteristics that are qualified when compared to the Indonesian Highway Department specification on asphalt mixtures (Table 7).

As reviewed in (Fig. 2–7), the graph represents the projection of the Marshall characteristic values in 3D. It is shown that the more the surface is directed toward the blue color, the more variation of the content and length of the coir shows the direction toward the minimum value that has been determined. Conversely, the more the surface is directed toward the red color, the variation of the content and length of the coir shows direction toward the maximum value. After carrying out the Response Surface Methodology process, all outputs (Fig. 2–7) as Marshall characteristic parameters are overlaid to eliminate values that do not meet the Indonesian Highway Department specification so that the optimum value can be found. As shown in (Fig. 8), the layering of 6 surfaces RSM projections is overlapped and then cut to choose the area that qualifies all the specifications. As shown in Fig. 8, the area that has been cut is the area of coir content and length variation that has met the Indonesian Highway Department Division 6 of Modified AC-WC specification; that area's data was then taken and then 1 variation with optimum status was selected (Table 8), that optimum variation is a mixture with a coir content of 0.5 % and a coir length of 0.63 cm, which has the highest stability value.

The data produced in this research (Table 9) shows that adding coconut coir at optimal content and length can improve the characteristics of the Asphalt Concrete Wearing Course Mixture, demonstrating the thoroughness and reliability of our study. Coconut coir fills voids in the asphalt mixture, whereas asphalt mixtures that use pure Buton asphalt tend to have large voids. This statement is concluded based on the VIM, VMA, VFB, Stability, Flow, and MQ values (Table 9) of the OAC+Coconut Coir mixture representing better characteristics than the OAC one. The data also represent that the mixture modified with coconut coir proved to reduce Void (VIM, VMA); thus, because coconut coir is speculated to fill the void of its mixture, this is proved by the increment of the VFB value (Table 9). Referring to the data in Table 8, the optimum coir content selected was 0.5 %, the lowest content of all content variations that had been determined. In contrast, the optimum coir length chosen was 0.63 cm. Speculation occurred when looking through data from Marshall stability testing results shows that the higher the coconut coir content used, the more it can reduce the VIM, VMA, and Flow values but increase the VFB, Stability, and MQ values. Referring to the length of the coconut coir, the longer the coconut coir used, the lower the VFB, Stability, and MQ values, but the VIM, VMA, and Flow values increase. This study found the optimum content of pure Buton asphalt, coconut coir content, and length. The comparison between the OAC sample and the OAC+Coconut Coir sample shows the performance improvement due to the coconut coir addition, with the latter demonstrating better characteristics in terms of void reduction and stability increase.

Our study, unlike a previous one [7], found that the addition of coconut coir to the asphalt mixture could increase the stability value of Marshall Testing by 38.9 kg, from 1174.68 in the condition without coconut coir to 1213.58 kg, which is approximately a 3.31 % increase. This suggests that adding coconut coir to Pure Buton Asphalt can enhance the pavement's plastic deformation resistance and stiffness under vehicle load, as demonstrated by the OAC+coconut coir mixture.

The dynamic stability value was obtained by using a Wheel Track Machine, which machine makes a simulation related to traffic conditions. Using the same passes in the simulation, pure Buton asphalt mixture deformation is higher than that of the modified one. At passes of 3,300 exactly at 60 minutes of simulation, the deformation of pure Buton asphalt mixture is 12.38 mm. Meanwhile, the deformation of modified Buton asphalt with coconut coir is 10.60 mm. The final results of dynamic stability for pure Buton asphalt are 2062.50 passes/mm, and for the modified Buton asphalt with coconut coir – higher; the dynamic value is about 2357.14 passes/mm, increased by 14.14 % (Table 10). The deformation that occurs in asphalt mixtures without coconut coir is higher than in mixtures using coconut coir (Fig. 9) because coconut coir in the mixture increases the strength of the structural asphalt.

Dynamic stability shows the durability of a road pavement when subjected to dynamic loads that result in rutting/permanent deformation. 2357.14 passes/mm means that the OAC+coconut coir mixture requires 2357.14 road passes to produce 1 mm deep rutting. Of course, this is related to long-term use; this research also proves that the Pure Buton Asphalt+coconut coir mixture has higher rutting resistance than Pen 60/70 asphalt, which has a rutting resistance of around 1,000–1,600 passes/mm. The results on these aspects suggest a potential for significantly enhanced pavement performance and paving the way for a more durable and reliable road network.

The limitation of this study is the minimal content and quality of the data collection about pure Buton asphalt. Then, this study was conducted under controlled laboratory conditions, which are not entirely affected by factors in real asphalt construction. Meanwhile, the shortcoming of this study is using pure Buton asphalt with performance grade 70 or PG-70 only. The results may not apply to other types of asphalt and coir from other plants. However, this study's results are based on specific design experimental ranges, which might require some testing to ensure the same effectiveness. In addition, the disadvantage of this study is that using pure Buton asphalt requires additional cost to purify it so that it can be used easily in the pavement mixture. This could be overcome in the future by carrying out purification processing on a mass scale to reduce costs.

The following aspects are expected to meet the requirements for the better development of this research:

– pay more attention to the mixture temperature after the asphalt and aggregate mixing process towards the compacted process. This is done to meet the compaction temperature range of pure Buton asphalt because the temperature changes are faster than for oil asphalt;

– use other variations of coir content, ranging around the optimum coir content, to significantly affect the mixture.

For further research development, another coir material, such as pineapple coir, cigarette filter, etc., which has similar fiber characteristics to coconut coir, could be used. However, before using these fibers, it is necessary to confirm the strength of the material if they are used in the asphalt mixture. Another research could be done to check whether the mixture of pure Buton asphalt and coconut coir can be used for the Asphalt Concrete Base Course (AC-BC).

7. Conclusions

1. The Optimal Asphalt Content (OAC) of pure Buton asphalt mixture is 6.67 %, with a stability value of 1174.68 kg, as determined by the Marshall Test.

2. The addition of coconut coir to pure Buton asphalt with 0.5 % content and 0.81 cm length, produces Marshall characteristics with a stability value of 1213.58 kg, which has increased by 3.31 % from asphalt without added coir, Flow 2.68 mm, which has decreased by 6.62 % from asphalt without added coir, MQ 482.49 kg/mm, which has increased by 17.82 % from asphalt without added coir, VMA 15.47 %, which increased by 1.4 % from asphalt without coir addition, VIM 4.64 %, which decreased 5.11 % from asphalt without coir addition, and VFB 69.96 %, which increased 1.63 % from asphalt without coir addition, and dynamic stability 2357.14 passes/mm, which increased 14.14 % from asphalt without coconut coir addition.

3. The dynamic stability of 2357.14 passes/mm increased by 14.14 % from asphalt without coconut coir addition.

Conflict of interest

The authors in this manuscript do not have any conflicts of interest, whether financial, personal, authorship or otherwise, that could affect the research and results presented in this paper.

Financing

The study was performed without financial support.

Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Research Report 318 Clay mineralogy of modified marginal aggregates (2007). Available at: https://www.nzta.govt.nz/resources/research/reports/318/
2. Hermadi, M., Ronny, Y. P., Firdaus, Y. (2022). Comparison of Characteristics Between Pure Asbuton Hot Asphalt Mixtures, Asbuton Grain B 50/30 And Pen 60 Oil Asphalt. Proceeding KRTJ.
3. Lumintang, R. C. A., Soenoko, R., Wahyudi, S. (2012). Komposit Hibrid Polyester Berpenguat Serbuk Batang dan Serat Sabut Kelapa. Jurnal Rekayasa Mesin, 2 (2), 145–153. Available at: https://rekayasamesin.ub.ac.id/index.php/rm/article/view/137
4. Hadiwardoyo, S. P. (2013). Evaluation of the addition of short coconut fibers on the characteristics of asphalt mixtures. Civil and Environmental Research, 3 (4), 63–73. Available at: https://iiste.org/Journals/index.php/CER/article/view/5049/5148
5. Syaviq, M. F., Arifin, M. Z., Bowoputro, H., Djakfar, L., Ambarwati, L. (2018). Studi Pengaruh Penambahan Serabut Kelapa Terhadap Karakteristik Marshall Pada Campuran Aspal Porus. Rekayasa Sipil, 12 (2), 92–98. https://doi.org/10.21776/ub.rekayasasipil.2018.012.02.3
6. Kusuma, T. A., Rahman, A. H. (2022). The Effect of Variations in Content and Length of Coir as a Modifying Material for the Top Layer of Asphalt Concrete Mixed Asbuton Layer (AC-WC) on the Performance of Marshall and Catanbro. Universitas Brawijaya.
7. Khasawneh, M. A., Alyaseen, S. K. (2020). Analytic methods to evaluate bituminous mixtures enhanced with coir/coconut fiber for highway materials. Materials Today: Proceedings, 33, 1752–1757. https://doi.org/10.1016/j.matpr.2020.04.870
8. Abiola, O. S., Kupolati, W. K., Sadiku, E. R., Ndambuki, J. M. (2014). Utilisation of natural fibre as modifier in bituminous mixes: A review. Construction and Building Materials, 54, 305–312. https://doi.org/10.1016/j.conbuildmat.2013.12.037
9. Panda, M., Suchismita, A., Giri, J. (2013). Utilization of Ripe Coconut Fiber in Stone Matrix Asphalt Mixes. International Journal of Transportation Science and Technology, 2 (4), 289–302. https://doi.org/10.1260/2046-0430.2.4.289
10. Ma, J., Cui, Y., Xing, Y., Chen, X., Wu, J. (2024). Optimization and pavement performance of buton-rock-asphalt modified asphalt mixture with basalt-fibre. Case Studies in Construction Materials, 21, e03429. https://doi.org/10.1016/j.cscm.2024.e03429
11. Jeffry, S. N. A., Jaya, R. P., Abdul Hassan, N., Yaacob, H., Satar, M. K. I. M. (2018). Mechanical performance of asphalt mixture containing nano-charcoal coconut shell ash. Construction and Building Materials, 173, 40–48. https://doi.org/10.1016/j.conbuildmat.2018.04.024
12. Guo, Y., Tataranni, P., Sangiorgi, C. (2023). The use of fibres in asphalt mixtures: A state of the art review. Construction and Building Materials, 390, 131754. https://doi.org/10.1016/j.conbuildmat.2023.131754
13. 2018 General Specifications for Road and Bridge Work (2018). Highway Department, Ministry of Public Work Indonesia.
14. Anwar, K., Istiqamah, F., Hadi, S. (2021). Optimasi Suhu Dan Waktu Ekstraksi Akar Pasak Bumi (Eurycoma Longifolia Jack.) Menggunakan Metode RSM (Response Surface Methodology) Dengan Pelarut Etanol 70%. Jurnal Pharmascience, 8 (1), 53. https://doi.org/10.20527/jps.v8i1.9085