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OPTIMIZATION OF ASPHALT CONTENT THROUGH MARSHALL CHARACTERISTICS USING MODIFIED ASBUTON

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ABSTRACT: The use of locally available natural resources is increasingly becoming popular for the production of novel building materials, particularly in terms of creativity. In Indonesia, Buton Island has significant amounts of asphalt that can be altered to produce high-grade building materials. During the asphalt manufacturing process, energy efficiency and environmental preservation must be considered, as modified asphalt requires less energy. Therefore, this study aimed to investigate the optimal asphalt content from various mixtures, including Asphalt Concrete Wearing Course (AC-WC), Asphalt Concrete Binder Course (AC-BC), and Hot Rolled Sheet Wearing Course (HRS-WC). Several parameters such as stability, flow, the Marshall Quotient (MQ), void in the mix (VIM), void in mineral aggregate (VMA), and void-filled bitumen (VFB) were used as attributes of Marshall. Subsequently, an empirical laboratory (Marshall) test was carried out to measure deformation resistance. The results showed that the appropriate asphalt concentration for AC-WC, AC-BC, and HRS-WC combinations was 6.25%, 5.80%, and 6.50%, respectively. The analysis showed the significance of determining optimal asphalt content for these mixtures containing modified Asbuton binder. The excellent adhesive properties of Asbuton-based bitumen made these mixtures suitable for applications requiring high fracture toughness and low strength, such as concrete barriers.

Keywords: Optimum asphalt content, Marshall characteristics, Asphalt mixtures, Modified Asbuton

1. INTRODUCTION

Increased vehicle traffic significantly causes higher emissions and environmental damage around road infrastructure [1]. This phenomenon is attributed to the quality of road infrastructure, which is influenced by contractors and unskilled laborers, thereby increasing the risk of project failure [2]. Therefore, the use of efficient materials that are resistant to the destructive effects of climate change, weather, and vehicle emissions is required during construction [3, 4].

Precision in the expression of components should be maintained to ensure quality road infrastructure. For example, Hot Mixed Asphalt (HMA) is a particulate composite material consisting of total mixtures, asphalt binder, and air holes. Due to the widespread use of binders, degrees, and various cover changes, the composition of asphalt mixtures has changed. In the southern region of Indonesia's Buton Island, several areas contain sedimentary rocks naturally rich in hydrocarbon compounds, including asphalt. Specifically, the estimated reserves of natural asphalt, also known as Natural Asphalt Buton Rock Asphalt (BRA), are approximately 60,991,554 or 24,352,833.07 barrels of oil [5]. The percentage of bitumen in rocks varies from 15% to 35% of their total weight.

In Indonesia, approximately 600,000 tons of petroleum bitumen are imported annually to build and maintain flexible pavements. However, due to the surplus of BRA, its efficient usage could alleviate the dependency on imported petroleum bitumen. In recent years, BRA has been subjected to a mechanical process to produce Buton Granular Asphalt (BGA) on grains with water, bitumen, and penetration value in accordance with requirements [6–9].

Numerous studies have documented the use of Buton asphalt as a material substitute for petroleum bitumen. By using these abundant natural resources, there is a prospect to enhance the stability and effectiveness of asphalt mixtures [10–17]. Modified Buton asphalt, a processed semi-extracted from natural resources, has also shown potential as a binder in asphalt mixtures [18].

An empirical laboratory test, known as the Marshall test, is frequently used to gauge deformation resistance in asphalt mixtures [19]. As the wheel traverses, deformation due to tensile tension develops in the pavement structure beneath an approaching wheel load. To address this deformation, Marshall test offers a promising potential, consisting of six different methods, namely stability, flow, Marshall quotient (MQ), Void in Mix (VIM), Void in Mineral Aggregate (VMA), and Void-Filled Bitumen (VFB), to determine the ideal asphalt content [20].

The primary objective of this study was to scrutinize the potential applicability of semi-extracted Asbuton as a bituminous asphalt binder in the formulation of asphalt mixtures. Through a rigorous investigative process, semi-extracted Asbuton was employed as a substitute bituminous asphalt binder, with particular focus on its efficacy in various asphalt mixtures. Specifically, the study delved into the impact of utilizing semi-extracted Asbuton on the optimal asphalt content within different mixtures, including AC-WC, AC-BC, and HRS-WC compositions.

This study not only addressed the specific inquiry regarding the suitability of semi-extracted Asbuton as a bituminous asphalt binder but also provided valuable data for optimizing asphalt mixture compositions to enhance performance and sustainability in infrastructure projects.

2. STUDY SIGNIFICANCE

The study aimed to assess the potential suitability of semi-extracted Asbuton as a bituminous asphalt binder in asphalt mixtures. By employing semi-extracted Asbuton in this capacity, the research examined its influence on the optimal asphalt content in different mixtures, including AC-WC, AC-BC, and HRS-WC compositions. The test results were thoroughly analyzed to determine any discernible effects, with the findings subsequently published for wider dissemination. This investigation holds significance for paving technology and infrastructure development, potentially offering a sustainable alternative for asphalt binder sources. Overall, the study contributes valuable insights to the field of asphalt engineering and materials science.

3. MATERIALS AND METHOD

3.1 Buton Granular Asphalt

As shown in Figure 1 and Table 1, measurements of BGA and a few BGA type 20/25 features are shown individually.

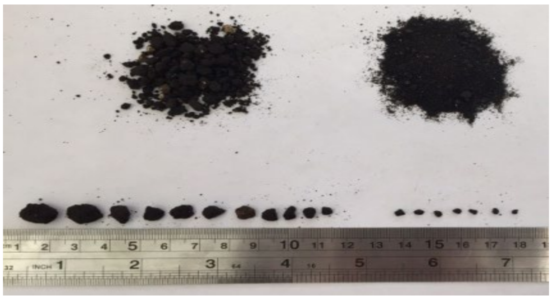


Fig.1 BGA dimension in mm

BGA used in this study has a grain size distribution that is generally regular, with the largest of 1.18 mm. To create modified Asbuton, this semi-extracted BGA was combined with petroleum bitumen at a specific ratio.

Table 1. Some properties of BGA

Parameter	Value
Content of Bitumen (%)	23.00
Content of Asphalt Mineral (%)	77.00
Water content (%)	1.70
Flashpoint (mm)	1.68
Melting point (^{0}C)	86

3.2 Characteristics of Aggregate

As shown in Table 3, two types of coarse aggregate obtained from crushed river stones were used, with 5-10 mm and 10-20 mm diameters, respectively. Subsequently, river sand and stone leftovers from the crushed stone process were used as fine aggregate and filler, respectively. The characteristics of coarse aggregate, fine aggregate, and filler from Membramo River in Jayapura, as listed in Tables 2, 3, and 4.

Table 2. Properties of coarse aggregate

Properties	(Crushed Stone) 0.5 - 1 (cm)	1 - 2 (cm)
Water absorption, %	2.071	2.08
Bulk specific gravity	2.622	2.627
Saturated surface dry specific gravity	2.677	2.682
Apparent specific gravity	2.773	2.779
Flakiness index, %	20.1	9.38
Abrasion aggregate, %	25.72	24.36

Table 3. Properties of fine aggregate

Water absorption, %	2.792	
Sand equivalent, %	89.66	
Bulk specific gravity 2.449	Saturated surface dry specific gravity 2.518	Apparent specific gravity 2.629

Table 4. Properties of mineral filler

Water absorption, %	2.283	
Sand equivalent, %	69.57	
Bulk specific gravity 2.595	Saturated surface dry specific gravity 2.654	Apparent specific gravity 2.758

3.3 Modified Asbuton

Table 5 shows the characteristics of modified Asbuton, with the commercial Asbuton variant serving as the main binder. A particular percentage of Buton asphalt was combined with petroleum bitumen to create modified Asbuton, which was used as mixtures going through a semi-extraction process.

Table 5. Properties of modified Asbuton

Properties	Testing result
Penetration before weight loss (mm)	78.6
Softening point (°C)	52
Ductility in 25°C, 5cm/minute (cm)	114
Flashpoint (°C)	280
Specific gravity	1.12
Weight loss	0.5
Penetration after weight loss (mm)	86

3.4 Marshall Characteristics

According to the Indonesia National Standard (SNI 06-2489-1991), the six categories of tests constituting Marshall characteristics include stability, flow, Marshall quotient (MQ), Void in Mix (VIM), Void in Mineral Aggregate (VMA), and Void Filled Bitumen (VFB). These tests, including the Marshall empirical test, were created to examine a variety of in-situ behavioral characteristics of asphalt mixtures (Shell Bitumen Handbook, 2015). Among these tests, MQ, flow, and stability are examples of stability attributes. Specifically, MQ is used to draw a contrast between flow and stability, as shown in Figure 2. The three components of Marshall volumetric are VIM, VMA, and VFB. For the analysis, different asphalt mixture specimens were subjected to a Marshall volumetric test in accordance with SNI 06-2489-1991, as shown in Figure 3.

Tables 7, 8, and 9 show that Hot Bin I, Hot Bin II, Hot Bin III, and Hot Bin IV are the material compositions used. According to Indonesian road requirements, a hot bin serves as a designated storage area for hot aggregate, with each fraction occupying a separate space after passing through the heated filter.

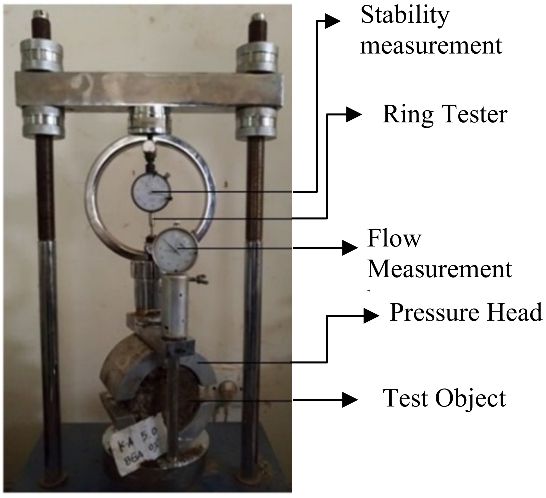


Fig.2 Marshall test stability equipment

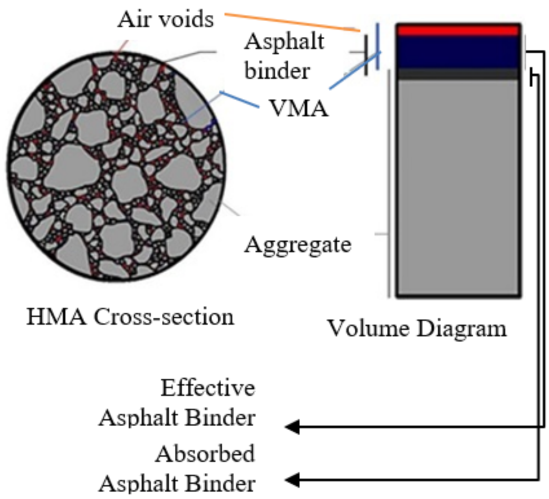


Fig.3 Volumetric properties

3.5 Asphalt Mixtures

In this study, three different kinds of asphalt mixtures were used, namely AC-WC, AC-BC, and Hot HRS-WC. The combined aggregate gradations of these mixtures are shown in Table 6.

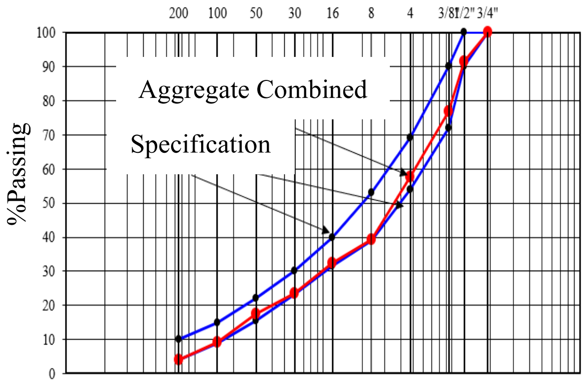
Table 6. Combined aggregate gradation of asphalt concrete

Sieve size (mm)	% of the weight passed to the total aggregate in the mixture								
	SS		HRS				AC		
			Gap gradation		Spring gap gradation				
	Class A	Class B	WC	Base	WC	Base	WC	BC	Base
37.5									100
25								100	90 - 100
19	100	100	100	100	100	100	100	90 - 100	76 - 90
12.5			90 - 100	90 - 100	87 - 100	90 - 100	90 - 100	75 - 90	60 - 78
9.5	90 - 100		75 - 85	65 - 90	55 - 88	55 - 70	77 - 90	66 - 82	52 - 71
4.75							53 - 69	46 - 64	35 - 54
2.36		75 - 100	50 – 72	35 - 55	50 – 62	32 - 44	33 - 53	30 - 49	23 - 41
1.18							21 - 40	18 - 38	13 - 30
0.600			35 - 60	15 - 35	20 – 45	15 - 35	14 - 30	12 - 28	10 - 22
0.300					15 – 35	5 - 35	9 - 22	7 - 20	6 - 15
0.150							6 - 15	5 -13	4 - 10
0.075	10 - 15	8 – 13	6 - 10	2 - 9	6 – 10	4 - 8	4 - 9	4 - 8	3 - 7

4. RESULT AND ANALYSIS

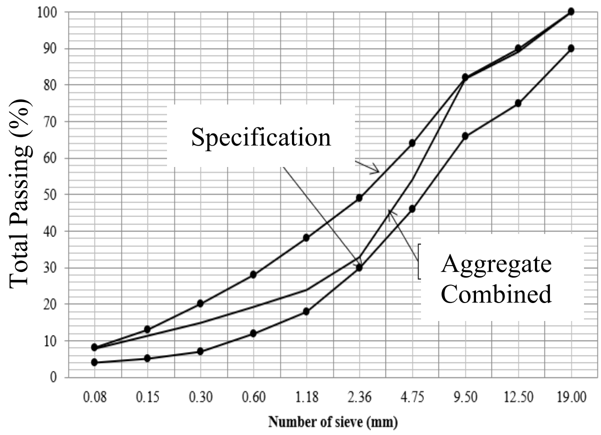
4.1 Combined Aggregate Gradation

Figures 4, 5, and 6 illustrate the aggregate gradation of the AC-WC, AC-BC, and HRS-WC combinations, revealing consistent patterns without any discernible changes. These representations provide a visual overview of the composition of each mixture, offering insights into the distribution of aggregate sizes within them. Meanwhile, in Tables 7, 8, and 9, the weights of the laboratory-prepared mixtures are documented, providing quantitative data corresponding to each combination. These tables offer a comprehensive summary of the experimental setup, facilitating further analysis and comparison of the asphalt mixtures' characteristics and properties.



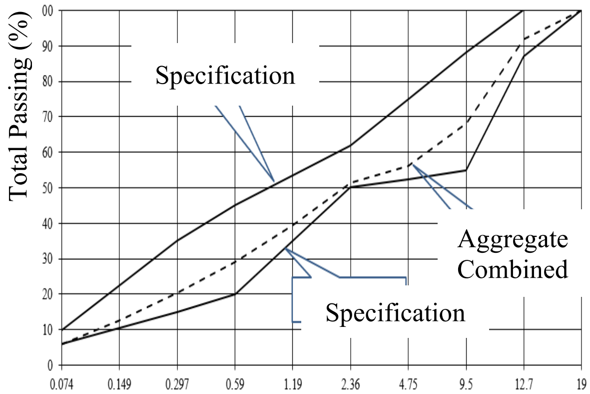
Number of Sieve (mm)

Fig. 4 Combined aggregate gradation of AC-WC mixture



Number of Sieve (mm)

Fig.5 Combined aggregate gradation of AC-BC mixture



Number of Sieve (mm)

Fig.6 Combined aggregate gradation of HRS-WC mixture

Table 7. Asphalt mixtures for 1,200 grams (AC-WC)

Materials	Materials size (mm)	Weight (gram)				
Hot Bin I	0 – 5	625.70	622.40	619.70	617.10	613.80
Hot Bin II	5 – 10	318.50	316.80	315.50	314.20	312.50
Hot Bin III	10 – 20	170.60	169.70	169.00	168.30	167.40
Hot Bin IV	20 – 30	0.00	0.00	0.00	0.00	0.00
Filler	Stone dust	22.80	22.60	22.50	22.40	22.30
Asphalt (%)	Modified Asbuton	4.5 54	5.0 60	5.5 66	6.0 72	6.5 78
Total		1200	1200	1200	1200	1200

Table 8. Asphalt mixtures for 1,200 grams (AC-BC)

Materials	Materials size (mm)	Weight (gram)				
Hot Bin I	0 – 5	573.00	570.00	567.00	564.00	561.00
Hot Bin II	5 – 10	343.80	342.00	340.20	338.40	336.60
Hot Bin III	10 – 20	194.82	193.80	192.78	191.76	190.74
Hot Bin IV	20 – 30	0.00	0.00	0.00	0.00	0.00
Filler	Stone dust	34.38	34.20	34.02	33.84	33.66
Asphalt (%)	Modified Asbuton	**4.5** 54	**5.0** 60	**5.5** 66	**6.0** 72	**6.5** 78
Total		1200	1200	1200	1200	1200

Table 9. Asphalt mixtures for 1,200 grams (HRS-WC)

Material	Material size (mm)	Berat (gram)				
Hot Bin I	0 – 5	486.71	484.16	481.61	479.06	476.51
Hot Bin II	5 – 10	229.20	228.00	226.80	225.60	224.40
Hot Bin III	10 – 20	194.82	193.80	192.78	191.76	190.74
Hot Bin IV	20 – 30	0,00	0,00	0,00	0,00	0,00
Fine aggregate	Sand	160.78	159.94	159.10	158.26	157.42
Filler	Stone dust	74.49	74.10	73.71	73.32	72.93
Asphalt (%)	Modified Asbuton	**4.5** 54	**5.0** 60	**5.5** 66	**6.0** 72	**6.5** 78
	Total	1200	1200	1200	1200	1200

The aggregate in this study is designated as Hot Bin I, Hot Bin II, Hot Bin III, and Hot Bin IV with material sizes of 0–5 mm, 5–10 mm, 10–20 mm, and 20–30 mm, respectively.

4.2 Determination of Optimum Asphalt Content Using Modified Asbuton

The analysis of establishing the ideal asphalt content of AC-WC, AC-BC, and HRS-WC mixtures using modified Asbuton as a binder is shown in Tables 10, 11, and 12, based on the Indonesia Highways requirement and SNI 06-2489-1991. The ideal bitumen content required in hot asphalt mixtures in modified Asbuton is 6.25% for an AC-WC mixture, according to the Marshall parameters (stability, flow, MQ, VIM, VMA, and VFB). Except for VIM readings, which only satisfy criteria at levels of 6.0% and 6.5% asphalt, all asphalt content complies with Marshall parameter specifications.

Tables 10-12 provide a grayscale representation, indicating the Marshall quality that meets the criteria. According to Table 10, asphalt content that satisfies requirements is 6.0% for the VIM parameter and 6.5% for others. Table 11 shows 5.5%, 6.0%, and 6.5% for Marshall VFB characteristics, while 5.5% and 6.0% are obtained for VIM. Marshall VFB characteristics in Table 12 show that the amounts of asphalt content 6.0%, 6.5%, 7.0%, and 7.5% satisfy the requirements. Flow characteristics, which satisfy the requirements, are asphalt content of 6.0%, 6.5%, and 7.0%, while VIM characteristics have values of 6.0%, 6.5%, and 7.0%.

All asphalt content used complied with Marshall parameter requirements, except for VIM and VFB values of 5.5%, 6.0%, and 6.5%, respectively. VIM requirements based on Indonesian National Standards are 3-5%, while a minimum of 65% is required for VFB. The ideal bitumen content needed in hot asphalt mixtures using modified Asbuton is 5.80% for an AC-BC mixture. According to the Marshall parameters, 6.50% bitumen is the ideal amount needed for hot asphalt mixtures using modified Asbuton.

The results show that all asphalt content complied with Marshall parameter requirements, except VIM and flow values, deviating at 5.0%, 5.5%, and 6.0%. Meanwhile, only 5.0%, 5.5%, 6.0%, and 6.5% of asphalt levels meet standards for VFB and MQ values. Since HRS-WC mixtures require a higher level of optimal asphalt compared to AC-WC and AC-BC, more gaps are found in gradation. These gaps gradation in HRS-WC can be used in areas where fine aggregate is required for truly gapped HRS-WC, at least 80% of the aggregate passing sieve No. 8 (2.36 mm) must also pass sieve No. 30 (0.600 mm).

The combination of modified Asbuton and aggregate filler creates weak spots within the mixture, which weakens bonding ability. This is due to the rearrangement of chemical components when modified Asbuton bitumen and minerals are combined to create mixtures as well as membrane layer covering aggregate. The presence of finer solid minerals (filler) of modified Asbuton filled gaps left by water in the various asphalt mixtures. Consequently, various asphalt mixtures including modified Asbuton, as indicated in Tables 10 through 12, have sufficient stability with resistance to deformation and strength to overcome the tensile stress.

Based on the results, the optimal asphalt concentration found in the AC-WC, AC-BC, and HRS-WC mixtures were 6.25%, 5.80%, and 6.50%, respectively. Compared to others, HRS-WC gradation has a higher percentage of passes on each filter and uses a gap gradation, as shown in Table 6.

Positive effects are observed from using modified Asbuton as a binder, which helps to lower the amount of petroleum bitumen used in AC-WC, AC-BC, and HRS-WC asphalt mixtures. This phenomenon occurs because modified asphalt is made by semi-extraction of Buton asphalt, resulting in BGA, which is combined in a certain ratio with petroleum bitumen.

The use of Buton asphalt as a binding material has been extensively investigated in previous studies, with BGA serving as a petroleum bitumen replacement. According to Tumpu M. et al. (a)., 2020 and Tumpu M. et al. (b)., 2020 [5, 7], when Lawele Granular Asphalt (LGA) is substituted for petroleum bitumen in the AC-WC mixture, the ideal asphalt content is 6.50%. Therefore, further investigation is required, focusing on a full or semi-extraction process when using granular LGA. This allows the minerals in LGA or BGA to separate from the bitumen, according to their formulas, as filler materials. The results indicate that asphalt mixtures may bleed when LGA or BGA is used after exposure to heat for an extended period due to the separation of bitumen and minerals in LGA or BGA. This phenomenon could lead to a higher-than-specified filler mineral content in asphalt mixtures.

A semi-extraction or full extraction procedure is carried out using LGA or BGA as a binder in asphalt mixtures to produce modified Asbuton. Practically, modified Asbuton is an imitation of how LGA or BGA is used in the market in a manner similar to petroleum bitumen. With several Buton Asphalt deposits across Indonesia currently underutilized, the addition of LGA or BGA could positively impact the asphalt output of the country [6] due to the variation in bitumen and mineral levels at each site. By creating a modified Asbuton product, it is feasible to conduct a full extraction, and when viable, a semi-extraction process is carried out to achieve uniformity.

Another study investigated the behavior of asphalt mixtures regarding cracks and grooves under tensile loading conditions. According to Birgisson B. et al. (2007) and Tayfur S., Ozen H., & Aksoy A. (2007) [3, 4], cracks and rutting that become tensile loads are common issues in asphalt mixtures. To address these issues, the use of modified Asbuton as a binding material offers a promising solution [11].

Table 10. Determination of optimum asphalt content of AC-WC mixture using modified Asbuton

Marshall Characteristics	Asphalt contents that meet specification (%)					
	5.0	5.5	6.0	6.5	7.0	7.5
Void in Mineral Aggregate (%) VMA) (min. 15%)						
Void Filled Bitumen (%) (VFB) (min. 65%)						
Void in Mix (%) (VIM) (3% – 5%)						
Stability (kg) (min. 800 kg)						
Flow (mm) (2 – 4)						
Marshall Quotient (kg/mm) (min. 250 kg/mm)						

Table 11. Determination of optimum asphalt content of AC-BC mixture using modified Asbuton

Marshall Characteristics	Asphalt contents that meet specification (%)				
	4.5	5.0	5.5	6.0	6.5
Void in Mineral Aggregate (%) (VMA) (min. 15%)					
Void Filled Bitumen (%) (VFB) (min. 65%)					
Void in Mix (%) (VIM) (3% – 5%)					
Stability (kg) (min.1000 kg)					
Flow (mm) (2 – 4 mm)					
Marshall Quotient (kg/mm) (min. 250 kg/mm)					

Table 12. Determination of optimum asphalt content of HRS-WC mixture using modified Asbuton

Marshall Characteristics	Asphalt contents that meet specification (%)				
	5.5	6.0	6.5	7.0	7.5
Void in Mineral Aggregate (%) (VMA) (min. 18%)					
Void Filled Bitumen (%) (VFB) (min. 63%)					
Void in Mix (%) (VIM) (4% – 6%)					
Stability (kg) (min. 800 kg)					
Flow (mm) (min. 3 mm)					
Marshall Quotient (kg/mm) (min. 250 kg/mm)					

The negative impacts of heavy loads on the road can be reduced by using modified Asbuton, which is an imitation of LGA or BGA obtained through a semi-extraction or extraction procedure [8, 9]. Various ingredients can be used to reduce as a binder, such as calcium hydroxide [16], pertalite as a modifier [13], anti-flaking additive [10], and cornice adhesive [17]. Although the performance of asphalt mixtures is improved by using these ingredients, maintenance of current condition without cracks and grooves from excessive loading will be difficult.

Israil, Tjaronge M.W., Ali N., and Djamaluddin R. (2016) [12] investigated an additional advantage of using a binder derived from the extraction of Buton asphalt. Full extraction of LGA or BGA and the creation of emulsified asphalt are among the outcomes achieved. The emulsified asphalt mixtures' performance satisfies the requirements set for cold asphalt mixtures. According to the results of Marshall characteristics test, semi-extraction or Buton asphalt extraction can be used in hot and cold asphalt mixtures with good performance.

Gaus A., Tjaronge M.W., Ali N., and Djamaluddin R. (2015) carried out an additional investigation, replacing the petroleum bitumen in the AC-BC combination with BGA. Compressive strength was measured on the resultant AC-BC mixture. The results showed that BGA enhanced the performance of the asphalt mixture but did not reduce rutting and grooves. Therefore, semi-extraction and Buton asphalt extraction outcomes are required to enhance asphalt mixtures performance and reduce the effects of grooves and rutting caused by excessive loading. In addition, national infrastructure development based on local materials and the environment can be attained by fully using the materials found on Buton Island, Indonesia. These results can be used to support the usage of modified Asbuton as a binder, which can help road pavement designers by concurrently predicting the ideal asphalt content value in the laboratory for AC-WC, AC-BC, and HRS-WC mixtures.

5. CONCLUSIONS

In conclusion, this study showed the effect of asphalt mixtures using modified Asbuton and Retona 55. The results showed that good cohesiveness between BGA and petroleum bitumen at the bead stage resulted in a significant correlation between bitumen and aggregate particles. The optimal asphalt content for AC-WC, AC-BC, and HRS-WC mixtures containing modified Asbuton was 6.25, 5.80, and 6.50%, respectively. These results provided valuable information to support the use of local materials, namely natural Buton asphalt in Indonesia. The implication of applying optimal asphalt content depends on providing insights into the optimal asphalt content for each type of asphalt mixtures using modified Asbuton as a binder.

6. ACKNOWLEDGMENTS

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