Bioasbuton as an Alternative Binder for Hot Mix Asphalt

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ABSTRACT
Hot mix asphalt (HMA) with buton granular asphalt has long been known in Indonesia with maximum use of 15%. With this dose, the use of binder asphalt Pen 60/70 is still needed. Bioasphalt is a fraction of bio-oil derived from biomass resulting from the pyrolysis process whose raw materials are coconut shells and straw. This study tries to determine whether the results of the pyrolysis of coconut shells (BioCS) and straw (BioST) can be categorized as bioasphalt. In addition, it also aims to analyze the potential of bioasbuton, namely a binder consisting of BioCS and bitumen of Asbuton B 50/30 (ASB) as a binder in the AC-WC HMA. From this study, it is known that the BioCS and BioST can be categorized as bioasphalt. The addition of bioasphalt to ASB bitumen can produce bioasbuton with different properties from the original asbuton. The addition of 6% BioCS or 8% BioST to ASB bitumen produces bioasbuton with relatively similar properties to Pen 60/70. The effect of BioCS on changes in rheological properties ASB bitumen is stronger than BioST. The use of bioasbuton made from 15% ASB (by weight of HMA) and 25% BioCS (by weight of ASB) can produce an AC-WC HMA which is equivalent to using pen 60/70. Bioasbuton can be used as an alternative binder to substitute the use of Pen 60/70 in HMA.

Keywords: *Bioasbuton, Binder, HMA, Bioasphalt*

1. INTRODUCTION

Buton granular asphalt (BGA) is one type of rock buton asphalt (asbuton) on the market and has been widely used both as an active filler asphalt modifier and as a binder asphalt. The type of BGA that can be used as a binder for hot mix asphalt (HMA) is B 50/30. To optimize the use of BGA as a binder for hot asphalt mixtures, petroleum asphalt is still needed in its utilization [1]. Although its use in HMA can reach a maximum of 10% of the weight of the mixture [2]. So that it can contribute about 3% of asphalt, the actual percentage of its use depends on the fulfillment of the desired HMA gradation.

Bioasphalt is a fraction of bio-oil derived from biomass obtained from the pyrolysis process (rapid heating of coral waste material without oxygen, as well as a carbonization process) coral waste such as leaves, twigs, and grass [3], waste agriculture or plantations containing lignin [4][5] or industry and livestock [6]. Several materials that have been used to produce bioasphalt include straw [7], pine wood [8], cooking oil [9], sawdust [10] and coconut shell [11]. According to Peralta et al. (2012), apart from being an anti-oxidant in asphalt, bioasphalt can also be used as a rejuvenator, modifier, asphalt substitute (partial replacement) or as a substitute for asphalt (full replacement) [12].

Based on the description above, in order to optimize the use of BGA and reduce the use of petroleum asphalt as well as to utilize coconut shell waste which is very large in Indonesia, this study aims to analyze the potential of bioasbuton, namely a binder consisting of bioasphalt coconut shell (BioCS) and bitumen of Asbuton B 50/ 30 [13], as a HMA binder.

2. METHODS

The materials used in this study are

- Asbuton B 50/30 (ASB)
- Bioasphalt produced by fast pyrolysis of coconut shell (BioCS) and straw (BioST) at temperatures. 300 °C and 350°C.
- Binder Asphalt Pen 60/70 as control asphalt (comparison).

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The method used in this study was only based on laboratory tests on two rheological properties of asphalt (penetration and softening point)[14][15], Fourier Transform Infrared (FTIR) spectroscopy, and asphalt morphology test using a Scanning Electron Microscop (SEM). These tests were carried out to determine the effect of adding bioasphalt to asb bitumen physically, chemically, and microscopically, as proof that bioasphalt is an asphalt bitumen based on the chemical structure of pure asphaltene, then to prove that bioasphalt can soften hard bitumen based on its physical, chemical structure and morphology. In addition, testing of the hot mix asphalt type with continuous graded wear (asphalt concrete wearing course, AC-WC) was also carried out with the aim of seeing the used of bioasbuton as a binder in hot asphalt mixtures (HMA). For the record, in addition to bioasbuton made from bioCS and bitumen of Asbuton B 50/30 which has been studied by Sihombing, 2021, this study also looks at the effect of bioasbuton from straw (bioST) on ASB bitumen [13].

3. RESULTS AND DISCUSSION

Before being mixed with asbuton B 50/30 extract, BioCS and BioST was first tested for chemical structure and the fractions contained therein to determine whether these two materials could be classified as asphalt. As a comparison, this test was also carried out on ASB bitumen and Pen 60/70. The results of these tests are as shown in Figure 1.

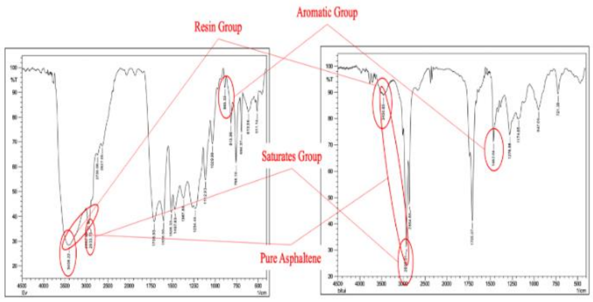


Figure 1. Chemical structure of bioasphalt coconut shell and straw.

From Figure 1, it can be seen that BioCS has a transmittance peak at 3408.22 cm^{-1} and 2933.73 cm^{-1}. The peak value of BioCS is almost the same as the peak of BioST, namely 3450.65 cm^{-1} and 2926.01 cm^{-1}. According to Bermudez et al. (2008) pure asphaltene transmittance peak values at 3433 cm^{-1} and 2920 cm^{-1}[16]. When the peak values are juxtaposed, it can be said that in BioCS and BioST there is pure asphaltene.

Referring to IR spectrum Table and Chart by Skoog et al., 1983 [17], and the compound functional groups table by Coates, 2006 [18], further analysis of the FTIR results as shown in Figure 1 shows that in both BioCS and

Table 1. Effect of bioasphalt on bitumen asbuton.

Sample	Bioasphalt (%)	Penetration (0,1 mm)	Softening Point (°C)	Penetration Index
BioCS	0	40	58.5	-3.8152
	4	44	58.0	-2.6473
	5	51	57.0	-0.7051
	6	63	53.5	1.8315
	8	76	48.5	3.6036
	16	145	42.5	9.5934
BioST	0	40	58.5	-3.8152
	4	41	54.5	-3.5427
	5	48	53.5	-1.5582
	6	52	52.0	-0.7401
	7	57	51.0	0.4602
	8	67	50.5	2.2672
	8,5	77	49.0	3.7768
	9	86	48.0	4.9886
	16	135	40.5	8.8806
Pen 60/70	-	65	48	

BioST there is an OH group (identified by the presence of a transmittance peak at 3308.22 cm^{-1}, 3450,65 cm^{-1}, and 3433 cm^{-1}). This shows that both bioasphalt contains resins groups in the form of alcohol and phenol. In addition, the presence of transmittance peaks that appear at waves 3051.33 cm^{-1}, 3080 cm^{-1}, and 3050 cm^{-1} indicates that in both bioasphalts there are also double-chain aromatic groups (=C-H). Other peaks that appear at waves 2933.73 cm^{-1}, 2926.01 cm^{-1}, and 2920 cm^{-1} indicate the presence of saturate groups in the form of CH_3 and CH_2 (aliphatic groups) in these two bioasphalts. From the description above, it can be concluded that BioCS and BioST are bioasphalts which not only contain pure asphaltene but also resins and saturates.

Furthermore, to see the effect of bioasphalt on ASB bitumen on rheological properties, chemical structure and morphology, penetration, softening point, FTIR and SEM tests were carried out on both BioCS-ASB and BioST-ASB, namely asphalt test specimens made by mixing ASB bitumen with BioCS and BioST, respectively, using the method as done by Williams et al., 2009 and raouf et.al., 2009, using a magnetic stirrer with hot plate stirring each samples with a rotation speed of 0.4 – 0.6 kr/sec at a temperature of 120 °C for 15 – 20 minutes [4][19]. The two bioasbutons were made with the percentage variation of bioasphalt (BioCS and BioST) to the weight of ASB bitumen by 2%, 4%, 6%, 8%, and 16%. Each test conducted in this experimental consisted of three test specimens for each condition and material. The results of the tests are as shown in Table 1 and Figures 2, 3, 4 and Figure 5.

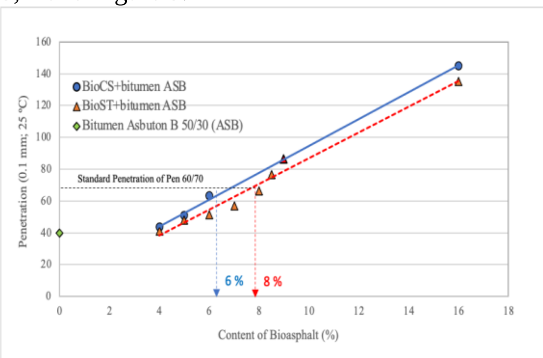


Figure 2. The effect of bioasphalt on penetration/ hardness of bitumen asbuton b 50/30.

If the addition of BioCS or BioST to ASB bitumen is intended to obtain asphalt with a hardness value and softening point equivalent to Pen 60/70, plotting the penetration value and softening point of pen 60/70 in Figure 2 and 3 to obtains the percentage addition of BioCS and BioST, by 6 % and 8% respectively. Then for a mixture of 6% bioCS + ASB bitumen called Bioasbuton A, and a mixture of 8% bioST + ASB bitumen called Bioasbuton B.

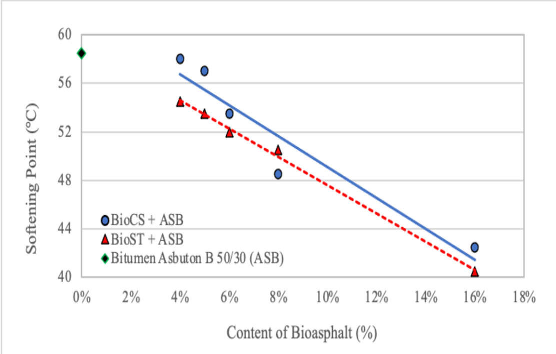


Figure 3. The effect of bioasphalt on softening point of bitumen asbuton b 50/30.

From Figure 2 and 3, it can be seen that the addition of BioCS or BioST can soften ASB bitumen and at the same time reduce the ASB bitumen softening point. In addition, it can reduce sensitivity to the temperature of the bioasbuton it produces. This is understandable because BioCS or BioST are bioasphalts that are rich in resin (remains in a liquid state at room temperature) so that the addition of bioasphalt will soften the bitumen hardness. Although the effect of adding BioCS or BioST on ASB bitumen has the same tendency, BioCS gives a relatively stronger effect.

From the FTIR tests carried out on pen 60/70, ASB bitumen, bioasbuton A and bioasbuton B, the results as shown in Figure 4 can be seen that all types of asphalt (each has 5 peaks). which occurred at medium absorption peaks at 3400 cm^{-1}, sharp absorption at 3000 – 2800 cm^{-1}, strong absorption peaks at 1500 – 1570 cm^{-1}, strong absorption peaks at 1690 – 1760 cm^{-1}, and strong absorption peaks at 690 – 900 cm^{-1}.

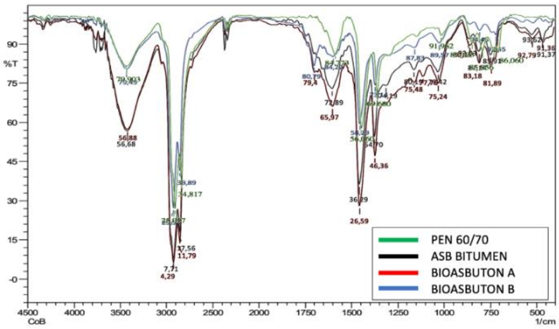


Figure 4. Chemical structure of asphalt pen 60/70, asb bitumen, bioasbuton a, and bioasbuton b FTIR test results.

Table 3. Asphalt aging index based on FTIR test results data.

Aging Index	Samples			
	Pen 60/70	ASB bitumen	Bioasbuton A	Bioasbuton B
Carboxylic ($I_{C=O}$)	0.00472	0.00809	0.00786	0.01048
Sulfoxide ($I_{S=O}$)	0.00944	0.01214	0.01048	0.00682

The moderate absorption peak at 3400 cm^{-1} that occurred in bioasbuton indicated the presence of aromatics with double bonds (=C-H), the peaks in this section were slightly widened, this happens because of the presence of an alcohol group (-OH) which indicates the presence of a resin component. At the absorption peak of 3000 – 2800 cm^{-1} indicates the presence of a saturates component which is dominated by the aliphatic alkane (C-C) structure, and the absorption peak is strong at 690 – 900 cm^{-1} indicates the presence of an ether group (C-O) and alkyl amine (C-N) which are the functional groups of resins. With the percentage of absorption getting smaller in both absorption regions containing saturates and resins, it means that the malthenes component in bioasbuton is increasing. The absorption value of bioasbuton A is getting smaller, in contrast to bioasbuton B itself, both of which have higher absorption values and are the same as that of pen 60/70.

According to Lamontagne et al. (2001.a and 2001.b) the results of the FTIR test can be used to identify aging on asphalt, by looking at the carboxylate index (Ic=o) and the sulfoxide index (Is=o)[20][21]. The index relevant to Ic is IR 1700 cm^{-1} in the range 1740 – 1690 cm^{-1} and Is is IR 1030 cm^{-1} in the range 1055 cm^{-1} – 1030 cm^{-1}. The quantitative analysis he proposes to calculate Ic and Is is given in Equations (1) and (2). The smaller Ic and Is, the fresher the asphalt.

$$I_{c=o} = \frac{Area\ of\ the\ carbonyl\ band\ around\ 1.700\ cm^{-1}}{Area\ of\ the\ spectral\ bands\ between\ 2.000\ and\ 600\ cm^{-1}} \quad (1)$$

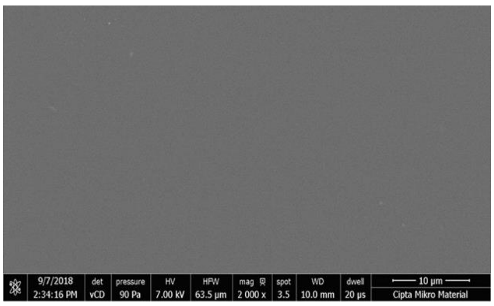
$$I_{s=o} = \frac{Area\ of\ the\ carbonyl\ band\ around\ 1.030\ cm^{-1}}{Area\ of\ the\ spectral\ bands\ between\ 2.000\ and\ 600\ cm^{-1}} \quad (2)$$

By using the two equations above, the aging analysis of pen 60/70, ASB, bioasbuton A, and bioasbuton B is given in Table 3. From this table it can be seen that by adding BioCS to ASB bitumen will reduce the Ic and Is of the bioasbuton it produces. As for the addition of BioST, although there was a decrease in Ic, it was followed by an increase in Is. This is an indication that BioCS can rejuvenate (soften) ASB bitumen. This indication is in line with the results of the asphalt hardness test as previously shown.

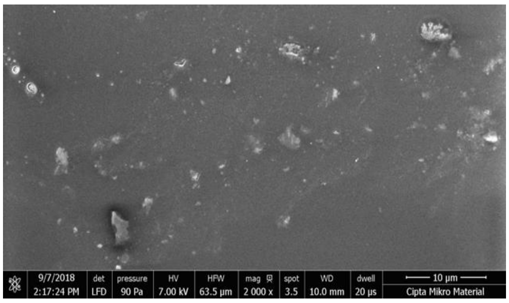
From the results of the SEM test on Pen 60/70, ASB bitumen, bioasbuton A and bioasbuton B as shown in Figure 5, it can be seen that the morphology of pen 60/70 (Figure 5.a) looks clean and homogeneous (Fig. the gray color is evenly distributed in all parts), while in ASB bitumen (Figure 5.b) there are white spots which indicate that the asphalt is harder or older. The white spot is also called the bee or the catana phase or the dispersion phase [22]. According to Rebelo et al., (2013), the greater the catana phase in the asphalt, it indicates the harder or older the asphalt is [23]. Based on this opinion, it can be said that ASB bitumen is older (harder) than Pen 60/70 asphalt. This is in line with the penetration value of the two asphalts as previously shown in Figure 2.

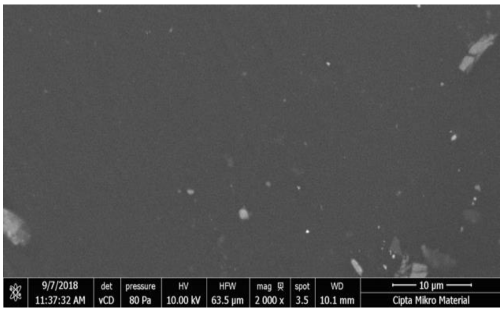
Figure 5.c shows the effect of adding BioCS to ASB bitumen. If Figure 5.b is compared with Figure 5.c, it can be seen that there is a change in the morphology of ASB bitumen due to the addition of BioCS, namely the reduction of white spots (catana phase) in bioasbuton A. In other words, it can be said that ASB bitumen becomes softer due to the addition of BioCS. The same results also occurred in the ASB bitumen sample added with BioST (Figure 5.d), it was seen that the morphology of bioasbuton B was gray without white spots, and was clean similar to the morphology of Pen 60/70.

From the description above, it can be said that the analysis of Ic and Is from the results of the FTIR bioasbuton A and bioasbutn B is in line with the morphological reality produced from the SEM results.



a. pen 60/70


b. ASB bitumen


c. Bioasbuton A

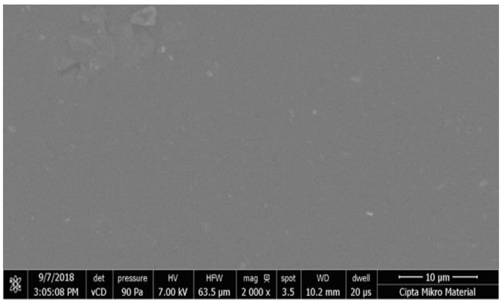

d. Bioasbuton B

Figure 5. Effect of addition of bioasphalt on morphology of bioasbuton (sem test results with 2000 x magnification).

To find out whether bioasphalt can replace the role or can only subsidize pen 60/70 as a binder in hot mix asphalt, Marshall test was carried out on HMA AC-WC specimens containing 15% asbuton B 50/30 and 6% BioCS by weight of ASB bitumen (as result from figure 2). To pursue variations in the total asphalt content in the mixture as much as 5% to 7% of the total weight of the HMA AC-WC, the difference in the target asphalt content was added with pen 60/70.

From the test results, it can be seen that the use of 15% asbuton B 50/30, 6% BioCS and Pen 60/70 (with varying amounts), produces HMA AC-WC as shown in Table 4. It can be seen that the AC-WC produced has a high strength which has a high stability value of 1212 kg, but has poor durability as indicated by a very high VIM value (around 11.2%) and a VFB (Void Field with Bitumen) which only reaches 49.8%. This means that the use of 6% BioCS cannot activate or remove Asbuton bitumen from its minerals. This may be because the light oil from BioCS is absorbed by the mineral ASB which in this case is ultra-alkaline lime.

Based on the above, to activate bitumen of 15% asbuton B 50/30, the percentage of use of BioCS is increased by 25% (weight of ASB) or 1.95% (weight of asphalt mixture). HMA AC-WC specimens were made with variations in asphalt content as in the previous experiment. With this composition, HMA AC-WC is produced with properties as shown in Table 4, it can be seen that with the addition of 25% BioCS, HMA AC-WC is produced which can meet the requirements with 0.5% asphalt content, which is smaller than HMA AC-WC with binder asphalt pen 60/70. Thus, it can be said that BioCS can be used as a substitute for Pen 60/70 for hot mix asphalt with Asbuton B 50/30.

Table 4. Characteristics of HMA AC-WC from bioasbuton and asphalt pen 60/70

Mixture characteristics	Mixture type		
	A	B	C
Optimum Binder Content, OBC (%)	6.3	-	5.85
Stability (kg)	1425	1212	1290
Flow (mm)	3.62	4.18	3.74
VIM (%)	3.7	11.2	4.2
VFB (%)	77.5	49.8	78.4
VMA (%)	16.6	22.3	17.5

HMA ACWC + Pen 60/70 without ASB as a control mixture
HMA ACWC + 15% B 50/30 + 6% BioCS + Pen 60/70
HMA ACWC + 15% B 50/30 + 25% BioCS + Pen 60/70

4. CONCLUSION

This study shows that bioasphalt from coconut shells (BioCS) and from straw (BioST) can be categorized as bioasphalt because it contains asphaltene, resin and saturate. The addition of bioasphalt, either BioCS or BioST to Asbuton B 50/30 can change the chemical and physical properties of asbuton bitumen. The addition of 6% BioCS or 8% BioST to ASB bitumen resulted in bioasbuton A and bioasbuton B with relatively similar properties to Pen 60/70. The influence of BioCS on changes in the rheological properties of asphalt is stronger than that of BioST. The use of bioasbuton made from 15% asbuton B 50/30 (towards the total weight of the mixture) and 25% BioCS by weight asbuton B 50/30 can produce HMA AC-WC that is equivalent to HMA AC-WC control (using pen 60/70). Bioasbuton can be used to substitute the use of Pen 60/70 in HMA AC-WC. This research is an initial study conducted to determine the use of bioasbuton in asphalt mixtures, which can be used as a reference for later conducting research on the use of bioasbuton in asphalt mixtures with variations in the amount and type of BGA, before conducting research at the direct trial stage in the field.

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