Civil and Environmental Research
ISSN 2222-1719 (Paper) ISSN 2222-2863 (Online)
Vol.3, No.3, 2013
www.iiste.org

Use of Buton Asphalt Additive on Moisture Damage Sensitivity and Rutting Performance of Asphalt Mixtures

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Abstract

Reducing the service life of the road pavement can be caused by weather effects in addition to increased traffic load. This study investigates the benefits of using Buton asphalt as a material additive. Buton asphalt additive by 20%, 25%, 30% and 40% is added to the bitumen pen 60/70 to get aspalt concrete wearing course (AC-WC) mixture. The evaluation has used the results of marshall standard, marshal immersion, indirect tensile strength and wheel tracking test at optimum bitumen content 5.9%. Wheel tracking test was performed on conditions at 30 ° C and 60 ° C of the 4000 cycle. The result in this study that, the addition of additives in the virgin asphalt has increased the softening point, lower the value of penetration, increased penetration index and lower ductility values. Hot-mix Buton Aspalt Modified (HMBAM) have shown an increase in resistance to deformation of 1.24 times compared to Hot-mix Asphalt (HMA). Tensile Strength Ratio (TSR) increased 2.6% more resistance to the effects of temperature. The addition of additive content of 25% is recommended in order to avoid reduction in ductility lower.

Keywords : Asphalt concrete, rutting performance, Buton asphalt, indirect tensile strength

1. Introduction

There are several methods of asphalt mixture design in various countries. In Indonesia, the Ministry of Public Works of the Republic of Indonesia (MOPW) has developed a specification for the design and construction of highways. One specification is a method of designing mixed-use Buton Asphalt as modified asphalt mixtures. Large rock asphalt deposits exist on Buton Island, South-East Sulawesi, Indonesia, and are referred to locally as Aspal Buton (ASBUTON). The use of ASBUTON in Indonesian road infrastructure development is increasing because the deposits are estimated to be 677 million tons while current annual production is only approximately 20,000 tons (Subagio et.al. 2003).

Damage to roads in Indonesia is caused many environmental impact, overload and based construction. Environmental factors are often difficult to predict such as rainfall and temperature changes in the road surface. Available asphalt from refinery is too soft for paving in high temperature areas in summer, and too brittle for a subzero temperature in winter in various parts of the country. The durability of asphalts is largely influenced by its chemical composition (Attaelmanan, 2011). Under this condition, MOPW has established an alternative method to improve the performance of the road pavement, such as to improve the performance of asphalt mixture by mixing additives in asphalt. Some asphalts, depending on crude oil source and refining practice are more temperature susceptible than others. Asphalt cement may be modified by the addition of components that increase the strength of the material or otherwise alter its properties (Al-Hadidy, 2009). The increase in temperature and traffic load has been believed to affect the properties asphalt concrete, such as rutting. Indonesia as a tropical country has problems of road damage in the form of rutting. It was found that environment temperature reduced the stability of the asphalt concrete considerably. Temperature increases both viscosity and ductility of asphalt cements (Ozga, 2011). To minimize the potential for rutting, certain key factors affecting rutting need to be identified so the design process could be optimized by modifying important factors (Apeagyei, et.al., 2011). Jitsangiam et.al (2013) has stated that the survey found that rutting is the major premature damage mechanism of Thailand's asphalt pavements, in addition to minor pavement damage through fatigue cracking. The cracking resistance of hot-mix asphalt (HMA) mixtures is directly related to the fatigue performance of flexible pavement (Shu et. al., 2008).

Completeness of the element of the road is one factor for the achievement of service life of road construction, such as form the road surface, drainage, and other. Damage may occur due to the presence of water on the road surface, which was not immediately able to flow out of the road surface. The pressure of vehicle wheels along with the presence of water on the road surface cause the stripping of the asphalt mixture. Stripping occurs when the bond between the asphalt and the aggregate is broken by water. The water may be sent on or in the aggregate because of incomplete drying or it may come from some other source after construction (Aksoy et.al., 2005). Performance of asphalt mixtures designed to withstand the effects of water, temperature and traffic load. The growth of high traffic loads can cause rutting deformation faster than expected in the road maintenance program. Asphalt mixtures with additives to improve the performance of asphalt mixtures to overcome these effects. It is known that different mix compositions of asphalt mixtures will give rise to different rutting resistance responses. It is also known that even when the mix composition remains unchanged, a change of the type of aggregate or binder would change the rutting characteristics of the asphalt mixture (Fwa et.al., 2004). Therefore, the development of a high modulus asphalt binder should be a key element for the successful implementation of the design concept of the long life asphalt pavement (Lee et. al., 2007).

The main objective of this study is to evaluate the effects of additives on performance of asphalt mixtures. Buton Asphalt additive added to the mix asphalt concrete wearing course (ACWC) at used the surface layer. Furthermore, we evaluated the influence of temperature susceptibility Hot-Mix Buton Asphalt Modified (HMBAM) and compared with the results of Hot-Mix Asphalt (HMA). Other performance evaluation consists of the value of resilient modulus and permanent deformation through each test the Indirect Tensile Strength and Wheel Tracking.

2. Materials and methods

2.1. Asphalt cement and aggregate

The coarse and fine aggregates used in the pavement for this experiment were crushed rock imported from Rumpin Bogor, West Java, Indonesia. The asphalt mixture used in this study was the Asphalt Concrete Wearing Course (AC-WC) defined by the Hot-Mix Asphalt Specifications by the MOPW (2008) and other relevant standards, including ASTM and AASHTO. The AC-WC gradation using the Fuller curve method has a maximum density with a void mineral aggregate (VMA) minimum (Fig. 1).

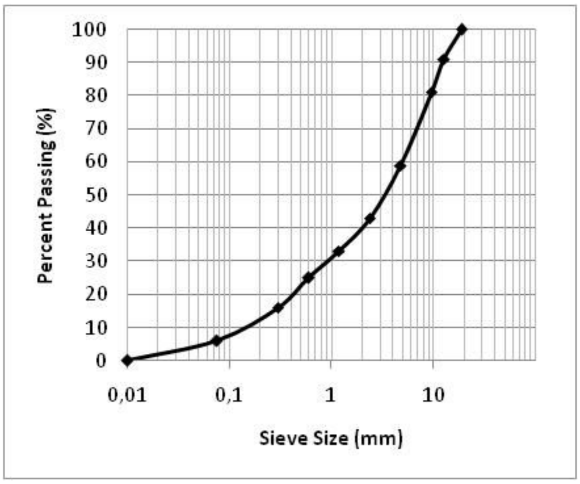

Figure 1. Aggregate gradation chart

The gradation of the aggregate is required between the control points and must be restricted to a zone located at the maximum density line (Fuller curve) between the intermediate sizes 2.36 mm (No.8) or 4.75 mm (No.4) and 300 microns (No.50). The results of these laboratory tests are given in Table 1. The AC-WC mixture gradation falls above the Fuller curve to provide more refined grain sizes and make mixing and compacting easier, but it has a relatively low resistance to deformation.

Table 1 Design gradation of aggregate

Sieve	Sieve (mm)	Passing (%)	Restriction area	Lower-upper limits
3/4 in	19.1	100	-	100
1/2 in	12.7	91	-	90-100
3/8 in	9.52	81	-	90
No. 4	4.76	59	-	-
No.8	2.36	43	39.1	28-58
No. 16	1.18	33	25.6-31.6	-
No. 30	0.6	25	19.1-23.1	-
No. 50	0.3	16	15.5	-
No. 200	0.075	6	-	4-10

The coarse aggregate properties evaluated with laboratory tests were aggregate impact value, aggregate crushing value, water absorption, specific gravity, impact and angularity. Only specific gravity was determined for the fine aggregates and filler (Table 2).

Type of asphalt that has been used in this study which is obtained from bitumen 60/70 PT Pertamina production. Test characteristics and properties of the asphalt has been done based on the requirements of standards and methods as shown in Table 3.

Table 2 Basic properties of aggregate

Aggregate Property	Method	Value		
		Coarse	Medium	Fine
Bulk specific gravity (Gsb)	AASHTO T84/T85	2.519	2.524	-
Surface saturated dry gravity (SSD)	AASHTO T84/T85	2.579	2.586	-
Apparent specific gravity (SG)	AASHTO T84/T85	2.681	2.690	-
Specific gravity	ASTM C-188-95	-	-	2.526
Falt and elongated particles, %	BS-812	6.84	-	-
Impact	SNI 03-4426-1997	8.37	-	-
Absorption, %	AASHTO T84/T85	0.95	2.48	-
Sand Equivalent, %	AASHTO T96	-	66.38	-
Los Angeles abration, %	AASHTO T96	18.82	-	-
Passing no. 200, %		-	-	6.26

Table 3 Physical properties of asphalt cement

Properties of the asphalt cement		Specification used
Penetration (25 °C, 100 g, 5 s, dmm)	67.75	ASTM D 5
Specific gravity	1,034	ASTM D 70
Softening point (°C)	51.5	ASTM D 36
Loss on heating (%)	0.034	ASTM D 6
Flash point (°C)	263	ASTM D 92
Ductility (25°C, 5 cm/min)	> 110	ASTM D 113

2.2. Rheological tests of Buton Rock Asphalt (BRA)

Buton Asphalt Modified (BAM) is a result of asphalt binder material mixing additive BRA with asphalt pen. 60/70 on the number and specific way. BRA is the result of rock asphalt refinery on the island of Buton, South Sulawesi, Indonesia as the name of production Buton Natural Aspal (BNA). BNA added in the form of materials with low penetration levels and contains minerals (Hadiwardoyo, 2011). BAM is made by adding BNA on virgin asphalt at a temperature of 170 °C. The process of mixing with stirring for 2-4 min at 170 °C constant temperature. BAM can be stored for ready use as needed.

The addition of BNA with asphalt pen. 60/70 has changed the value of penetration at standard temperature (25 °C). BAM penetration values will continue to decline with increasing addition of BNA content. On the other hand, the addition of BNA is to increase the softening point BAM although ductility values are likely to continue declining as shown in Table-4.

Table 4 showed that the addition of additive BNA percentage has increased softening point and lower penetration asphalt. On the other hand, index penetration modified binders have illustrated an increase from -0.207 to 0.35 on adding 40% additive BNA. Although the addition of BNA has proven additive percentage continue to increase penetration index value. But from Table 4 it can be seen that the ductility valuescontinue to decline, so it needs to be taken into consideration to establish the maximum percentage BNA additive.

Table 4 Basic rheological properties of BNA (Hadiwardoyo, 2013)

% BNA	Penetration (25 °C, 100 g, 5 s, dmm)	Ductility (25 °C, 5 cm/min)	Softening point (°C)	Penetration Index
0	67.8	110	51.5	-0.207
20	55.6	65.5	52.5	-0.340
25	53.0	64.0	53.7	-0.220
30	50.3	63.0	54.8	-0.070
40	39.4	54.0	59.5	0.350

2.3. Mixture design

2.3.1. Optimization of the mixtures

Determination of optimum bitumen content (OBC) in aggregate asphalt mixing process is done by marshall test (ASTM D-1559). For that purpose have been made 4 variations in bitumen content of the asphalt mixture using a pen. 60/70 (5%, 5.5%, 6% and 6.5%) of the total weight of the mixture. It has been established that the air void between 3% - 6% (applicable requirements in Indonesia) the amount of qualified bitumen is 5.9%. Optimum bitumen content is also used to set the Hot Mix Buton Asphalt Modified (HMBAM). Further specimens were used to marshall test, indirect tensile strength and wheel tracking on the same optimum bitumen content.

2.3.2. Preparation of Marshall, Indirect Tensile Strength and Wheel Tracking

All specimens used in this study using a mixture of asphalt concrete wearing course asphalt specification (AC-WC). Optimum bitumen content of 5.9% (by weight of the total mixture) obtained from the calculation of the asphalt concrete mixture using asphalt pen.60/70.

Preparation of samples for all the testing is done by mixing aggregate and asphalt modified as follows:

1. Aggregate coarse, medium and filler are heated and mixed at a temperature of 160 °C, the heating process is controlled by an electronic thermostat.
2. Asphalt modified with aggregate, each of which has been heated then mixed at a temperature of 160-170 °C for 2-4 minutes.
3. Preparation of the specimen at a temperature of 10 °C below the temperature of mixing using the electric compactor 75 times the load compaction (ASTM D 1559). Specimens removed from the mold and then allowed to stand in the open air for 24 hours, the rest of the plastic tightly closed when not used for testing.

There are 24 specimens for asphalt-aggregate mixture using additive BNA and 6 specimens for virgin asphalt pen 60/70 as a control.

From a number of such specimens, 12 specimens of which are used to test the standard marshall and marshall immersion. Specimens placed in water bath at 60 °C for 30 minutes and for 24 hours to test Marshall Immersion, and then the specimen is placed in the test apparatus expense ratios Marshall at 50.8 mm / min.

The rest, 12 specimens were used to test Indirect Tensile Strength 25 °C (ASTM D4123) at a temperature of 27 °C, this activity is carried out after the specimen is at the desired temperature constant for 30 minutes. There are 4 specimens for use on Wheel Tracking test 42 passes / min. Wheel load is placed in the middle of the specimens with 4.000 cycles at 30 °C and 60 °C. Contact pressure of 642 kPa and a total of 1.37 kN wheel load. Specimen produced with a mixture of asphalt as the marshall test and indirect tensile strength at the same air void and the optimum bitumen content 5.9%. The density of the specimens made using the mold wheel tracking test 300 x 300 x 50 mm compacted by a roller compacter to targeted air void.

3. Results and discussion

3.1. Temperature susceptibility

Characteristics of bitumen is strongly influenced by temperature changes. Huang (1993) has formulated bitumen susceptibility measurements of temperature, defined as follows:

$$A = [\log(\text{pen at } T) - \log 800]/(T - T_{R\&B}) \quad (1)$$

where T is the temperature at which the test (° C) and TR & B is the temperature of Ring and Ball softening point (° C).

Bitumen characteristics expressed in penetration index, PI, is expressed in:

$$PI = [(20 - 500A)/(1 + 50A)] \quad (2)$$

Figure 2 illustrates the relationship between the penetration index and the percentage of additive BNA. It can be seen that the addition of additive BNA has increased the penetration index value. The modified binders have increased susceptibility to the effects of temperature.

The addition of materials additives to the virgin asphalt have known that PI of BAM tends toward the value of PI positive.

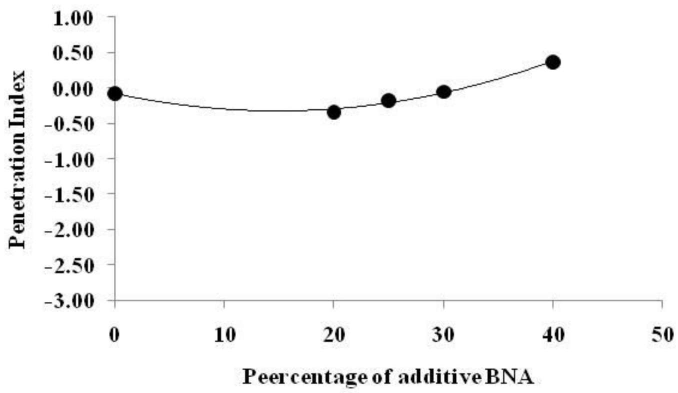

Figure. 2. Relationship between BNA content and penetration index

3.2. *Moisture susceptibility*

Marshall Immersion testing of mixed asphalt pen 60/70 and bitumen modification has been performed at Optimum Asphalt Content. Testing has shown indications of susceptibility or durability of the mixture to the effects of water and temperature changes. The dry and wet tensile strengths of virgine and modified asphalt were mesured, and test results are summarized in Table 5.

The resistance of asphalt mix to the detrimental moisture effect is expressed as tensile strength ratio (TSR). The TSR is defined as the tensile strength ratio of dry and wet specimens (Lee at.al, 2007). It is known that a higher TSR value indicates more resistant to moisture damage of asphalt mixture. As shown in Table 5, the TSR values obtained from all mixes are greater than 80% that satisfies the mix design specification. However, the TSR value of the modified asphalt mixtures (HMBAM) are greater than that of the conventional asphalt mix (HMA).

Table 5 Results of moisture susceptibility test

Mixture	Dry		Wet		TSR (%)
	Air void (%)	Strength (kPa)	Air void (%)	Strength (kPa)	
HMA	4.38	1,496	3.30	1,201	80.27
HMBAM	4.31	1,688	3.63	1,401	82.98

3.3. *Laboratory testing*

3.3.1. *Marshall test*

The relationship between modified asphalt properties and Marshall had plotted the optimum binder content (5.9% of the total weight of the mixture). The Table 6 shows the effect of modified asphalt in the Marshall stability, flow and air voids. The modified asphalt has decreased the flow by increases stability 12.8% in addition of BNA 25%. This is caused by the specific gravity modification asphalt smaller than the virgin asphalt. This condition serves to penetrate between particles and interlock perfectly aggregates, increasing stability and decreasing flow. Table 6 indicates that the composition of asphalt modification 25% BNA provide satisfactory results for air void 4.31%, this position ductility value stands at 64.

Table 6 Marshall results of modified asphalt mixes (HMBAM)

% BNA	Stability (kg)	Flow (mm)	Marshall quotient (kg/mm)	air void (%)
0	1,496	4.43	337.77	4.38
20	1,645	3.92	419.64	4.34
25	1,688	3.87	436.17	4.31
30	1,722	3.82	450.79	4.29
40	1,794	3.76	477.13	4.25

3.3.2. Indirect tensile strength test

Tensile strength for modified asphalt mixture is shown in Table 7. The results indicate that the resilient modulus and resilient modulus ratio increases. Tensile stress for asphalt modified slightly higher than the virgin asphalt mix. Al-Hadidy et.al (2009) noted that the increase in tensile stress indicates an increase in adhesion between aggregate and asphalt. In other words, the increase in tensile stress will decrease the value of asphalt stripping. It can be described that asphalt modification (HMBAM) can improve the resistence to moisture susceptibility of the asphalt mixtures.

Table 7 Summary of effects of additives on mixture properties for indirect tensile test

Property	Bulk specific gravity	Air voids	Force	Tot Recov Strain	Tensile Stress	Resilient Modulus
		(%)	(N)	(με)	(kPA)	(MPa)
Control (HMA)	1.496	4.38	3,000	76.97	295.60	4,153.15
HMBAM (25%)	1.105	4.31	3,000	58.68	289.37	5,506.00

3.3.3. Wheel tracking test

The wheel tracking test were conducted at the 30 °C and 60 °C of temperature to evaluate the permanent deformation characteristics of asphalt mixtures. Details on the wheel tracking test result are presented in Tabel 8.

Table 8. Results of wheel tracking test

		HMA		HMBAM	
		30°C	60°C	30°C	60°C
Rut depth (mm)	mm	2.90	4.59	2.34	3.52
Number of load application	cycles	3,780	3,780	3,780	3,780
Load level	kN	1.37	1.37	1.37	1.37
Dynamic stability	N/mm	3,937	1,675	5,833	2,441

Figure 3 shows a comparison of rut depth with a number of cyclic loading for virgin asphalt and bitumen modification. Asphalt mixture HMA has demonstrated ruth dept 2.90 mm approximately 4,000 cycles.

On the other hand, the maximum ruth dept for modification of asphalt mix HMBAM 2.34 mm in temperature 30 °C. At a temperature of 60 ° C has been increased by 58% ruth depth on HMA and 50% in HMBAM. From the curve it appears that the increase is smaller than the virgin asphalt mix. It can be concluded that the asphalt modification has the potential to decrease the permanent deformation. When the gradation of the aggregate in the asphalt mixture is the same, the increase in resistance is due to the use of modified asphalt.

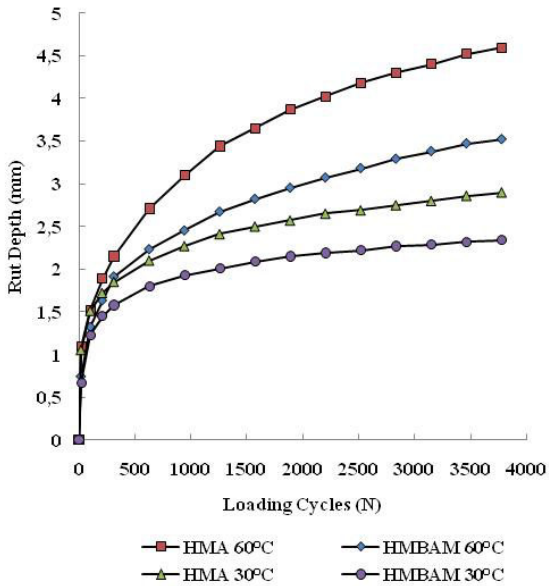

Figure. 3. Cumulative rut depths with number of load applications

4. Conclusions

This study was conducted to investigate the moisture susceptibility in asphalt mixtures. Based on the results from the study, the following conclusions can be summarized:

- The results of moisture susceptibility test show that the resistance to damage from HMBAM 2.6% better than a conventional asphalt mixture. It appears that the TSR HMBAM have a higher value. The wheel tracking test results indicate that the resistance to permanent deformation HMBAM is 1.24 times higher than conventional asphalt mixtures. It can be concluded that HMBAM can be considered as a material for better performance to overcome the effects of temperature.
- The value of penetration at 25 °C decrease with increasing content of BNA this fact indicates that the improvement shear resistance at high temperatures. On the other hand there has been a decline in the value of ductility. Therefore, the addition of BNA should be limited.
- Softening point tends to increase with the addition of BNA content, which indicated improvement in resistance to deformation, and penetration index value indicates that HMBAM reduce temperature susceptibility of asphalt mixture.
- The results presented in this article as preliminary findings, further study needed to evaluate the fatigue performance of HMBAM.

Acknowledgements

The authors gratefully appreciate to the technician Structure and Materials Laboratory Department of Civil Engineering Universitas Indonesia.

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