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Performance of Asphalt Mixture with Asbuton Based on Marshall Characteristics Compacted at Hot and Cold Temperatures

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Abstract: The use of natural asphalt is an alternative to meet the high demand for oil asphalt. Asbuton is natural asphalt from Buton Island, Indonesia. However, the use of Asbuton is not as easy as oil asphalt because the asphalt it contains is hard. The asphalt-concrete mixture must go through a rejuvenation process for several days before being compacted. This study aims to determine the performance of asphalt-concrete mixture using Asbuton if it is compacted immediately after mixing, without giving time for the rejuvenation process. Compaction is done when the mixture is hot and after the mixture is cold. Compaction of the asphalt-concrete mixture in hot temperature (150°C), based on mechanical characteristics (stability, flow, and Marshall Quotient), has better performance than that compacted in cold temperature (30°C). However, compaction in both hot and cold temperatures, based on their volumetric characteristics, does not meet the requirements for use as road pavements. The performance of the asphalt mixture can be improved by giving time in the process of softening the asphalt content in Asbuton.

Keywords: hot compacted; cold compacted; asphalt concrete; Asbuton

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Introduction

The current national road infrastructure development requires asphalt up to 1.6 million tons/year (Sumiati et al., 2018). The limited availability of oil asphalt as a binder for road pavement layers requires innovation to find other alternative binders. One alternative is the use of natural asphalt. Buton Island in Southeast Sulawesi is one of the producers of natural asphalt in Indonesia (Lapian et al., 2021). According to its origin, it is called Aspal Buton, abbreviated Asbuton. Asbuton resources in Buton Regency are estimated at 746.9 million tons (Yamin & Faizal, 2012). The amount is sufficient for the needs of road construction in Indonesia.

Compared to oil asphalt, Asbuton in the asphalt-concrete mixture can increase the durability of road infrastructure because it has a higher softening point. Higher nitrogen compounds and lower paraffin compounds than oil asphalt cause Asbuton to have better adhesion (Sumiati et al., 2018). The use of Asbuton for asphalt mixtures can improve: 1) Marshall stability and dynamics so that it is resistant to loads; 2) high fatigue, meaning longer construction life; 3) resistant to temperature changes; 4) High modulus value (Ardhian et al., 2016).

However, the use of Asbuton has not been able to compete in terms of quality. A certain treatment is needed so that the binder of Asbuton becomes soft, namely by mixing rejuvenating and ripening materials (leaving the asphalt mixture for a certain time before it is compacted). With a view to giving the rejuvenating agent time in the process of softening the Asbuton binder. The curing time does not match the quality

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improvement (Sarwono et al., 2017). The longer the curing is done, the better the performance of the asphalt concrete mix with Asbuton based on the Marshall test (Mulyono, 1996).

The mixing and compaction process is the main factor that determines the performance of the asphalt-concrete mixture and the quality of the material. The quality of the asphalt concrete mix pavement is strongly influenced by the mixing temperature (Delgadillo & Bahia, 2008) and compaction (Mohamed & Boulbibane, 2011) (Setiawan et al., 2016). Compaction should be carried out at a temperature of 155^{O}C (Kementerian PUPR; Ditjen Bina Marga, 2018). However, due to the conditions and location of the work, this is not always possible. These conditions, among others, the distance from the asphalt mixing plant (AMP) to remote locations takes a long time, making it difficult to maintain the temperature. (Hou, 2012). The preparation of the mixture in limited quantities and the urgent need for maintenance are also reasons for cold compaction.

In addition, the use of materials such as natural asphalt takes time to increase its binding capacity because the asphalt content in hard natural asphalt will soften after adding a modifier, with a certain time. So the mixture needs to be allowed to stand before compacting.

The use of Asbuton in asphalt mixtures for road pavements has an impact on the need for storage areas. It is necessary to find a post-mixing compaction method to perform well by making two treatments related to the compaction time. Namely hot compaction (temperature 150^{O}C) and cold compaction (temperature 30^{O}C). Furthermore, the performance of the asphalt concrete mix with natural asphalt (Asbuton) without curing the two treatments was compared. So it can be recommended whether the mixture can be spread and compacted directly in hot or cold conditions without giving the rejuvenating agent a chance to rejuvenate the asphalt in Asbuton.

Method

Research method

The research was conducted on a laboratory scale to obtain quantitative data, the data obtained from testing samples made from the same material, with different treatments. In the first treatment, the sample is compacted in hot temperatures immediately after complete asphalt mixing. The samples were compacted at cold temperatures 24 hours after the material mixing process in the second treatment. Samples were made from a mixture of asphalt with the same composition, material, and temperature for the first and second treatments.

Material

Materials used to make samples: (1) Aggregate: coarse aggregate, fine aggregate, and filler; (2) Asbuton (natural asphalt from Buton Island, Indonesia); (3) Modifiers: bunker oil (15%), kerosene (22%) and asphalt (63%). Asbuton used is type 5/20. This means Asbuton with a penetration of 5 mm and an asphalt content of 20% (Setiawan, 2011). The materials used can be seen in Figure 1.

(a) Agregat (b) Asbuton (c) Modifier

Figure 1. Asphalt mixture material

Mixed composition

Aggregate used is 70.5%, Asbuton 25% and modifier 4.5%. So the asphalt mixture content is 7.8% (from Asbuton = 25%x20%=5%; from modifier = 4.5%x63%=2.8%). According to requirements between 6% to 8% (Kementerian PUPR; Ditjen Bina Marga, 2013). The composition of coarse aggregate, fine aggregate, and filler is different for each treatment. See Table 1.

Table 1: Composition of coarse aggregate, fine aggregate, and filler

Item	Compaction treatment	Coarse aggregate (%)	Fine aggregate (%)	Filler (%)
1	Hot compacted	38.0	57.0	5.0
2	Cold compacted	48.2	45.2	6.6

Sample production

The sample was made referring to the hot asphalt mixture test using the Marshall Method (Puslitbang Teknologi Prasaranan Jalan Bandung Departemen Pemukiman dan Pengembangan Wilayah, 2003). The material is mixed by heating at a temperature of 155^{O}C. After that, it was compacted with two treatments using a standard Marshall test compactor with 75 collisions for heavy traffic. Compaction is carried out in two conditions (treatments), namely:

1) Directly compacted after asphalt mixing is complete, at a temperature of 150^{O}C.
2) Left for 24 hours at room temperature, then solidified at 30^{O}C.

The sample in the two conditions (treatment) is shown in Figure 2.

(a) Hot compacted (b) Cold compacted

Figure 2. Samples compacted at hot and cold temperatures.

Sample testing

The sample test followed the asphalt mixture testing procedure using the Marshall method (Puslitbang Teknologi Prasarana Jalan Bandung Departemen Pemukiman dan Pengembangan Wilayah, 2003). In the test, the performance data of the asphalt mixture was sought with two treatments according to the sample made. These data are used to find the volumetric and mechanical performance of asphalt mixtures. Volumetric performance includes: Void in the Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA), and mechanical performance of asphalt mixture, namely Stability, Flow and Marshall Quotient (MQ).

Mixed characteristic data analysis

Data analysis to find the performance of asphalt mixtures based on test results data, including:

a) Volumetric analysis using the following equations (Harnaeni & Kirnawan, 2013) :
   - Void in the Mix (VIM)
     $VIM = 100 + \frac{Gmm-Gmb}{Gmm}$ .... (1)
   - Void in Mineral Aggregate (VMA)
     $VMA = 100 - \frac{Gmb-Ps}{Gsb}$ .... (2)
   - Void Filled with Asphalt (VFA)
     $VFA = 100\ \frac{VMA-VIM}{VMA}$ .... (3)

   with:

   Gmm = Maximum density of uncompacted asphalt concrete (without pores/air)
   Gmb = Bulk density of solid asphalt concrete
   Ps = Aggregate content, % by weight of solid asphalt concrete.

The requirements for volumetric characteristics of asphalt mixtures for road pavement materials for hot compaction are VIM between 3% to 5%, minimum VMA 15%, and minimum VFA 65%(Kementerian PUPR; Ditjen Bina Marga, 2018). Meanwhile, cold compaction of VIM is between 4% to 10%, minimum VMA is 16%, and minimum VFA is 60% (Kementerian PUPR; Ditjen Bina Marga, 2013).

b) Mechanical analysis using the following equations (Suhelmi et al., 2019):
   - Stability (MS), in kg
     $MS = s\ x\ k\ x\ kb$ .... (4)
   - Flow (MF), in mm
     $MF = \frac{f}{100}$ .... (5)
   - Marshall Quotientt (MQ), in kg/mm
     $MQ = \frac{MS}{MF}$ .... (6)

   with:

   s = The reading of the stability value on the proving ring dial
   k = Marshall tool calibration value
   kb = Correction number of test object
   f = Reading the flow value on the proving ring dial

The requirements for the mechanical characteristics of asphalt mixtures for road pavement materials are stability of at least 800 kg, flow between 2 mm - 4 mm, and Marshall Quotient of at least 250 kg/mm (Kementerian PUPR; Ditjen Bina Marga, 2018). Meanwhile, the minimum requirements for cold compaction are 500 kg stability and flow between 3 mm - 5 mm (Kementerian PUPR; Ditjen Bina Marga, 2013).

Result and Discussion

Results and analysis

The results of measuring the volumetric characteristics of asphalt-concrete mixtures using Asbuton, with two treatments (hot and cold compacted) are shown in Table 2.

Table 2. Results of sample volumetric measurements

(a) Hot compacted

Sample code	Sample height (cm)	Weight (gram)		
		In air	In water	Saturated surface dry
P.1/0	6.8	1,164.6	655.0	1,191.3
P.2/0	6.6	1,154.5	655.0	1,192.7
P.3/0	6.8	1,165.3	645.0	1,193.1
P.4/0	6.9	1,162.2	648.0	1,193.1
P.5/0	6.8	1,161.5	644.0	1,193.1

(b) Cold compacted

Sample code	Sample height (cm)	Weight (gram)		
		In air	In water	Saturated surface dry
D.1/0	7.3	1,121.5	556.0	1,132.4
D.2/0	7.4	1,126.1	557.0	1,138.4
D.3/0	7.4	1,135.1	571.0	1,144.1
D.4/0	7.3	1,133.7	568.0	1,140.8
D.5/0	7.3	1,125.5	566.0	1,133.8

Density of coarse aggregate (Gb1) = 2.55 gr/cm^3
Density of fine aggregate (Gb2) = 2.51 gr/cm^3
Filler density (Gb3) = 2.51 gr/cm^3
So that:
Aggregate bulk density (Gsb) = 2.53 gr/cm^3
Aggregate effective density (Gsb) = 2.62 gr/cm^3
The maximum density of the mixture (Gmm) = 2.38 gr/cm^3

The bulk density of asphalt mixture (Gmb) for sample P.1/0 is weight in air/ (surface dry weight-weight in water) = 1,164.6/ (1,191.33-655) = 2.17 gr/cm^3. The results of subsequent calculations and analysis of their volumetric values (VIM, VMA and VFB) in percent (with equations 1-3) are shown in Table 3.

Table 3: Results of volumetric analysis of asphalt mixture

(a) Hot compacted

Sample code	Gmb	VMA	VIM	VFB
P.1/0	2.17	18.73	8.64	53.90
P.2/0	2.15	19.65	9.66	50.80
P.3/0	2.13	20.43	10.55	48.37
P.4/0	2.13	20.21	10.30	49.04
P.5/0	2.12	20.83	11.00	47.20

(b) Cold compacted

Sample code	Gmb	VMA	VIM	VFB
D.1/0	1.95	27.29	18.24	33.18
D.2/0	1.94	27.62	18.61	32.64
D.3/0	1.98	25.99	16.77	35.47
D.4/0	1.98	26.04	16.83	35.37
D.5/0	1.98	25.93	16.70	35.58

The mechanical characteristics of the mixture were obtained by testing the Marshall method. The test results of asphalt mixture samples using Asbuton, with two treatments (hot and cold compacted), are shown in Table 4.

Tabel 4: Stability and flow measurement results

(a) Hot compacted

Sample code	Sample height (cm)	Diameter of the sample (cm)	Flow indicator reading	Stability indicator reading
P.1/0	6.8	10	300	124
P.2/0	6.6	10	310	136
P.3/0	6.8	10	315	148
P.4/0	6.9	10	325	154
P.5/0	6.8	10	325	161

(b) Cold compacted

Sample code	Sample height (cm)	Diameter of the sample (cm)	Flow indicator reading	Stability indicator reading
D.1/0	7.3	10	390	28
D.2/0	7.4	10	416	31
D.3/0	7.4	10	450	33
D.4/0	7.3	10	490	32
D.5/0	7.3	10	530	34

Based on the data in Table 4, using equations 4, 5, and 6, it is obtained that the mechanical characteristics of the mixture include stability, flow, and MQ.
Example calculation for the sample with code P.1/0.
Height of the test object (sample) = 6.8 cm
Diameter of test object = 10 cm
Tool calibration (k) = 22,001
Stability indicator reading (s) = 124
Flow indicator reading (f) = 300
Correction rate (kb) = 0.92
So that:

- Stability values (with formula 4) are :
  $MS = s\ x\ k\ x\ kb$ = 124x22.001x0.92=2,508 kg
- Flow value (with formula 5) is:
  $MF = \frac{f}{100} = \frac{300}{100} = 3$ mm
- MQ value (with formula 6) is:
  MQ = $\frac{MS}{MF}$= 2508/3 =836

Calculation of stability, flow, and MQ for the other samples was carried out in the same way as sample P.1/10. More details can be seen in Table 5.

Table 5: Stability and flow analysis results

(a) Hot compacted

Sample code	Correction rate (kb)	Stability indicator reading (s)	Stability (MS)	Flow (MF)	Marshall Quotientt (MQ)
P.1/0	0.92	124	2,508	3.0	836
P.2/0	0.94	136	2,798	3.1	903
P.3/0	0.87	148	2,834	3.2	900
P.4/0	0.87	154	2,931	3.3	902
P.5/0	0.89	161	3,139	3.3	966

(b) Cold compacted

Sample code	Correction rate (kb)	Stability indicator reading (s)	Stability (MS)	Flow (MF)	Marshall Quotientt (MQ)
D.1/0	0.81	28	498	3.9	128
D.2/0	0.80	31	543	4.2	131
D.3/0	0.80	33	578	4.5	128
D.4/0	0.81	32	567	4.9	116
D.5/0	0.81	34	604	5.3	114

Discussion

Comparison of VIM, VMA, and VFA values, asphalt concrete mix using Asbuton with hot and cold compaction, see Figures 3 – 5.

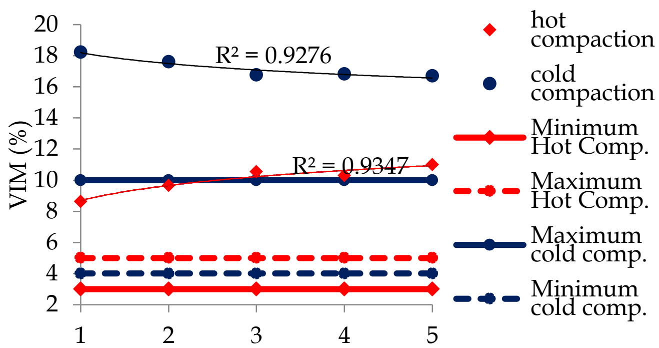

Figure 3. VIM value of asphalt concrete mix with Asbuton in two compaction conditions

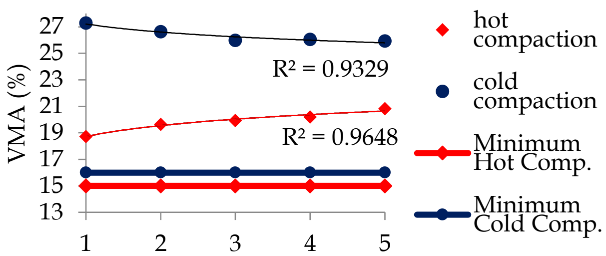

Figure 4. VMA value of asphalt concrete mix with Asbuton in two compaction conditions

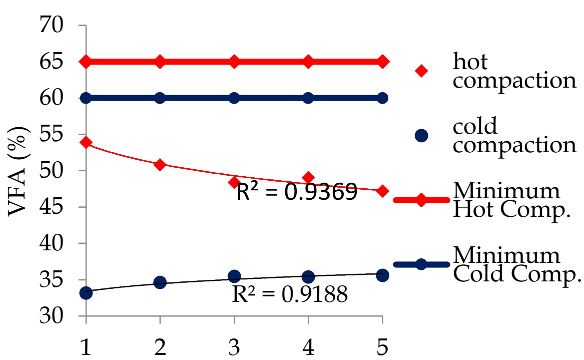

Figure 5. VFA value of asphalt concrete mix with Asbuton in two compaction conditions

The voids formed in the asphalt mixture (VIM) exceed those required for the pavement. This is because the asphalt in Asbuton is still in the process of softening, so it cannot fill the voids between aggregates (VMA). Because without the curing process, the modifier cannot maximally soften the asphalt in Asbuton, so that only asphalt that enters the VMA comes from the modifier. This condition causes the asphalt mixture content to be low because only a small portion of the asphalt serves as a binder. Asphalt content is too low, causing the mixture to be stiff, so it is difficult to achieve the specified density (Zaltuom, 2018).

This shows that the performance of asphalt-concrete mixtures based on volumetric characteristics is not optimal. Thus, it is not recommended to use without a curing process until the asphalt in Asbuton is soft. Because the hard asphalt content in Asbuton does not yet have adhesive properties, it cannot cover the aggregate and fill the voids between aggregates. Comparison of stability, flow, and Marshall Quotient values, asphalt concrete mix using Asbuton with hot and cold compaction, see Figures 6 – 8.

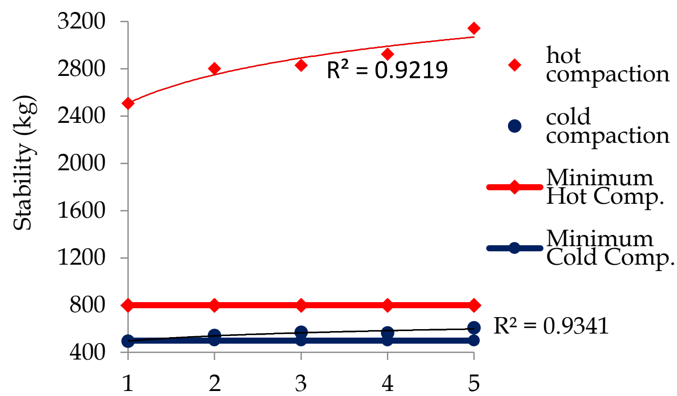

Figure 6. Stability value of asphalt concrete mix with Asbuton in two compaction conditions

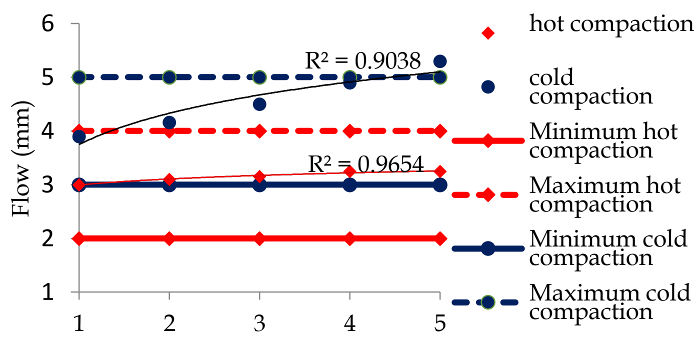

Figure 7. Flow value of asphalt concrete mix with Asbuton in two compaction conditions

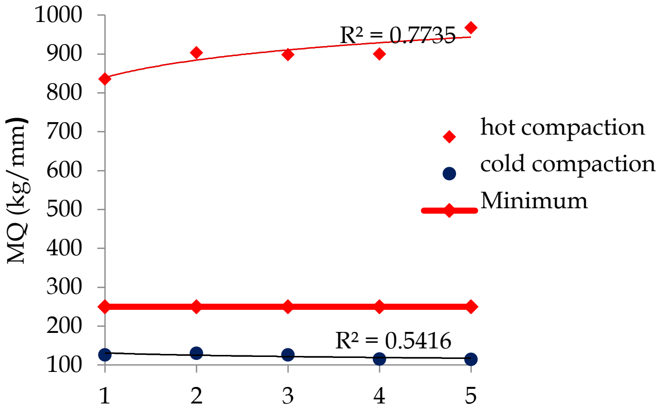

Figure 8. MQ value of asphalt concrete mix with Asbuton in two compaction conditions

In hot compaction, mechanical properties are met, high stability, flow in good intervals, MQ above 250 indicates an elastic mixture. Although Asbuton's asphalt content has not softened maximally, the mixture is elastic because the asphalt is still soft at hot temperatures.

Based on the mechanical characteristics, the asphalt mixture with Asbuton meets the requirements if it is compacted under hot conditions (150^{O}C). However, it is not fulfilled if it is carried out by cold compaction, especially at flow and MQ. Stability is met on average (>500 kg). High flow is caused by large voids in the mixture (VIM), due to asphalt not entering the voids (cannot coat the aggregate properly), so the mixture is stiff. This causes the bond between the aggregates to be weak.

Conclusion

Based on the mechanical properties (stability, flow, and MQ), asphalt mixture using Asbuton with rejuvenation which was compacted at a hot temperature (150^{O}C), had a better performance than that compacted at a cold temperature (30^{O}C). However, from a volumetric point of view, hot and cold compaction do not meet the requirements for use. It is necessary to cure the asphalt-concrete mixture at a certain time so that the asphalt softening process contained in Asbuton is achieved optimally to improve performance.

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