Impact Curing Time and Compaction Methods to the Performance of Hot Mix Asphalt Asbuton

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Abstract Asbuton is rock asphalt located on Buton Island, Indonesia. The contained asphalt is hard, produces very high viscosities, making it very difficult to facilitate uniform coating of aggregates and to bind asphalt mixtures. These challenges in the process of incorporating Asbuton in asphalt mixtures makes it less popular than the petroleum asphalt. The current Indonesia standards require Hot Mix Asphalt incorporating Asbuton (HMAA) to be cured for a few days before it is compacted (scenario 1). The curing duration is aimed to allow softening of the natural asphalt contained in Asbuton. This study investigated a new method of conditioning HMAA (scenario 2). The results showed that the volumetric and Marshall characteristics of HMAA were influenced by the curing time and compaction methods. The findings suggest that the curing method proposed in scenario 2 can be omitted, as such it can speed up the asphalting process. This study found that HMAA can be spread and compacted without curing, with a provision made for the road to be closed from traffic for a minimum of eight days after the compaction is complete.

Keywords Asbuton, compaction, curing time, Marshall stability, volumetric characteristics, rock asphalt

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1. Introduction

The asphalt mixture's composition is dominated by aggregate and asphalt. Therefore, efforts are made to obtain cheaper materials, so that production costs can be reduced. Some of them are the use of reclaimed asphalt pavement (RAP) mixed with shredded plastic waste (SWP) in a warm stone matrix asphalt (SMA) mixture. The resistance to cracking of SMA can be increased by the use of RAP and SWP of up to 12% [1]. The application of fly ash as an artificial aggregate [2], [3], has the potential as a partial substitute for natural aggregate [4], with skid resistance that meets the requirements of roads in urban areas with traffic speeds below 95 km/hour [5]. And, the use of rock asphalt containing aggregates and asphalt.

In Buton Island, Indonesia, there is naturally occurring asphalt, in the form of rock asphalt, containing 61.7% ash content, 2% moisture content, and 27% asphalt content [6], [7] called Asbuton. The high content of Asbuton deposits on Buton Island is in Lawele, Kabungka, Waisnu, Wariti, and Epe. It was noted that the highest Asbuton content was found in Lawele and Kabungka [8]. It is estimated that there are about 670 million tons of Asbuton deposits on Buton Island. The deposits are found in limestone formations with natural asphalt residues between 15% and 35% of asphalt by weight [9]. Asphalt and aggregates contained in rock asphalt, including Asbuton, have the potential to solve material problems for asphalt mixtures in the world, especially in countries with limited availability.

Resistance to deformation is a factor that needs to be considered in the design of road pavement construction. Deformation causes a decrease in the strength of the road surface layer due to repeated wheel loads and increases in road surface temperature [10]. The increase in temperature causes the bonding ability between asphalt and aggregate to decrease due to the asphalt softening [11]. Deformation can be anticipated by material engineering and asphalt mixing and compaction methods. For example, the technique uses Asbuton material with hot and cold compaction methods. The use of Asbuton is not as popular as the use of petroleum asphalt due to the complex processes for extraction and/or utilization of the natural asphalt. Expertise in the adhesive properties of asphalt can assist in producing more durable asphalt pavements [12]. The natural asphalt in Asbuton is hard, having very low penetration properties and very high viscosity. In order to facilitate mixing and binding with aggregates in asphalt mixtures, viscosity of the natural asphalt should be reduced. In the process of reducing viscosity, a rejuvenator is used so that the asphalt has suitable characteristics as a binder in the asphalt mixture [13]. This process is known as "rejuvenation" [14]. A mixture using Asbuton and petroleum asphalt is mixed with granular Asbuton that has been extracted, resulting in better performance [15]. Compared to conventional asphalt mixtures, hot mix using asphalt modification of Asbuton has better resistance to damage based on its moisture sensitivity [16]. However, its use requires a complicated process to allow softening of the natural asphalt to take place before compaction and asphalting can begin. The asphalt softening process by rejuvenation is done by storing loose coated asphalt mixtures in stockpiles, a lengthy process with takes several days [17].

Application in the field causes problems in stockpiling during the curing period. It is necessary to limit the pile height to avoid densification of the loose asphalt mixture at the bottom of the pile. Therefore, the process requires a large storage surface space. The maximum water content of the mixture is 0.1% by weight of Asbuton grains [18], requiring an elevation of the stockpile area to avoid inundation. This requires additional labor, if the stacking is done on the side of the road to be paved, and can also disrupt traffic. Therefore, another scenario is needed to ensure a more effective and efficient implementation method.

A new hypothesis has been considered to assess the impact from curing time and compaction method in the laboratory. Two scenarios were subsequently considered, namely: Scenario 1) Cold compaction, and Scenario 2) Hot compaction. Information about the time required for the rejuvenator to soften the asphalt in Asbuton [7], [17] was obtained in both scenarios (cold and hot compaction).

Scenario 1) Cold compaction: The treatment scenario in the laboratory was adjusted to reproduce the implementation plan in the field. As stated previously, a loose coated HMAA mixture would be cured for a few days before being spread and compacted at the site. This is the current method commonly used but creates problems related to allocating storage space (land) for curing. In the laboratory, specimens were prepared by compacting HMAA in cold conditions (ambient temperature). Before compaction, the HMAA was cured for several days. After curing for several days, the HMAA was compacted at ambient temperature and tested. This is intended so that Asbuton asphalt can be softened with a rejuvenating agent, so that it is characterized as a binder in asphalt mixtures. Furthermore, the asphalt mixture can be leveled and compacted at cold temperatures [19]. The Buton Granular Asphalt Mineral (Asbuton) grading method for the design of cold mix asphalt is widely used in Indonesia [20].

Scenario 2) Hot compaction: HMAA specimens were prepared and compacted in hot conditions, which is similar to that of conventional HMA. In this approach, the loose coated HMAA is immediately compacted (without curing). This is based on the finding that Marshall stability and compaction volumetric properties are affected by the compaction temperature of the asphalt mixture [21]. The decrease in air voids in the mixture occurs when the compaction temperature is increased. Alternately, a lower compaction temperature results in a decrease in the adhesion between aggregates due to an increase in asphalt viscosity [22]. The compacted HMAA specimens were subsequently conditioned over time before testing was carried out. The approach of immediately spreading and compacting fresh loose coated HMAA at the job site has not been done before. In this new approach, after compaction is complete, traffic closures must be carried out for several days until optimal asphalt mix performance is achieved. In this new approach, after compaction is complete, traffic closures must be carried out for several days until optimal asphalt mix performance is achieved.

This study aims to provide an alternative method of carrying out road pavement work using Asbuton. The results of this research can be used as a reference in the implementation of road pavement work using Asbuton related to curing time and compaction method. The primary goal was to develop a shorter processing time of HMAA without compromising the performance of the road pavement. Thus, the methodology adopted for this study: (1) the relationship of curing time to the density of the Asbuton mixture compacted under hot and cold conditions was explored.; (2) Then the relationship of curing time to the volumetric and Marshall characteristics of the Asbuton mixture compacted under hot and cold conditions was also investigated; (3) Finally, the impact from curing time on HMAA performance was evaluated; (4) Furthermore, a recommendation of compaction methods and curing time was proposed for the implementation of HMAA for road surface pavement layers.

2. Materials and Methods

2.1. Experimental Design

The research was conducted on Marshall test objects (specimen). Manufacture of specimen began with material preparation, mixing and compaction in the mold. At the preparation stage, it began with testing the mixed materials, then preparing the required amount based on the composition of the mix design. The specimen compaction process was carried out in two scenarios. Scenario 1 (cold compaction) with the process in Figure 1, and Scenario 2 (hot compaction) with the process as shown in Figure 2.

Figure 1. Preparation and testing of specimens under scenario 1 (compacting after curing)

Figure 2. Preparation and testing of specimens under scenario 2 (curing after compaction)

2.2. Material

HMAA mixture consisted of 1) Aggregates (coarse aggregate, fine aggregate, filler); 2) Asbuton; and 3) Rejuvenator additive (petroleum asphalt, kerosene, and bunker oil). The Asbuton and aggregates used are shown in Figure 3. The rejuvenator additive is shown in Figure 4.

Figure 3. Coarse aggregate, fine aggregate, filler and Asbuton

Figure 4. Rejuvenator Material

Grading of the combined aggregates used in each scenario were previously tested and reported. The rejuvenating additive comprised 63% petroleum asphalt (penetration 60/70), 22% kerosene, and 15% bunker oil [17], and having a liquid state at room temperature.

2.3. Mixing the HMAA specimens

Sampling began with the preparation of the materials according to their composition. One test object used 1,200 grams of mixture, so the amount of each material was 846 grams (70.5%) aggregate, 300 grams (25%) Asbuton, and 54 grams (4.5%) rejuvenator [17]. So that the asphalt content in the mixture is 7.91%, namely from Asbuton = 25% x 20.31% = 5.07% and from rejuvenator = 63% x 4.5% = 2.84%. Asbuton and aggregate were initially heated at a temperature of 165 °C and subsequently, rejuvenator was added and stirred until the loose coated HMAA mixture was homogeneous.

The specimen compaction process was carried out as per the two scenarios described in the hypothesis. Scenario 1 (cold compaction): following completion of mixing, the HMAA mixture is left for a certain time at an ambient temperature of 25-30 °C. Compaction of the cold HMAA specimens was carried out at different curing times. Five specimens were compacted immediately (without curing) whilst the other five specimens were compacted after curing at ambient temperature for 4, 8, and 12 days, then tested. These specimens were subsequently subjected to volumetric and mechanical testing (see Figure 1, illustrating the process for Scenario 1).

Scenario 2 (hot compaction): following completion of mixing, the loose coated HMAA mixture was immediately compacted at 155 °C. After compaction, these specimens were subjected to different curing times. Five specimens were immediately tested and the remaining five specimens each were tested after curing for 4, 8, and 12 days. The tests carried out were the same as those in Scenario 1, as illustrated in Figure 2.

2.4. Specimen testing and data analysis

The assessment of volumetric properties consisted of void in mix (VIM), void in mineral aggregate (VMA), and void in filled with bitumen (VFB). The data for calculating volumetric and density characteristics were: dry weight of the specimen (Ma), saturated surface dry (Mssd) and in water (Mw), diameter (d) and height (h) of the specimen. Other data were bulk specific gravity of the aggregate (Gsb), the maximum specific gravity of asphalt mixtures (Gmm), and the bulk specific gravity of compacted specimens (Gmb) and percentage (by mass) of aggregate in the total mixture (Ps) [23]–[25]. Calculation of the value of density (D) [26], VIM, VMA and VFB, can use equations 1-4 [17].

- $D = \frac{4\,\mathrm{Ma}}{\pi d^2 h}$ (1)
- $\mathrm{VIM} = 100\left(\frac{\mathrm{Gmm\ x\ Gmb}}{\mathrm{Gmm}}\right)$ (2)
- $\mathrm{VMA} = 100 - \frac{\mathrm{Gmb\ x\ Ps}}{\mathrm{Gsb}}$ (3)
- $\mathrm{VFB} = \frac{100\,(\mathrm{VMA - VIM})}{\mathrm{VMA}}$ (4)

Meanwhile, the data for the determination of Marshall characteristics are: 1) Reading of the stability value on the proving ring dial (s), 2) Marshall calibration value (k); The test object correction number (kb) and the reading of the flow value on the proving ring dial (f). Calculation of the value of stability, flow and Marshall Quotient, using equations 5-7 [17].

- Stability (MS), in kg

  $MS = s\ \ x\ \ k\ \ x\ \ kb$ (5)
- Flow (MF), in mm

  $MF = \frac{f}{100}$ (6)

- Marshall Quotient (MQ), in kg/mm

$$MQ = \frac{MS}{MF} \quad (7)$$

3. Results and Discussion

3.1. Gradation and aggregate test results

The properties of the aggregates used are shown in Table 1. The mixing gradation of Scenario 1 (cold compaction) and Scenario 2 (hot compaction) with the limitation of using gradation sizes (top and bottom) according to specifications [18] is shown in Figures 5-6.

Table 1. Aggregate properties for Asbuton mixture

Test	Requirement [16]	Coarse	Fine	Filler
Specific gravity	Min. 2.5			
Saturated surface dry density	Min. 2.5			
Apparent density	Min. 2.5			
Absorption (%)	Max. 3.0			
Aggregate adhesiveness to bitumen (%)	Min. 95			
Impact Wear (%)	≤ 30			

Figure 5. Gradation of aggregate scenario 1

Figure 6. Gradation of aggregate scenario 2

3.2. Type of Asbuton used and test results

Buton Granular Asphalt (BGA) with grain size smaller than 1.18 mm is categorized into several types, namely: type 5/20, 15/20, 15/25, and 20/25. The first number indicates the hardness (penetration) and the second number indicates the bitumen content. The Asbuton used was Type B 5/20. Asbuton characteristics based on testing are shown in Table 2. The added petroleum asphalt (penetration 60/70) has properties as shown in Table 3.

Table 2. Properties of Asbuton B 5/20

No.	Test type	Requirement [16]	Test result
1	Bitumen content		
2	Grain size		
	Pass sieve No. 4 (6.35mm) Pass sieve No. 8 (2.38mm) Passed sieve No.16 (1.19 mm) Passed sieve No.30 (0.59 mm)		
3	Water content		
4	Penetration at 25°C, 5 sec, 0.1 mm		9.4

Table 3. Properties of asphalt penetration 60/70

No.	Test Type	Specification [16]	Test Result
1	Penetration 25°C (0.1 mm)		
2	Softening point (°C)		
3	Flash point (°C)		

4	Ductility on 25°C (cm)
5	Specific gravity
6	Weight loss (%)
7	Penetration 25°C, after losing the original weight (%)
8	Ductility on 25°C, after weight loss (cm)

3.3. HMAA and curing specimen

The treatment conditions for the two scenarios are shown in Figure 7. Figure 7 a) shows the HMAA mixture being cured before being transferred to the compaction mold. While Figure 7 b) is the curing of the compacted HMAA specimens.

a) Loose coated HMAA b) Compacted HMAA

Figure 7. Asbuton mixture and specimens in the curing process

3.4. HMAA density

Figure 8 (The relationship between specimen density and curing time), shows that Scenario 1 (cold compaction) has a lower density than Scenario 2 (hot compaction). This shows that compaction is better if it is carried out when the temperature of the mixture is still high. The increase in curing time showed that the density of the mixture increased up to eight days, thereafter, there was no visible change.

The density of specimens with cold compaction (Scenario 1) did not seem to have changed much with time. This indicates very slow increase in density gains and the need for longer curing time before compaction. It is expected that a mixture that has a higher density value will be able to withstand a greater load, as compared to a mixture that has a lower density [27]. Density value affects Marshall stability and volumetric properties of the asphalt mixture [26].

Figure 8. Specimen density based on curing time

3.5. Asbuton mixture volumetric properties

In cold compaction (Scenario 1) and hot compaction (Scenario 2), the VMA value decreases. The longer the curing, the higher the softening of the Asbuton, which can facilitate filling of the voids. This means that the VMA cavity filled with asphalt, (FVB) increases, according to Figure 9. However, after day eight of Scenario 2, the VMA value did not change much. This may indicate that the Asbuton softening process had stopped.

In VIM the same phenomenon occurred, namely the longer the curing time, the smaller the VIM value, due to the softer Asbuton.

In VIM, the same phenomenon also occurred, namely the longer the curing time, the softer the asphalt in Asbuton. This resulted in more voids filled with asphalt, so the VIM value tends to decrease [28]. Asphalt fills the VMA due to a thickening of the asphalt film from softened Asbuton. Thus, the mixture becomes tight. This occurred in Scenarios 1 and 2, except after day eight for Scenario 2 when the VIM value did not seem to have changed much.

VMA and VIM values were higher in Scenario 1 specimens than those in Scenario 2 specimens. This shows that compaction at high temperatures facilitates superior densification, leading to smaller voids because the asphalt binder viscosity was lower. Nonetheless, Scenario 1 shows that extended curing can improve the performance of the mixture in terms of voids, both VMA and VIM. This means that the longer the mixture is cured prior to compaction, the better the densification of the mixture, leading to smaller voids formed. This is an effect of the asphalt content in the mixture. Compaction of the mixture becomes easy when the asphalt content is high, so the air voids are low. On the other hand, it is difficult to compact if the asphalt content is too low because the mixture is solid [29]. The relationship between the voids formed in the HMAA and the curing time is shown in Figure 9.

Figure 9. Relationship of voids with curing time

Based on the void properties of the test results in Figure 9, for Scenario 1 (cold compaction) and Scenario 2 (hot compaction), it can be determined the length of curing time with mixed performance meets the requirements in Table 4.

Table 4. Volumetric properties of test results based on curing time

In Table 4 it can be seen that in cold compaction (Scenario 1), the preservation of the mixture before compaction as a specimen is only fulfilled for the VMA properties, for all curing times. However, the VIM formed is too large, probably because the asphalt binder has not fully coated the aggregate and filled the VMA, leading to the low VFB value. Meanwhile, with hot compaction (Scenario 2), treatment after compaction, all properties were met on the 8th and the 12th days. Whereas, VMA is fulfilled for all curing times. This means that the compacted mixture can be opened to carry the traffic load from day eight, after compaction.

3.6. Marshall properties of the Asbuton mixture

Marshall properties of Asbuton mixture (stability, flow and MQ), calculated by equations 4-6, based on specimen test data. The properties of asphalt mixtures depend on the role of asphalt as a binder, in addition to aggregate as its main component. For mixture incorporating Asbuton, curing is necessary to allow softening of asphalt in Asbuton, causing it to actively coat and bind to the aggregate.

In Scenario 1 (cold compaction), it was found that the longer the curing time, the higher the stability. A different trend occurred in Scenario 2 (hot compaction), the stability values seemed to reach values above 2,400 kg since day 0. The stability values of Scenario 2 specimens were significantly (more than 10 times) higher than those of Scenario 1 specimens. The stability value is related to the binding force to resist the movement between aggregate grains when loaded with traffic [30].

Figure 10 shows that the flow values of Scenario 2 specimens are higher than those of Scenario 1 specimens. Higher flow value could be associated with poorer deformation resistance. Nonetheless, all specimens met the specification requirements for flow value.

The value of MQ depends on the value of stability and flow. When the MQ value increases, it indicates that the mixture is stiffening, on the contrary if the MQ value decreases, it indicates that the mixture is softening. The trend in MQ value changes with curing time and follows the same trend as that of stability value. The hoped for mix characteristics can be achieved through good compaction, thereby increasing the material's ability to distribute traffic loads more effectively. Compaction can increase the stiffness of asphalt concrete, so that it is met with high strength, durability, resistance to deformation, resistance to moisture damage, water resistance, and high skid resistance [26]. The results of the HMAA performance data analysis based on the results of the Marshall test, are shown in Figure 10.

Figure 10. HMAA performance based on curing time

Based on the mechanical properties of the test results in Figure 10, for Scenario 1 and Scenario 2, it can be determined the recommended length of curing time based on the mixture performance parameters shown in Table 5.

Table 5. Marshall Properties based on test results and curing time

Table 5 shows that in cold compaction (Scenario 1), the stability and flow properties were met for all curing times. However, the MQ property is not met, so it is not eligible for use. Meanwhile, with hot compaction (Scenario 2), the results of the specimen test show that the mixture of road pavement can be used (meets the requirements) as a road pavement surface layer.

3.7. Asbuton mixed performance based on two curing scenarios

Scenario 1: Cold compaction

Analysis of the data based on the results of testing the volumetric properties and mechanical properties showed that the curing of the asphalt mixture before compaction and the specimen from the compaction of the mixture affected the performance of the Asbuton mixture. The properties of the mixture with pre-compacting treatment did not meet the requirements for road pavement materials, namely VIM, VFB, and Marshall Quotient. It was found that the high VIM value and low VFB value were caused by rejuvenation which was not able to soften the hard asphalt contained in Asbuton until the 12th day of curing. Asphalt that is still hard is difficult to enter the mixed voids, resulting in the voids in the mixture enlarging.

Marshall Quotient (MQ) value is an indicator of mixed flexibility value. The value of MQ is used as an estimate of the level of stiffness of the mixture which is strongly influenced by the value of stability and flow. The MQ value in this study did not meet the mixed requirements for road materials because the stability value was low, and the flow value was high. The low stability value is due to the Asbuton mineral grains tendency to not to be cubical, hence having a significant effect on the interfacial adhesion of the aggregate by asphalt. However, the presence of short-term aging is conducive to improving asphalt adhesion [31].

Scenario 2: Hot compaction

The curing time of the specimen after compaction has a very strong relationship with the volumetric characteristics consisting of VMA, VIM, and VFB. The recommended minimum curing time is eight days after compaction. This recommended curing time was based on the volumetric characteristic specifications VMA, VIM, and VFB.

The curing time after compaction also has a very strong relationship with the mechanical properties (Marshall) of the mixture. From the results of this study, the best mechanical characteristics (stability, flow and MQ) were detected immediately (since day 0) after compaction.

Fig. 11 Analysis of properties as surface layer of AC-WC: a) cold compaction, b) hot compaction

Figure 11 shows the positions and values of the eligible properties. Figure 11(a) shows that the characteristics that are met are only VMA, stability and flow. This shows that with curing up to 12 days, the performance has not been met, so it cannot be implemented at the job site (requires longer curing). While in Figure 11(b) it can be seen that the performance is fully fulfilled by curing 8 to 12 days. This means, if implemented in the field, the road should be closed at least eight days after compaction so that the performance of the mixture is optimal. This condition is caused by the effectiveness of asphalt rejuvenation in Asbuton. The strength of the bond between asphalt and aggregate is strongly influenced by the asphalt source [32]. Efforts to improve the performance of the mixture can be done by using anti-stripping materials, which affect the cohesive energy and adhesion, so as to increase stability [33].

4. Conclusion

The curing process for the asphalt rejuvenation (softening) process in Asbuton can increase the density. Where, the density increases with the addition of curing time for hot Asbuton mixture starting on the 4th day, and tends to decrease on the 12th day. Meanwhile, for cold compaction, the tendency is increasing.

In Scenario 1, for all curing time variations, only the VMA volumetric characteristics (>15%) were met. However, VIM (outside the 4%-10% interval) and VFB (<60%), so the requirements were not met.

In Scenario 2, the VMA value (>15%) was met for the entire curing time, but the VIM (requirement 3.5%-5.5%) and VFB (requirement >65%) were only met on the 8th and 12th curing days.

The recommendation for implementation in the field is to follow Scenario 2 which is to compact the HMAA immediately after mixing, but with a provision to close traffic for the first eight days to allow for stabilization of the new road surface.

While the recommendation for further research is the treatment of materials and mixtures to be able to carry out scenario 2 so that the post-compacting road closure is less than 8 days.

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