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Effect of buton's granular asphalt gradation on marshall stability of cold emulsified asphalt mixtures under wet condition

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Abstract. This study aims to compare the performance of Cold Mix Asphalt with Buton's Granular Asphalt taking into account gradation of BGA and gradation of BGA Mineral in a combined gradation under wet condition. The specimens were made with optimum bitumen content of 8%, water content of 5%, and Buton's Granular Asphalt content of 6-13.5%. Marshall Stability testing refers to National Standard of Indonesia number 06-2489-1991. The maximal Marshall Stability of CEAM under wet condition which takes into account gradation of BGA in combined gradation is obtained at BGA content of 11.75%. The maximal Marshall Stability of CEAM under wet condition which takes into account gradation of BGAM in combined gradation is obtained at BGA content of 11%. The Marshall stability of CEAM taking into account BGA gradation in combined gradation were higher of 3-14% than which takes into account the gradation of BGA Mineral. Therefore, design gradation of Cold Mix Asphalt using Buton's Granular Asphalt which be recommended in The Construction and Building Guideline, Public Work Department of Republic of Indonesia of 2006, should be revised to take into account gradation of BGA in combined gradation.

1. Introduction

Technology of Cold Emulsified Asphalt Mixtures (CEAM) substantially supports sustainable development strategy initiated by Nation United [1]. The utilization of Cold Asphalt technology has dramatically grown in the worldwide. Compared to Hot Mix Asphalt, The advantages of CEAM are less negative impact on environment and low cost production. CEAM uses safer energy and reduces emission. This technology is suitable to be applied in tropical climates due to the presence of sunlight which can accelerate the evaporation process and increase the strength of CEAM at the initial service life. CEAM is usually designed to support light traffic load. CEAM can be produced using simple equipment. CEAM is also very suitable for small-scale road maintenance. However, the road construction that uses it has disadvantages, among others: the length of the evaporation process, the strength of the initial age, and the high porosity [2,3]. CEAM has inadequate performance and is prone to damage at the initial service life due to rainfall [4].

Some studies used natural asphalt product in asphalt mixture. The results of studies showed that this asphalt product could improve the mechanical performance of the mixture [5-8]. Indonesia has huge reserves of natural asphalt located in Buton Island-Southeast Sulawesi Province. Generally, the types of Buton natural asphalt product in the market include Refine Buton Asphalt (Retona) and Buton Granular



Asphalt (BGA). The natural asphalt has a potential of 677 million tons. It is estimated to be equivalent to 150 million tonnes of Petroleum Asphalt. (Hermawan K.F, et.al, 2015)[9].

The benefits of Baton Natural Asphalt product such as increasing elastic modulus, increasing unconfined compressive strength, resistance to rutting (increased dynamic stability), reducing bleeding problems, and having sufficient flexibility. The disadvantages of high BGA content are high disaggregation and more brittle [5-7]. Meanwhile, a study of Buton natural asphalt product in the form of emulsion asphalt carried out by Israil et al. (2016) showed that CEAM using Buton emulsion asphalt had good mechanical performance [8].

Referring to the Construction and Building Guidelines Number 001-05/BM/2006 which be issued by Directorate General of Highways, Department of Public Works, Republic of Indonesia (DGH-DPWRI), it states that a combined gradation of CEAM takes into account gradation of Buton's Granular Asphalt Mineral (BGA Mineral) [2]. Based on its physical characteristics, BGA has distribution of grain size as granular material. Therefore, this study attempts to compare the Marshall Stability of CEAM with BGA which considers the gradation of BGAM in combined gradation and which considers the gradation of BGA in combined gradation under wet condition.

In effort to support the construction of sustainable pavement, the objective of this study is to compare Marshall Stability of CEAM which takes into account the gradation of BGA into combined gradation and which takes into account the gradation of BGA Mineral into combined gradation using the local materials such as limestone as prime aggregates, and BGA as partial substitution of emulsion asphalt bitumen.

2. Literature Review

2.1. Elements of Buton asphalt

In general, Buton natural asphalt contains bitumen of 25% - 30% and mineral of 70% - 75%. Both of these elements will be very dominant in affecting the improvement of the mixture asphalt performance. [10]. The benefit of BGA is to ensure a stable performance. The characteristics of BGA include high asphaltene levels, strong bonds, having a very large micro void and high alkali content. They result in good adhesion and strong water resistance (Jinjin S. et al., 2016) [11]. The physical properties, chemical properties, and chemical composition of Buton asphalt are shown in Tables 1, 2, and 3 [10].

Table 1. Physical Properties of Buton Natural Asphalt [10].

	Natural Asphalt from Kabungka	Natural Asphalt from Lawele
Bitumen Content, %	20	30.08
Penetration, 0.1 mm	4	36
Softening Point, °C	101	59
Ductility, 25°C, 5 cm/min, cm	<140	>140
Solubility in C ₂ HCl ₃ , %	-	99.6
Flash Point, °C	-	198
Specific Gravity	1.046	1.037
Weight Loss (TFOT), 163°C, 5 hour	-	0.31
Penetration after TFOT, %	-	94
Softening Point after TFOT, °C	-	62
Ductility after TFOT, cm	-	>140

Table 2. Chemical Properties of Buton Natural Asphalt [10].

	Natural Asphalt from Kabungka	Natural Asphalt from Lawele
Nitrogen (N), %	29.04	30.08
Acidafins (A1), %	9.33	6.6
Acidafins (A2), %	12.98	8.43
Parafin (P), %	11.23	8.86
Parameter Maltene	1.5	2.06
Nitrogen/Parafin, N/P	2.41	3.28
Asphaltene Content, %	39.45	46.92

Table 3. Chemical Composition of Buton Natural Asphalt Mineral [10].

	Natural Asphalt from Kabungka	Natural Asphalt from Lawele
CaCO ₃	86.66	72.9
MgCO ₃	1.43	1.28
CaS	1.11	1.94
H ₂ O	0.36	0.52
SiO ₂	0.99	2.94
Al ₂ O ₃	5.64	17.06
Al ₂ O ₃ + Fe ₂ O ₃	1.52	2.31
Residu	0.96	1.05

2.2. Marshall Stability

Characteristics of Marshall consist of the stability, flow, and Marshall quotient. Marshall Stability is calculated using Equation:

$$MS = 1000 \frac{P \cdot k}{g} \quad (1)$$

where P is the compressive Strength (kN), k is the correction of specimen thickness, and g is the coefficient of gravity (9.81 m/s²).

Retained Marshall Stability (RMS) is the comparison between Marshall Stability of CEAM under wet condition and Marshall Stability under unconditioned. It is calculated using the following equation.

$$RMS = \frac{MS_{wet}}{MS_{dry}} \quad (2)$$

where MS_{wet} is Marshall Stability of CAEM under wet condition (kg), and MS_{dry} is Marshall Stability of CAEM under unconditioned (kg).

3. Material and Methods

3.1. Material

Materials used in this study consist of emulsion asphalt, BGA, and limestone aggregates. These materials are shown in Fig. 1.



(a) Emulsion asphalt

(b) Buton Granular Asphalt

(c) Limestone Aggregate

Figure 1. Types of materials in CMA

The type of emulsion asphalt is CSS-1h contains bitumen content of 64.35% and water content of 35.65%. The type of BGA used is BGA 50/30 containing bitumen content of 32.10%, Mineral content of 66.36%, and water content of 1.54%. Bitumen of BGA acts as a partial substitution of emulsion asphalt bitumen and BGAM acts as fine aggregates and filler. Gradation of BGA and gradation of BGA Mineral used in this study are listed in Table 4 [12].

Table 4. Gradation of BGA and Gradation of BGAM [12]

Sieve Size	Gradation of BGA Passed (%)	Gradation of BGA Mineral Passed (%)
No. 8	100	100.00
No. 16	59.86	98.13
No. 30	32.91	93.85
No. 50	12.66	87.73
No. 100	3.28	58.35
No. 200	0.82	39.42

The physical characteristics of coarse aggregates include Los Angeles abrasion of 27.5%, bulk specific gravity of 2.53 gr/cc, water absorption of 2.03%, and flat and elongated particle 1:1. While, the physical characteristics of fine aggregate are bulk specific gravity of 2.5 gr/cc, water absorption of 3.94%, and pH of 9.4.

3.2. Preparation of Specimens

3.2.1. Gradation

A combined gradation is designed with dense gradation for the Asphalt Concrete Wearing Course. The combined gradation of CAEM was simulated in two approaches. Firstly, the gradation of BGA Mineral

(BGAM) was taken into account in combined gradation. Secondly, the gradation of BGA was taken into account in combined gradation. The design of combined gradation is shown in Fig. 2.

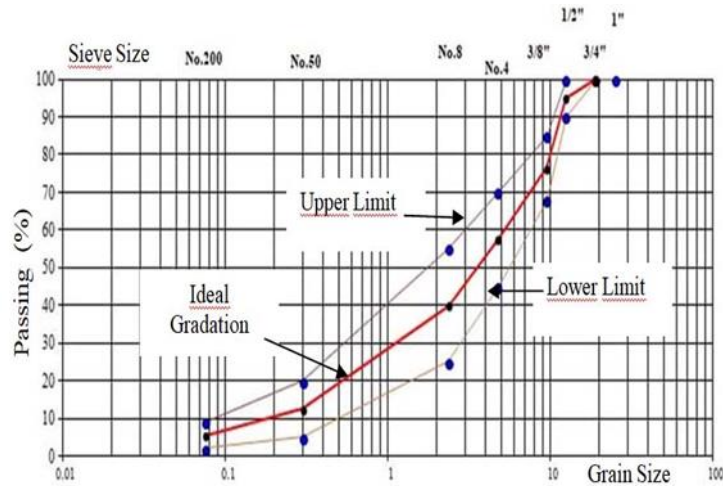


Figure 2. Design of Gradation for AC-WC

3.2.2. Marshall Specimens

All specimens were made with optimum bitumen content of 8% and optimum water content of 5% of their total weight. BGA which be used varies from 0%, 6%, 7.5%, 9%, 10%, and 12%. Specimens were classified into two group. Specimens of Group-1 were designed taking into account the amount of aggregate and BGA in combined gradation (CAEMa). Specimens of Group-2 were designed taking into consideration the amount of aggregate and BGAM in combined gradation (CAEMb).

Cylindrical Marshall Specimens had dimensions target of 101 mm in diameter and 63.5 mm in height. CMA Specimens preparation referred to Indonesia National Standard 06-2489-1991 on the method of asphalt mixtures testing with Marshall. All specimens were made with compaction of 2 x 50 blows. The compacted specimens along with the mould were cured for 24 hours at room temperature of 25°C, where the bottom and top of the specimen were left open and placed lying down. Then, the specimens were removed from the mould using an extruder tool and were cured in an oven at a temperature of 38°C for 24 hours. Before they were carried out Marshall Testing, all specimens were soaked as high as half of the specimen height for 2 x 24 hours, and then the specimens were reversed and soaked again as high as half of the specimen height for 2 x 24 hours.

3.2.3. Testing Method

Marshall Stability testing was carried out at a temperature of 25°C using a Universal Testing Machine (UTM) attached with Linear Displacement Transducer (LVDT) and data logger. The UTM tool was set with a load speed of 50 mm / minute. The Marshall Stability testing scheme is shown in Fig.3,

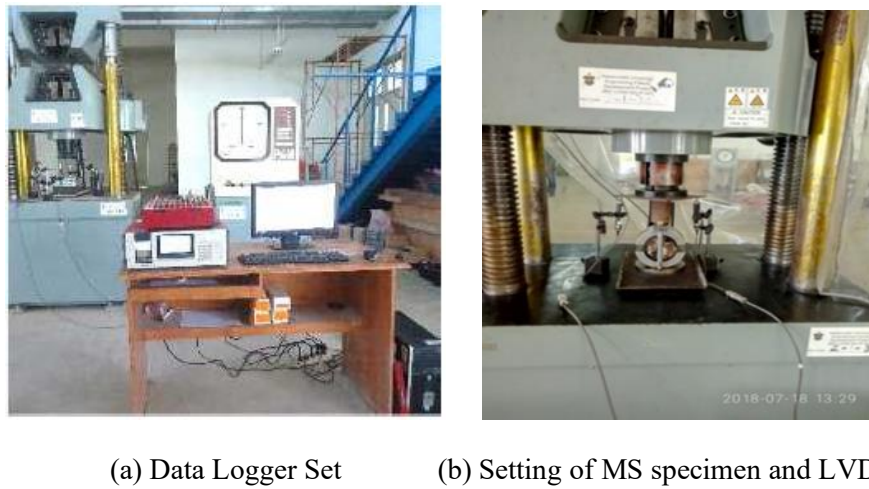


Figure 3. Scheme of Marshall Stability Testing.

4. Results and Discussion

4.1. Marshall Stability of CEAM taking into account gradation of BGA in combined Gradation

The average of Maximum Marshall Stability on CEAM taking into account gradation of BGA in combined Gradation (CEAMa) specimens at flow of 12 mm under wet condition were shown in table 4.1

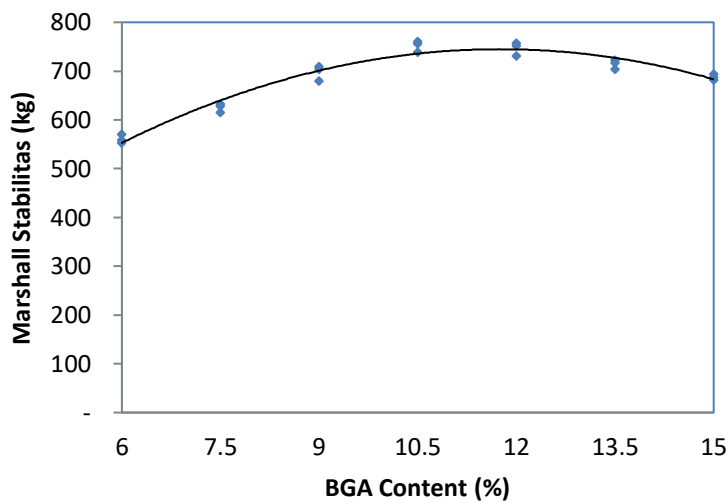


Figure 4. Relationship between BGA content and Marshall Stability of CEAMa under Wet Condition

Figure 4 shows the average of Maximum Marshall Stability of CEAMa under wet conditions at BGA content of 6%, 7.5%, 9%, 10.5%, 12%, 13.5%, and 15% respectively are 560 kg, 625 kg, 698 kg, 752 kg, 714 kg, 714 kg, and 688 kg. At BGA content of 6-10.5%, Marshall Stability tends to increase, and at BGA content of 10.5-15%, Marshall Stability tends to decrease.

The robust correlation between BGA content and Maximum Marshall Stability of CEAMa under wet condition is 95.5%. Correlation between BGA content and Marshall Stability of CEAMa under wet conditions can be predicted using the polynomial regression formulation shown in Equation 3.

$$MS_{wet} = -5.8099 X^2 + 136.52X - 57.156 \tag{3}$$

MS_{wet} = The Maximum Marshall Stability Average of CEAM_a under wet condition (kg)

X_b = BGA content (%)

Using the Eq. 4, the maximal Marshall Stability of CEAM_a was obtained at BGA content of 11,75%.

4.2. Marshall Stability of CEAM taking into account gradation of BGA Mineral in Combined Gradation

The average of Maximum Marshall Stability on CEAM taking into account gradation of BGA Mineral in combined Gradation (CEAM_b) at flow of 12 mm under wet condition were shown in Fig. 5. It is shown that the average of Maximum Marshall Stability of CEAM_b under wet conditions at BGA content of 6%, 7.5%, 9%, 10.5%, 12%, and 13.5% respectively are 543 kg, 597 kg, 674 kg, 665 kg, 655 kg, and 645 kg. At BGA content of 6-9%, Marshall Stability tends to increase. At BGA content of 9-13.5%, Marshall Stability tends to decrease. The maximal Marshall Stability of CEAM_b occurred at BGA content of 11%.

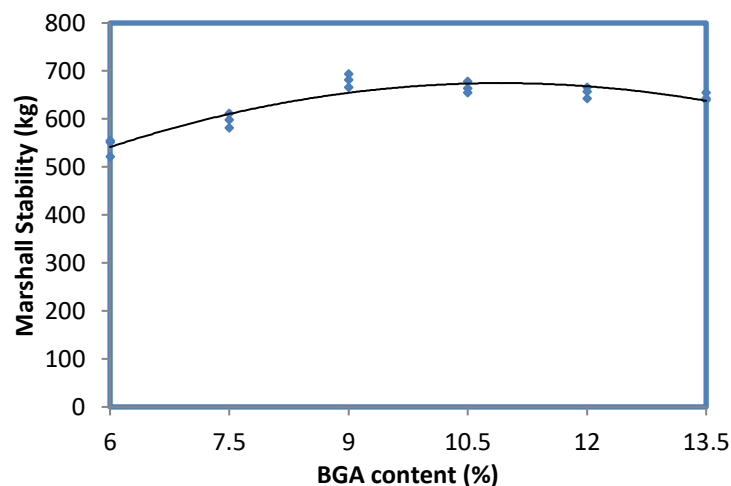


Figure 5. Relationship between BGA content and Marshall Stability of CEAM_b under Wet Condition

The robust correlation between BGA content and Maximum Marshall Stability of CEAM_b under wet condition is 86.91%. Correlation between BGA content and Marshall Stability of CEAM_b under wet conditions can be predicted using the polynomial regression formulation shown in Equation 4.

$$MD_{wet} = -5.3162 X^2 + 116.63 X + 33.128 \quad (4)$$

MS_{wet} = The Maximum Marshall Stability Average of CEAM_b under wet condition (kg)

X_b = BGA content (%)

Using the Eq. 4, the maximal Marshall Stability of CEAM_b was obtained at BGA content of 11%. Marshall Stability under wet condition of CEAM_a has higher than CEAM_b. At BGA content of 6%, 7.5%, 9%, 10.5%, 12%, and 13.5%, Marshall Stability of CEAM_a are 3%, 5%, 4%, 13%, 14%, and 11% higher than CEAM_b respectively. This is due to Void in Mixture of CEAM_a is less than Void in Mixture of CEAM_b at the same of BGA content [13].

4.3. Retained Marshall Stability of CEAM

The study which be carried out by One L., et al (in press)[12] showed that The average of Maximum Marshall Stability of CEAM_b under unconditioned at BGA content of 6%, 7.5%, 9%, 10.5%, 12%, 13.5%, and 15% respectively are 811 kg, 888 kg, 1,095 kg, 1,223 kg, 1,252 kg, 1,306 kg, and 1,388 kg.

Therefore, the RMS of CEAMb at BGA content of 6%, 7.5%, 9%, 10.5%, 12%, and 13.5% respectively are 0.69, 0.70, 0.64, 0.61, 0.60, and 0.55. At BGA content of 6-7.5%, RMS tends to increase. At BGA content of 7.5-13.5%, RMS tends to decrease. Specimens with BGA content of 6-12% have met the DGH-DPWRI specification of 2006, where the requirement of Retained Marshall Stability for CEAM is at least 0.6.

The study which be carried out by One L., et al (in press)[12] showed that The average of Maximum Marshall Stability of CEAMb under unconditioned at BGA content of 6%, 7.5%, 9%, 10.5%, 12%, and 13.5% respectively are 644 kg, 652 kg, 681 kg, 706 kg, 746kg, and 811 kg. [] Therefore, the RMS of CEAMb at BGA content of 6%, 7.5%, 9%, 10.5%, 12%, and 13.5% respectively are 0.84, 0.92, 0.99, 0.94, 0.88, and 0.80. At BGA content of 6-9%, RMS tends to increase. At BGA content of 9-13.5%, RMS tends to decrease. All specimens have met the DGH-DPWRI specification of 2006, where the requirement of Retained Marshall Stability for CEAM is at least 0.6.

The Retained Marshall Stability of CAEM which takes into account gradation of BGAM is higher than which takes into account gradation of BGA in combined gradation. This shows that the effect of water damage in the CAEM which takes into account gradation of BGA is greater than which takes into account gradation of BGAM in combined gradation.

5. Conclusion

This study has compared the Marshall Stability under wet condition of CEAM taking into account Gradation of BGA in combined gradation and which take into account Gradation of BGAM in combined gradation. Based on the results and discussion in this study, a number of conclusions can be drawn.

Firstly, CEAM which takes into account the gradation of BGA in combined gradation has higher Marshall Stability under wet condition than which take into account Gradation of BGAM in combined gradation.

Secondly, addition of BGA content to CAEM under wet condition increased Marshall Stability not only on CEAM which takes into account gradation of BGA in combined gradation but also on CEAM which takes into account Gradation of BGAM in combined gradation. The maximal Marshall Stability of CEAM under wet condition which takes into account gradation of BGA in combined gradation is obtained at BGA content of 11.75%. The maximal Marshall Stability of CEAM under wet condition which takes into account gradation of BGAM in combined gradation is obtained at BGA content of 11%.

Thirdly, the effect of water damage in the CAEM which takes into account gradation of BGA is greater than which takes into account gradation of BGAM in combined gradation. The use of BGA less than 12% in CAEM which takes into account gradation of BGA has met the DGH-DPWRI specification of 2006.

Finally, the design gradation of CAEM using Buton's Granular Asphalt which be recommended in The Construction and Building Guideline, DGH-DPWRI of 2006, should be revised to take into account gradation of BGA in combined gradation of CAEM.

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