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EFFECT OF BUTON GRANULAR ASPHALT GRADATION AND CEMENT AS FILLER ON PERFORMANCE OF COLD MIX ASPHALT USING LIMESTONE AGGREGATE

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Abstract

In Indonesia, gradation of Buton Granular Asphalt Mineral is taken into account in target gradation for the design of Cold Mix Asphalt. This study aims to analyse the performance of Cold Mix Asphalt with Buton Granular Asphalt and cement filler in term of Marshall Stability. The specimens were made with optimum bitumen content of 8%, water content of 5%, Buton Granular Asphalt content of 6-12% and cement content of 0-2.5%. The results of this study showed that at Buton Granular Asphalt content of 6%-12%, the Marshall stability of Cold Mix Asphalt which considers the gradation of Buton Granular Asphalt in target gradation was higher of 24%-55% than which, considers the gradation of Buton Granular Asphalt Mineral. While the use of cement content of 0.5%-2.5% in Cold Mix Asphalt with Buton Granular Asphalt could increase Marshall Stability about 7%-49%. In addition, when applying cement content of 0-2.5% and Buton Granular Asphalt content of 14% in Cold Mix Asphalt, it increased the Marshall stability of Conventional Cold Mix Asphalt by 114%-318%. Therefore, it is recommended that this study result can be implemented in the construction of flexible pavement in Indonesia.

Keywords: Buton granular asphalt, Cement filler, Cold mix asphalt, Gradation, Marshall stability.

1. Introduction

According to Vaitkus et al. [1] (2001), there are four types of asphalt mixture based on production temperature. They are hot mix asphalt (temperature of 150-190 ^{o}C), warm mix asphalt (temperature of 100-140 ^{o}C), half warm mix asphalt (temperature of 60-100 ^{o}C) and cold mix asphalt (temperature of 0-60 ^{o}C). Cold Mix Asphalt (CMA) technology innovation substantially supports safe energy use and emission reduction [2]. CMA has advantages for the environment, economy and logistics compared to Hot Mix Asphalt (HMA). CMA is designed to support light to moderate traffic. CMA is suitable for road construction in areas with tropical climates because it speeds up the evaporation process and increases the strength after compaction. Production of CMA may utilize manual equipment such as a simple mixer. CMA is also very suitable for use in the construction of small-scale roads, such as road maintenance including patching (holes) and pavement for pedestrians. Some of the disadvantages of CMA in the following: the process of evaporation that takes a long time, less strength at an early age, and high porosity [3, 4]. CMA has inadequate performance and is prone to damage at the initial service life due to rainfall [5].

Conventional CMA has poor mechanical performance and high humidity if it uses only emulsion asphalt as binder material without additive such as cement. In order to enhance the mechanical performance of CMA, many studies used Portland cement as material stabilization [6-10]. The addition of cement can provide better mechanical performance and resistance of CMA to the effect of moisture damage. Addition of cement as filler in CMA can improve the adhesion or strength of the surface bond between the emulsion asphalt and the aggregate in asphalt mortar. Additional cement also has positive effects on CMA strength at the early service life and the long-term service life of the road [6-10].

Other 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 [11-14]. Indonesia has huge reserves of natural asphalt. One famous natural asphalt in Indonesia is Buton natural asphalt. This natural asphalt can be abundantly found in Buton Island, Southeast Sulawesi Province. Generally, the types of Buton natural asphalt product in the market used for road construction include Refine Buton Asphalt (Retona) and Buton Granular Asphalt (BGA). They offer a number of benefits 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 [11-13]. Meanwhile, a study of Buton natural asphalt product in the form of emulsion asphalt carried out by Israil et al. [14] showed that CMA using Buton emulsion asphalt had a good mechanical performance.

Referring to the Construction and Building Guidelines Number 001-05/BM/2006 issued by Directorate General of Highways, Department of Public Works, Republic of Indonesia (DGH-DPWRI), it states that a target gradation of CMA considers gradation of Buton Granular Asphalt Mineral (BGAM) [3]. Based on its physical characteristics, BGA has a distribution of grain size as a granular material. Therefore, this study attempts to compare the mechanical performance of CMA with BGA, which considers the gradation of BGAM in target gradation and which considers the gradation of BGA in target gradation.

In effort to support the construction of sustainable pavement, the objective of this study is to improve the mechanical performance, especially in Marshall Stability, of CMA using the local materials such as limestone as prime aggregates, BGA as partial substitution of emulsion asphalt bitumen, and Portland Composite Cement (PCC) containing residual of coal combustion (fly ash) as stabilizing material.

2. Literature Review

2.1. Buton asphalt

Two main elements of Buton natural asphalt are bitumen and minerals. In general, Buton natural asphalt contains 25%-30% bitumen with high asphaltene and mineral content of around 70%-75%. Both of these elements will be very dominant in affecting the improvement of the mixture asphalt performance. BGAM is dominated by globigerina limestone. It has very smooth, relatively high calcium content and is good as filler in asphalt mixtures. [15].

The result of a study carried out by Jinjin et al. [16] showed that the mineral chemical composition of BGA contained oxide acid (SiO_2, Fe_2O_3, P_2O_5, TiO_2) of 10.447%, neutral oxide minerals (Al_2O_3) of 3.2%, and alkaline minerals of 76%. The high content of alkaline minerals in BGA can increase the ability to absorb bitumen ions. Furthermore, the result of microscopic photographs showed that BGA particles have high porosity, rough surfaces, large surface area, and high levels of crystalline. The BGAM also has good absorption ability in addition to having good performance against adhesion. The benefit of using BGA is it ensures 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 [16].

2.2. Hydration of cement

Hydration of cement is a reaction between cement and water particles including chemical and physical processes. It directly influences bonding (setting) and hardening properties [17]. Cement hydration is of particular importance to emulsion asphalt mixture. Water for cement hydration supplied by emulsion asphalt is more than enough to completely hydrate the amount of cement used in CMA [18]. Schematic representation of the hardening process of an asphalt and cement composite is shown in Fig. 1 [19].

After mixing, the mixture of aggregate, water, bitumen of emulsion asphalt, and the cement will form a homogeneous mixture (Fig. 1(a)). During this process, the particles of cement and aggregates are wet due to the presence of water, and there is no contact between aggregates and bitumen droplet as the emulsion asphalt has not yet broken. Under conditions of low relative humidity, the samples speed up evaporation, the mixture begins to dry out [20-22]. During the drying process, the distance of the bitumen droplets decreases. It begins to break in larger grains. At some points during this process, the emulsion asphalt will break [23, 24].

Water reduction during the curing process can be significantly accelerated by adding water-binding materials, such as Portland cement. If cement is added to the mixture, there will be two effects. First, cement will remove some water that is evaporated from the mixture, to be used in the hydration process. Second, it will change the pH of emulsion asphalt (Fig. 1(b)) [19]. In the early stage of hydration involves the rapid leaching of calcium into the bulk aqueous phase and the formation of a calcium depleted layer of orthosilicic species around the cement grains. This layer increases in depth as hydration progress into the grain. Then, the orthosilicic species will be converted to disilicate anions at the interface with the bulk aqueous phase at pH 12.6 [25].

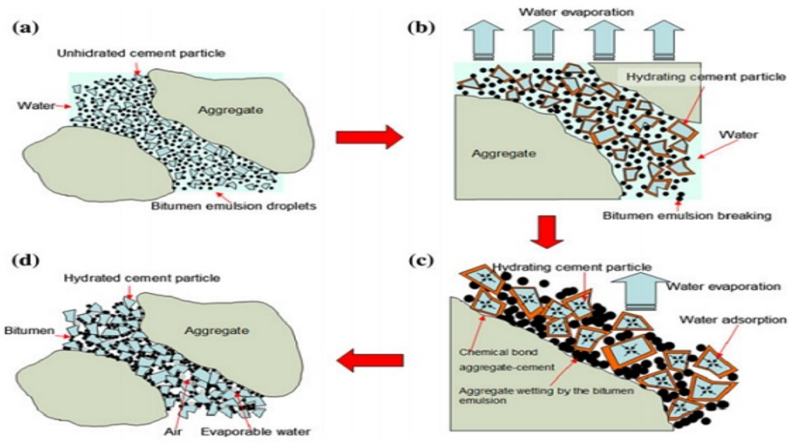


Fig. 1. Schematic representation of hardening process of composite emulsion asphalt [19].

2.3. Performance of asphalt mixture

According to Asphalt Institute [4], MS 4 edition 1989, the performance of asphalt mixture is determined by two main factors namely Marshall Characteristic and volumetric. Marshall Characteristic consists of stability, flow, and Marshall quotient. Volumetric consists of Void Mineral Aggregate (VMA), Void Filled Bitumen (VFB), and Void in Mixture (VIM). Marshall Stability reported in kilograms (kg) is calculated using Eq. (1).

$$MS = 1000x\frac{P\ x\ k}{g} \tag{1}$$

where P is the compressive Strength (kN), k is the correction of specimen thickness, and g is the coefficient of gravity (9.81 m/s^2).

Comparison of Marshall Stability on observation specimen to control specimen stated by Marshall Stability Index (MSI) calculated using Eq. (2).

$$MSI_i=\frac{SMi}{SMo} \tag{2}$$

where MS_i is Marshall Stability of the observed specimen (kg), MS_o is Marshall Stability of control specimen (kg).

Marshall Stability Ratio (MSR) is the comparison between Marshall Stability of CMA with BGA which considers the gradation of BGA in target gradation and which considers the gradation of BGAM in target gradation at the same BGA content. It is calculated using Eq. (3).

$$MSR = \frac{MS_{b-i}}{MS_{a-i}} \quad (3)$$

where MS_{a-i} is Marshall Stability of CMA_a specimen at BGA content of i%, and MS_{b-i} is Marshall Stability of CMA_b specimen at BGA content of i%.

The requirements of CMA refer to the Constructing and Building Guidelines Number 001-05/BM/2006 issued by the DGH-DPWRI are listed in Table 1 [3].

Table 1. Requirements for CMA modified emulsion asphalt [3].

Parameters	Requirement
Blows	2×50
Void Mineral Aggregate (VMA), (%)	Minimum 16
Void in Mixture (VIM), (%)	3-12
Marshall stability (kg)	Minimum 450
Ratio stability after soaked 4 × 24 hours (%)	Minimum 60
Asphalt film thickness, micron	Minimum 8
Course aggregate covering, %	Minimum 75

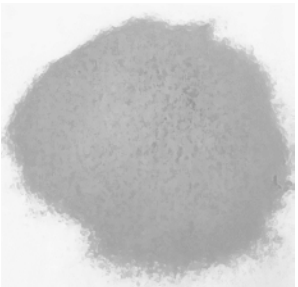
3. Material and Methods

3.1. Material

There are four types of materials used in this study. They are emulsion asphalt, BGA, Portland Composite Cement (PCC), and limestone aggregates. These materials are shown in Fig. 2.

(a) Emulsion asphalt.

(b) Buton granular asphalt.



(c) Portland cement composite.

(d) Limestone aggregate.

Fig. 2. Types of materials in CMA.

The type of emulsion asphalt used 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 BGAM used in this study are listed in Table 2.

Table 2. Gradation of BGA and gradation of BGAM.

Sieve size	Gradation of BGA		Gradation of BGAM	
	Passed (%)	Retained (%)	Passed (%)	Retained (%)
No. 8	100	0	100	0
No. 16	59.86	40.14	98.13	1.87
No. 30	32.91	26.95	93.85	4.28
No. 50	12.66	20.25	87.73	6.12
No. 100	3.28	9.38	58.35	29.38
No. 200	0.82	2.46	39.42	18.39
Pan	0	0.82	0	39.42

The type of cement utilized in this study is PCC. It is produced by a cement supplier in Indonesia. The results of a laboratory test conducted by the supplier in 2016 showed that the chemical characteristics of PCC utilized in the study were as the following: CaO of 61.79%, SiO_2 of 18.39%, Al_2O_3 of 5.15%, Fe_2O_3 of 3.41%, SiO_3 of 1.81%, MgO of 0.99%, Loss Ignition of 4.61%, and Insoluble Residue of 2.78%. Aggregate used is limestone aggregate which has an unconfined compressive strength of 38.8 MPa. The physical characteristics of coarse aggregates include Los Angeles abrasion of 27.5%, a bulk specific gravity of 2530 kg/m^3, water absorption of 2.03%, and flat and elongated particle 1:1. While, the physical characteristics of fine aggregate are bulk specific gravity of 2500 kg/m^3, water absorption of 3.94%, and pH of 9.4.

3.2. Preparation of specimens

3.2.1. Gradation

Generally, aggregate gradation is classified in the following: dense or well-graded, gap graded, open-graded, and uniformly graded. Incorporation of geometrically cubical aggregate is beneficial in improving physical and mechanical characteristics of coarse aggregate in Asphalt Mixture [26]. Aggregate gradation has more influence on asphalt mixture performance than asphalt content [27]. A target gradation is designed for the Asphalt Concrete Wearing Course (AC-WC). Thus, the target gradation used is dense gradation. The design of target gradation is shown in Fig. 3. The design of ideal gradation as the target gradation was determined based on the average of lower limit gradation and upper limit gradation following the requirements stated in the Construction and Building Guidelines Number 001-05/BM/2006 [3]. The target gradation of CMA was simulated in two approaches. Firstly, the gradation of BGAM was considered in target gradation. Secondly, the gradation of BGA was considered in target gradation.

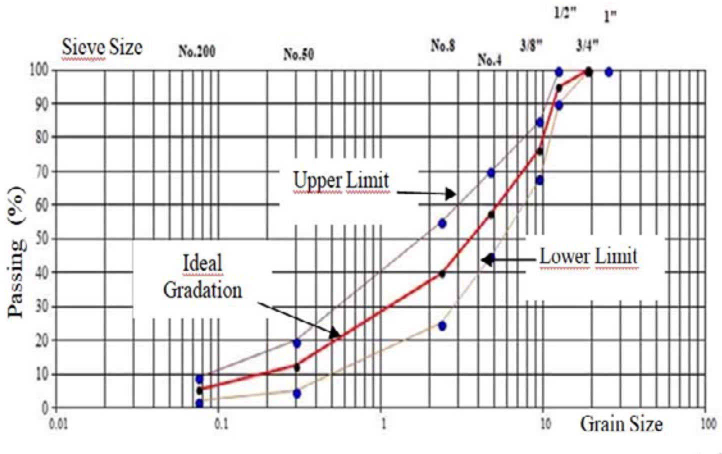


Fig. 3. Design of target gradation for AC-WC.

3.2.2. Composition of materials

All specimens have 1200 grams of weight with optimum bitumen content of 8% and optimum water content of 5% of their total weight. The amount of limestone aggregate and BGAM in the mixture is 1440 grams. BGA used varies from 6% to 12% of total weight with an interval of 1.5%. It is determined based on the recommendation of the Public Work Department of the Republic of Indonesia, as stated in the Constructing and Building Guideline of 2006 (Book: 1). The guideline determines the maximum BGA content of 10.5% in CMA, especially BGA 20/25. In addition, an interval of 1.5% is specified by trial and error.

Specimens of Group-1 were designed considering the amount of aggregate and BGA Material in target gradation (CMA_a). Specimens of Group-2 were designed taking into consideration the amount of aggregate and BGA in target gradation (CMA_b). The mix design for CMA with BGA and limestone aggregate is shown in Table 3.

Table 3. Composition of materials in CMA.

BGA (%)	BGA (g)	Emulsion Asphalt (g)	Water (g)	Limestone aggregate (g)	Aggregate and BGA (g)
0	0	149	7	1044	1044
6	72	113	19	996	1068
7.5	90	104	21	984	1074
9	108	95	24	972	1080
10.5	126	86	27	960	1086
12	144	77	30	948	1092

3.2.3. Specimens

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 2×50 blows. The compacted specimen along with the mould was cured for 24 hours at room temperature of 25 ºC, 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 ºC for 24 hours.

3.2.4. Testing methods

Marshall Stability testing was carried out at a temperature of 25 ºC 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. 4.

(a) Data logger set. **(b) Setting of MS specimen and LVDT.**

Fig. 4. Scheme of marshall stability testing.

4. Results and Discussion

4.1. Effects of BGA gradation on volumetric of CMA

Increasing the use of BGA in CMA both CMA_a and CMA_b would make VMA and VIM bigger and VFB smaller. This is due to the ability of BGA as a substitute for bitumen of emulsion asphalt to fill the void of aggregate and void amongst the aggregates smaller than bitumen of emulsion asphalt. Effects of BGA gradation on volumetric CMA are displayed in Figs. 5 to 7.

Figure 5 shows that VMA obtained from all BGA contents complies the specification set by the DGH-DPWRI, which is 16% at the minimum. At the same BGA content, VMA of CMA_b was smaller than VMA of CMA_a. Increasing the use of BGA content, both VMA of CMA_a and VMA of CMA_b are increasing.

Figure 6 shows that at the same BGA content, VFB of CMA_b was bigger than VFB of CMA_a. Increasing the use of BGA content, both VFB of CMA_a and VFB of CMA_b are decreasing.

Figure 7 shows that VIM obtained from all BGA content met the DGH-DPWRI specification which was a minimum of 3%. Meanwhile, in order to meet the DGH-DPWRI specification at maximum VIM of 12%, it was obtained from the BGA content of 14.47% in CMA_b, and BGA content of 8.14% in CMA_a. At the same BGA content, VIM of CMA_b was smaller than VIM of CMA_a.

At BGA content of more than 14.47%, the VIM of CMA with BGA which consider the gradation of BGA in target gradation was more than VIM maximum of 12%. While, at BGA content of more than 8.14%, The VIM of CMA with BGA, which considers the gradation of BGAM in target gradation was more than VIM maximum of 12%.

Based on volumetric of CMA requirement, the utilization of BGA content in CMA with BGA, which considers gradation of BGA in target gradation can be used more than CMA with BGA, which considers gradation of BGAM in target gradation.

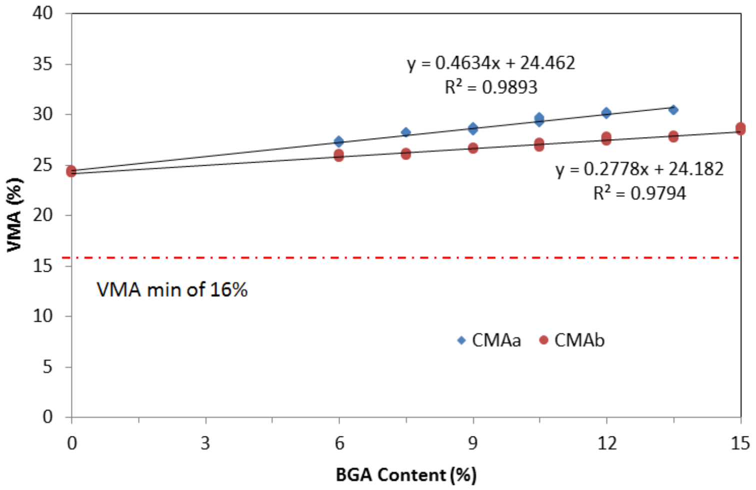


Fig. 5. VMA of *CMA_a* and *CMA_b* vs. BGA content (%).

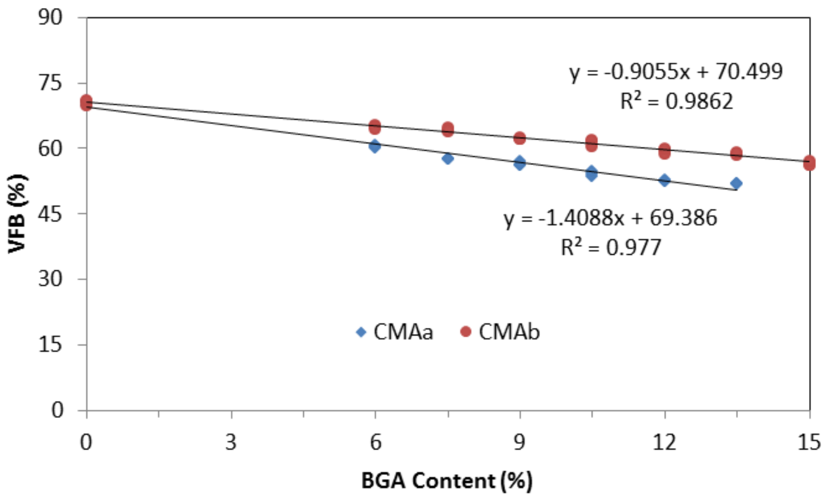


Fig. 6. VFB of *CMA_a* and *CMA_b* vs. BGA content (%).

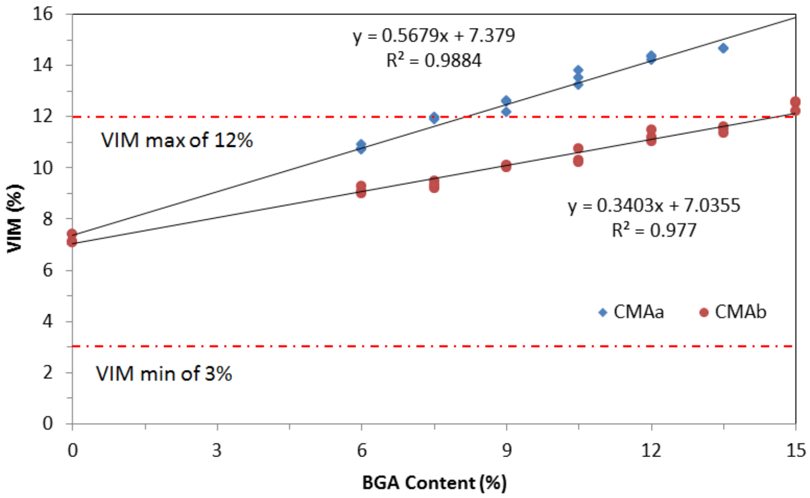


Fig. 7. VIM of CMA_a and CMA_b vs. BGA content (%).

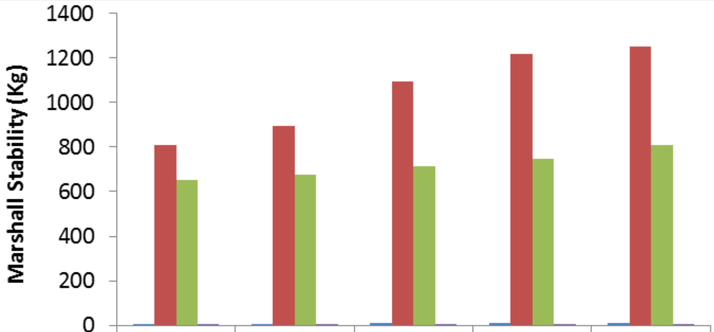
4.2. Effects of BGA gradation on marshall stability of CMA

Testing result of Marshall Stability on CMA_a and CMA_b specimens shows that at a flow of 12 mm, all specimens deform without fracture. This means that CMA specimens using BGA and limestone aggregate have high ductility. Deformation of specimens after Marshall testing is presented in Fig. 8.

Fig. 8. Deformation of specimens after Marshall testing at flow of 12 mm.

Addition of BGA content to both CMA_a and CMA_b increased Marshall Stability in dry conditions. At the same BGA content, CMA_b has higher Marshall Stability (MS) than CMA_a. Figure 9 shows the use of BGA in the same BGA content of 6%, 7.5%, 9%, 10.5%, and 12%, the Marshall Stability of CMA_b is better than that of CMA_a. The MS of CMA_b increased by 24%, 32%, 54%, 63% and 55% respectively compared to that of CMA_a.

Increasing BGA utilization in CMA both CMA_a and CMA_b would improve Marshall Stability. This is due to BGA containing high asphaltene levels, having a very large micro void, and high alkali content which results in good adhesion and strong bonds [15]. The Marshall stability of CMA_b is higher than that of CMA_a because the void in the mixture (VIM) of CMA_b was less than that of CMA_a. Also, in the same BGA content, the density of CMA_b was more than that of CMA_a.



	P0B6	P0B7.5	P0B9	P0B10.5	P0B12
BGA content (%)	6	7.5	9	10.5	12
MS of CMAb (Kg)	810	894	1095	1216	1252
MS of CMAa (Kg)	653	675	712	746	808
MSR	1.24	1.32	1.54	1.63	1.55

Fig. 9. Marshall stability of CMA_a and CMA_b vs. BGA content (%).

4.3. Effects of BGA gradation on Marshall stability of CMA

Marshall Stability Testing of CMA containing PCC was designed to CMA containing BGA with higher Marshall Stability in accordance to the DGH-DPWRI specification with maximum VIM of 12%.

This was obtained from CMA_b with BGA content of 14%. PCC used in CMA containing BGA and limestone aggregate acts as fillers and stabilizing material with variations PCC content of 0-2.5% at intervals of 0.5% at BGA content of 14%. Addition PCC content to CMA using BGA and limestone aggregates could increase Marshall Stability.

The effect of PCC on Marshall Stability of CMA using BGA is shown in Fig. 10. The use of PCC content of 0-2.5% in CMA containing BGA content of 14% and limestone aggregate complied the Marshall Stability requirements based on the DGH-DPWRI Specification of 2010. The minimum Marshall stability of HMA containing BGA required is at least 1000 kg.

Figure 10 shows that the Marshall Stability average of CMA_b using Limestone aggregate, BGA content of 14%, and PCC content of 0%, 0.5%, 1%, 1.5%, 2%, and 2.5% respectively are 1373 kg, 1467 kg, 1593 kg, 1726 kg, 1844 kg, and 2045 kg. Therefore, the MSI of CMA_b containing PCC content of 0.5%, 1%, 1.5%, 2%, and 2.5% on CMA_b without PCC respectively are 1.07, 1.16, 1.26, 1.34, and 1.49. This shows that PCC as filler of 0.5-2.5% added to CMA_b at BGA content of 14% can increase Marshall Stability of 7-49%.

While, MSI of CMA_b containing PCC content of 0%, 0.5%, 1%, 1.5%, 2%, and 2.5% on conventional CMA, which have Marshall Stability of 643 kg respectively are 2.14, 2.28, 2.48, 2.68, 2.87, and 3.18. This shows that PCC as a filler of 0.5-2.5% and BGA content of 14% added to CMA_b can increase the Marshall Stability of conventional CMA up to 114%-218%.

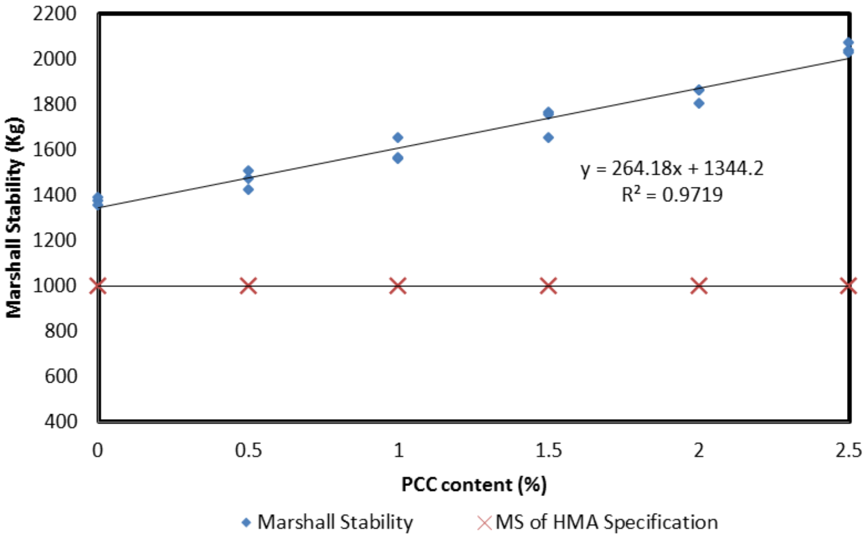


Fig. 10. PCC content (%) vs. Marshall stability (kg).

5. Conclusions

This study has analysed the performance of Cold Mix Asphalt with Buton Granular Asphalt and cement filler. Based on the results and discussion in this study, a number of conclusions can be drawn.

Firstly, Cold Mix Asphalt which considers the gradation of Buton Granular Asphalt in target gradation has higher Marshall Stability than Cold Mix Asphalt which considers the gradation of Buton Granular Asphalt Mineral in target gradation. This is due to Void in Mixture of Cold Mix Asphalt considering the gradation of Buton Granular Asphalt in target gradation is less than Void in Mixture of Cold Mix Asphalt considering the gradation of Buton Granular Asphalt Mineral in target gradation.

Secondly, the addition of Buton Granular Asphalt content to Cold Mix Asphalt containing Limestone aggregate increased Marshall Stability not only on Cold Mix Asphalt, which considers gradation of Buton Granular Asphalt in target gradation but also on Cold Mix Asphalt which considers Gradation of Buton Granular Asphalt Mineral in target gradation.

Thirdly, the addition of Portland Composite Cement to Cold Mix Asphalt with Buton Granular Asphalt and limestone aggregate improved Marshall Stability.

Finally, the significance of this study in the flexible pavement construction on Indonesia is; enhancing the use of local material such as Buton Granular Asphalt and limestone aggregate for road construction, improving the performance of cold Mix Asphalt, and supporting sustainable pavement construction.

This research proposes the following recommendations:

- The study result can be implemented in the flexible pavement construction in Indonesia, especially in regions with wide availability of limestone aggregate and limitation of asphalt mix plant.

- The Construction and Building Guideline of DGH-DPWRI of 2006, which considers gradation of BGAM in target gradation of CMA should be revised to consider gradation of BGA in target gradation.
- Further research is needed to analyse the performance of CMA with BGA and cement filler under repeated load.

Acknowledgement

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Nomenclatures

CMA_a	Cold Mix Asphalt with BGA, which considers gradation of Buton Gralular Asphalt Mineral in target gradation
CMA_b	Cold Mix Asphalt with Buton Gralular Asphalt, which considers gradation of BGA in target gradation
g	Coefficient of gravity, m/s^2
K	Correction of specimen thickness
P	Compressive load, kN

Abbreviations

BGA	Buton Granular Asphalt
BGAM	Buton Granular Asphalt Mineral
CMA	Cold Mix Asphalt
DGH-DPWRI	Directorate General of Highways, Department of Public Works, Republic of Indonesia
HMA	Hot Mix Asphalt
LVDT	Linier Vertical Displacement Transducer
MS	Marshall Stability (kg)
MSI	Marshall Stability Index (kg/kg)
PCC	Portland Composite Cement
UTM	Universal Testing Machine
VFB	Void Filled with Bitumen (%)
VIM	Void in Mixture (%)
VMA	Void Mineral Aggregate (%)

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