Analysis The Use of Artificial Aggregates As a Substitute of Coarse Agreggates for Surface of Flexible Pavement

Mirza Al Mahbubi and Ervina Ahyudanari
Department of Civil Engineering, Faculty of Civil, Environmental and Geo Engineering,
Institut Teknologi Sepuluh Nopember, Surabaya, 60111
e-mail: Ervina@ce.its.ac.id

***Abstract*— The quality of flexible pavement construction is strongly influenced by the composition of the material used, including the type of aggregate, and asphalt. Aggregates are generally defined as hard and dense earth shell formation. The mechanical properties of the asphalt mixture are strongly influenced by the fraction and aggregate properties, because the aggregate fills the majority of the asphalt mixture volume (more than 80%) and mass (about 95%). Aggregates have various forms and textures including round and cube shapes. At present, infrastructure development in Indonesia continues to increase the amount of natural aggregate usage, so this will cause the availability of materials to continue to thin out. For this reason, an effort needs to be made to find an alternative to the use of natural aggregate, one of which is the utilization of waste generated by the steam power plant (PLTU), namely fly ash. In this study the artificial aggregate was varied in spherical (AB) form from processed granulaor and angular (ABSC) from processed stone crusher. The results obtained in each variation provide a value that meets the specifications. The full use of artificial aggregates of 25% AB 75% ABSC on dense gradations provides stability of 1258.13 kg. In this study, the use of artificial aggregates can be used as an alternative as an aggregate substitute for nature. In addition to improving mixed quality, the use of artificial aggregates can be an alternative use of waste.**

***Keywords*—Stability, Marshall, Artificial Aggregate, Pavement Design**

I. INTRODUCTION

THE quality of flexible pavement construction is strongly influenced by the composition of the material used, including the type of aggregate, bearing capacity of the soil, and asphalt. The material used must produce a pavement mixture that is able to withstand loads that are strong and durable. Aggregates are generally defined as hard and dense earth shell formation. The mechanical properties of asphalt mixture are strongly influenced by the fraction and aggregate properties, because the aggregate fills the majority of the asphalt mixture volume (more than 80%) and mass (about 95%), physical and mechanical performance of the mixture is strongly influenced by geometric aggregate morphology and interlocking amount (size) of aggregate particles[1]. Aggregates must have properties that are capable of adhering to the asphalt. Under high-speed tire pressure, water vapor on the road surface produces hydrodynamic pressure, which causes the asphalt to shift from the aggregate surface, causing a hole in the surface, raveling and other problems. One of the main causes of this interference is the poor adhesive properties between asphalt and aggregate. Therefore, when the pavement design, the physical properties that exist in the aggregate must be very carefully considered [2].

The use of aggregates in asphalt or pavement mixtures currently uses aggregates produced by natural stone exploration. Along with increasing road construction in Indonesia, the availability of natural aggregates is running low. Massive use of natural aggregates will also threaten environmental conditions. The need for aggregate to support infrastructure development cannot be fully fulfilled in every region of Indonesia, especially in isolated areas. Therefore there needs to be an alternative use of natural aggregates, one of which is by developing the use of artificial aggregates from residual coal combustion or the Steam Power Plant (PLTU) namely fly ash.

The use of fly ash as a geopolymer material has hard properties, is resistant to weather, chemical attack, high temperature, and when mixed with sand or other minerals can resemble ceramics [3]. Fly ash coal must be reacted with chemical solutions as a mixed material so that it can become a geopolymer material. In this study will be analyzed the use of fly ash as an artificial aggregate base material on flexible pavement with Marshall parameters, Fly ash will be mixed with a chemical solution in the form of sodium hydroxide (NaoH) and sodium silicate (Na2SiO3). In this study the artificial aggregate of geopolymer fly ash used as a pavement mixture is only used on coarse aggregates and will be varied with the round shape resulting from the use of granulators and fractions produced from the stone crusher.

II. MATERIAL

The material used in this study is aggregate and asphalt. The aggregates used include natural aggregates and artificial aggregates. Artificial aggregates are produced from the use of fly ash which is reacted with chemicals such as NaOH and Na2SiO3. The asphalt used is asphalt pen 60/70.

A. Aggregate

Aggregates can be divided into coarse aggregates, fine aggregates, and filler. The aggregate based on processing is divided into:

1. The aggregate is ready to use, which is an aggregate that is used as a pavement material with shape and size as obtained at its original location or with little processing, this aggregate is formed based on the process of erosion and degradation. This aggregate is often called natural aggregate.
2. Aggregates that need to be processed before being used, namely aggregates obtained in the hills, in the mountains,

or in rivers. Aggregates on mountains and on hills are generally found in massive forms, so it is necessary to do a first breakdown so that they can be lifted to the stone crusher.

3. Artificial aggregate is an aggregate obtained from chemical or physical processes from several materials to produce a new material that resembles aggregate. Some of these aggregates are a by-product of industrial processes and from material processes that are deliberately processed so that they can be used as aggregates or as filler minerals.

The texture of the flexible pavement depends on the aggregate shape and the gradation used. Therefore the aggregate shape also affects skid-resistance on pavement [4].

B. Coarse Aggregate

The coarse aggregate function is to provide stability and mixed friction resistance to a displacement action. Stability is determined by the shape and texture of coarse aggregate surfaces. Generally the morphological characteristics of coarse aggregates can be seen from several aspects, namely the shape, size, angularity, and surface texture [5]. In this study artificial aggregates were only used on coarse aggregates. irregularities in the coarse aggregate cause stress concentrations in the mixture, so the mixture will gradually experience microcracking and structural changes will eventually decrease overall performance against the mixture [6].

C. Fine Aggregate

The function of fine aggregates is in graded gaps, subtle aggregates at # 8 to # 30 are reduced to obtain adequate air cavities for certain amounts of bitumen. The balance of the proportion of the use of coarse and fine aggregates is important in order to obtain a non-slippery surface with the desired amount of bitumen. Fine aggregates are generally used to fill cavities and stabilize coarse aggregates in pavement structures and have a potential effect on pavement performance [7]. The aggregate consists of coarse particles (> 2 mm) and fine particles (<2 mm), both of which have very different effects on the asphalt mixture. In the internal structure, coarse aggregates are generally responsible for aggregate interlocking, thus forming a granular structure which increases the stability of the asphalt mixture. To ensure the integrity of the asphalt mixture, fine aggregates are added to the coarse aggregate frame and provide an important effect on mixed shear resistance [8].

D. Asphalt

Asphalt is a material which at room temperature is solid to slightly dense, and is thermoplastic. Asphalt will melt if heated to a certain temperature, and again freezes when the temperature drops [9].

E. Fly Ash

Fly ash must be activated with sodium hydroxide and sodium silicate. The finer the fly ash particles show the shortest time in the formation of geopolymers. The compressive strength, melt and drying of shrinkage in fine particle fly ash shows the best characteristics [10]. Fly ash used is the result of coal combustion. Fly ash is a pozzolanic material, namely silicate minerals and alumina which can react with calcium hydroxide and form cement compounds.

III. METHOD

The method of this research is done by preparing artificial aggregates first. In the process of making artificial aggregates, compiler materials such as fly ash and alkali activator are needed (Na_2SiO_3 and NaOH). The alkali composition of activator used in this study follows secondary data taken from previous studies, namely 1: 2.5 [11]. The comparison of fly ash and alkali activator used is 75%: 25%. In this study the artificial aggregate used is divided into 2 forms, namely:

1) Artificial aggregates are round, this aggregate is made through a granulator machine.
2) Artificial aggregates produced from the stone crusher, the first step in making this aggregate composition of the prepared mixture inserted into the mold then stirred and waited for 28 days to harden. After that, the artificial aggregate is removed from the mold and inserted into the stone crusher.

The prepared artificial aggregate is then mixed with asphalt using the Marshall Method following the specifications of the Federal Aviation Administration (FAA). The asphalt mixture variations in this study are:

1) Variation 1 (V1) 100% Natural Aggregate (AA)
2) Variation 2 (V2) 25% Rounded Aggregate (AB)
3) Variation 3 (V3) 25% AB 25% Stone Crusher Aggregate (ABSC) 50% AA
4) Variation 4 (V4) 25% AB 75% ABSC

This study uses a dense gradation following FAA specifications. The following of Fig 2 are FAA gradation specifications used in this study.

(a) (b) (c)

Figure 1. (a) Fly Ash (b) Activator (c) Mold

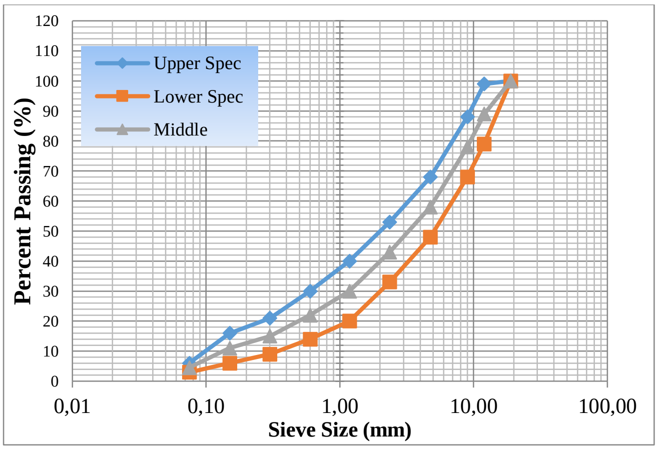

Figure 2. Dense Graded Distribution

A. Marshall Test

There are several methods for planning a good mix, one of which is the Marshall test. The mixed method that is most widely used in Indonesia today is a mixed design method based on empirical testing, namely by using a Marshall tool [3]. The Marshall test is an important step in determining the characteristics of a paved mixture.

Characteristics of paved mixtures which are Marshall parameters are density, void in mixture (VIM), void in mineral aggregate (VMA), void filled in asphalt (VFA), Stability, flow and Marshall Quotient. Table 1 is a requirement for FAA Marshall specifications for airport pavement:

Table 1.
Spesification Of Flexible Pavement (Airport)

Properties	Airport Pavement Design (gross weights) ≥60.000 Lbs (≥27216 kg) dan Tire pressures ≥100 psi
Amount of Impact	75
Stability, pounds (Newtons) minimum	2150 (9560)
Flow	10-16
Target air voids	3.5
VMA	15%

Source : Federal Aviation Administration (2014)

IV. RESULTS AND DISCUSSION

A. *Artificial Aggregate Characteristics*

To find out the value of properties produced by artificial aggregates, several tests were carried out. This is needed to see the feasibility of artificial aggregates in the asphalt mixture. The tests carried out are specific gravity testing, water absorption, attachment to asphalt, abrasion and impact. Table 2 and Table 3 are the results of testing the characteristics of artificial aggregates.

Table 2.
Result of AB Characteristic.

Test	Spesification	Result
Bulk Specific Gravity, gr/cm^3	-	1.85
Absorption, %	Maks. 3	6.08
Soundness, %	Maks. 18	5.219
Abrasion, %	Maks. 40	22.78
Affinity Aggregate of Ashpalt, %	Min. 95	97

Table 3.
Result of ABSC Characteristic.

Test	Spesification	Result
Bulk Specific Gravity, gr/cm^3	-	1.963
Absorption, %	Maks. 3	5.840
Abrasion, %	Maks. 40	24.03
Affinity Aggregate of Ashpalt, %	Min. 95	96
Impact, %	Maks. 30	14.11

Based on Table 2 and Table 3 it can be seen that the value of both property of the artificial aggregate has fulfilled the specification. Only the absorption value of the two types of artificial aggregates does not meet the requirements of greater than 3%. But for other parameters, the value obtained has met the requirements so that it can be used in the asphalt mixture.

B. *Characteristics of Asphalt Mixture*

Marshall testing on optimum bitumen content was carried out to determine the best Marshall characteristics in each mixed variation. From this result, a mixture of artificial aggregate variations that are suitable for use on flexible pavements will be obtained. The optimum bitumen content value in each mixture variation produces different values. The following are the results of Marshall testing on each mixture variation at the optimum bitumen content of each mixture.

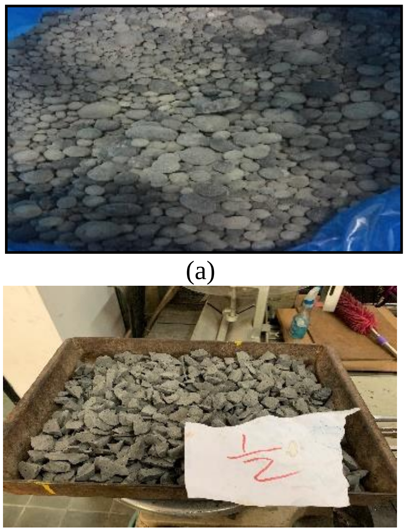
(a)
(b)
Figure 3. (a) AB (b) ABSC

Table 4.
Result of Marshall Characteristic on Optimum Bitument Content (V1)

Test	Result	Spesification
Optimum Bitument Content (%)	5.875	-
Density (g/cm3)	2.33	-
Flow (mm)	3.93	2.5-4
VIM (%)	3.78	3-4
VMA (%)	18.24	≥ 15
VFA (%)	79.3	76-82
Stability (Kg)	1916.97	≥ 2150 lbs (971kg)
MQ (Kg/mm)	490.52	≥ 250

Table 5.
Result of Marshall Characteristic on Optimum Bitument Content (V2)

Test	Result	Spesification
Optimum Bitument Content (%)	5.10	-
Density (g/cm3)	3.6	-
Flow (mm)	3.76	2.5-4
VIM (%)	5.10	3-4
VMA (%)	17.88	≥ 15
VFA (%)	78.97	76-82
Stability (Kg)	2039.08	≥ 2150 lbs (971kg)
MQ (Kg/mm)	571.79	≥ 250

Table 6.
Result of Marshall Characteristic on Optimum Bitument Content (V3)

Test	Result	Spesification
Optimum Bitument Content (%)	6.325	-
Density (g/cm3)	2.16	-
Flow (mm)	3.43	2.5-4
VIM (%)	3.72	3-4
VMA (%)	17.32	≥ 15
VFA (%)	78.55	76-82
Stability (Kg)	1301.89	≥ 2150 lbs (971kg)
MQ (Kg/mm)	381.43	≥ 250

Table 7.
Result of Marshall Characteristic on Optimum Bitument Content (V4)

Test	Result	Spesification
Optimum Bitument Content (%)	6.50	-
Density (g/cm3)	2.03	-
Flow (mm)	3.6	2.5-4
VIM (%)	3.81	3-4
VMA (%)	16.09	≥ 15
VFA (%)	76.33	76-82
Stability (Kg)	1258.13	≥ 2150 lbs (971kg)
MQ (Kg/mm)	358.54	≥ 250

Based on Table 4, 5, 6, and Table 7 it can be seen the value of Marshall characteristics on the optimum bitumen content test. The effect of artificial aggregates gives different results in each mixed variation. In all Marshall tests the optimum bitumen content of all variations meets the specified specifications. The use of artificial aggregates gives a relatively larger optimum bitumen value. Mixes of V2 gives the biggest stabililty , 2039.08 kg.

C. Marshall Test Analysis

The Marshall test results that have been obtained are then analyzed to see how the effect of the use of artificial aggregates on the characteristics of the asphalt mixture.

1) Arttificial aggregates and stability

Artificial aggregates and Stability can be seen in Figure 4 . The addition of the aggregate percentage of artificial stone crusher to the mixture decreases Stability. The more number of artificial aggregates, Stability tends to decrease. However, the stability values provided still meet the specified specifications. Addition of 25% AB gives Stability of 2039 kg. Decreased Stability that occurs due to the addition of artificial stone crusher aggregates due to irregularities in the resulting shape. Apart from that, a smaller abrasion value also causes the aggregate to be used more worn out, thus reducing the stability. The use of artificial aggregates in asphalt mixture is still able to provide good results and meet specifications set by the FAA.

2) Arttificial aggregates and flow

Artificial aggregate and flow can be seen in Figure 5 that the flow value produced tends to fluctuate. There is no difference that is too large, the given flow value still meets the requirements. The 100% AA mixture gives the highest flow value of 3.93 mm. Artificial aggregates can still be used in any asphalt mixture varied. Mixtures that have a low flow value and high Stability will become rigid pavements so that they are prone to cracking, while the asphalt mixture which has a high flow value and low Stability has a more plastic nature which has the potential meet permanent deformation at the time of loading.

3) Arttificial aggregates against air void (VIM)

Artificial aggregates against Air Void (VIM) can be seen in Figure 6 that the value of the void in the mixture in each variation of the mixture has met the requirements. The use of artificial aggregates is able to provide a good VIM value due to the increasing use of asphalt levels in this mixture.VIM values affect the durability of the mixture and are needed to provide enough space for compaction due to traffic loads and also the effect of increasing temperature. Therefore the VIM value determines the characteristics of the mixture.

4) Arttificial aggregates and VMA

Artificial aggregates and VMA can be seen in Fig. 7 that the values of VMA in each variation of asphalt mixture have met the specifications. The use of artificial aggregates gives a VMA value that is close to the minimum. VMA values close to the minimum limit indicate that the mixture has more durability while the high VMA value will cause the mixture to experience large deformations. The use of artificial aggregates can provide VMA values that are closer to the minimum so that the mixture will have more durability.

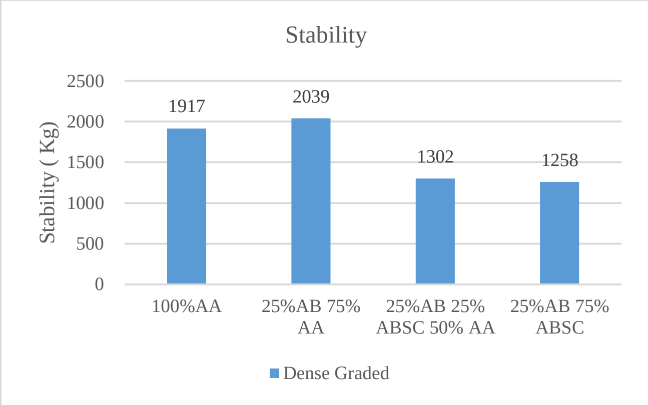

Figure 4. Mixture VS Stability

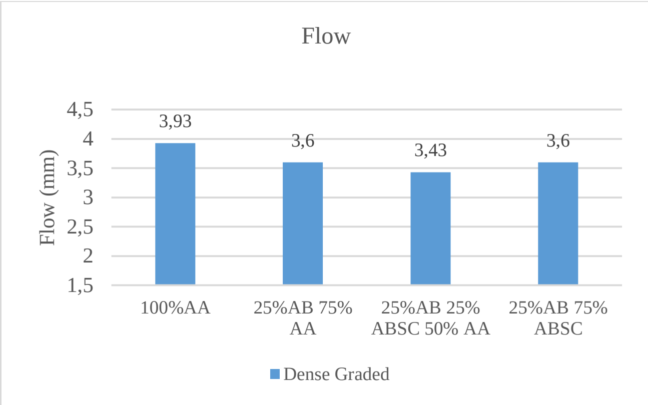

Figure 5. Mixture VS Flow

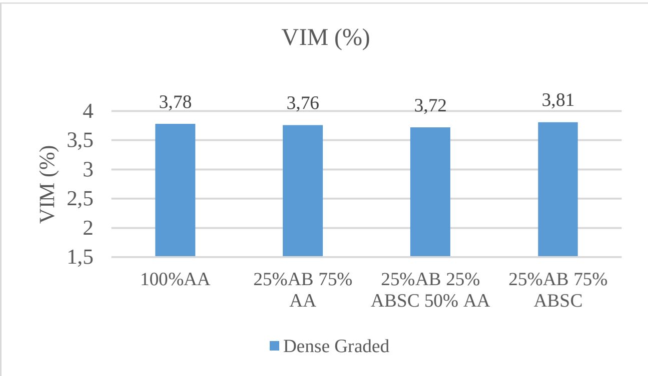

Figure 6. Mixture VS Air Void (VIM)

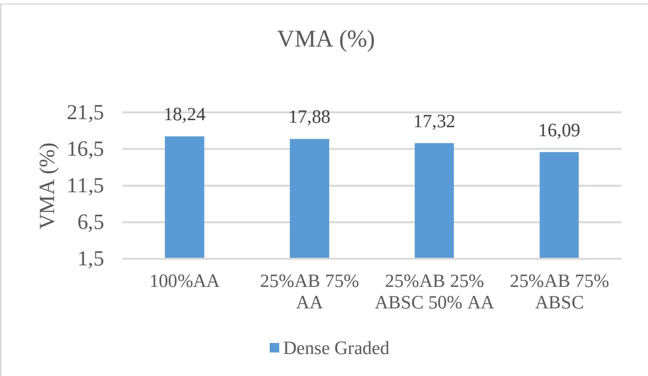

Figure 7. Mixture VS Void in Mineral Aggregate (VMA)

V. CONCLUSION

Based on the research that has been carried out, the tests for the values of round artificial aggregate and stone crusher characteristics have fulfilled the specified specifications so that they can be used on flexible pavements.The use of artificial aggregates requires an optimum asphalt level which is relatively higher, V4 gives the optimum asphalt content value of 6.5% while V1 is only 5.85%. This is because the absorption value of artificial aggregates is greater than 3%. This is due to differences in the large absorption values of the artificial aggregates against natural aggregates, this large absorption value indicates that the artificial aggregates have pores so that they absorb larger asphalt, but paraffin is used for soaking the pore size which is actually in the mixture. In addition, the magnitude of the abrasion value on the artificial aggregate makes a decrease in stability.

Marshall characteristic values for each mixed variation meet the specified specifications. The artificial aggregate of stone crusher tends to reduce the Stability value, this is because the aggregate produced has an irregular shape which affects the interlocking power between aggregates and also its caused by the degradation that occurs in the aggregate causing the size of the coarse fraction to change, for example the previous aggregate size is No. 3/8 but when there is collision, there is a broken aggregate which causes a shift in size on the aggregate.

The use of artificial aggregates provide VMA values that are close to the minimum, meaning that the use of artificial aggregates shows that the mixture has more durability. Based on all the results of this study, the application of artificial aggregates to coarse aggregates can be an alternative as an aggregate substitute. if the use of this artificial aggregate can be applied, this will help reduce the use of natural aggregates that endanger the environment.

REFERENCES

[1] H. Wang, Y. Bu, Y. Wang, X. Yang, and Z. You, "The Effect of Morphological Characteristic of Coarse Aggregates Measured with Fractal Dimension on Asphalt Mixture ' s High-Temperature Performance," vol. 2016, 2016.

[2] P. Cui, Y. Xiao, B. Yan, M. Li, and S. Wu, "Morphological characteristics of aggregates and their influence on the performance of asphalt mixture," *Constr. Build. Mater.*, vol. 186, pp. 303–312, 2018.

[3] J. Davidovits, *Geopolymer*, 4th Editio. Saint-Quentin, France: Institut Geopolymere, 2015.

[4] B. Sengoz, A. Onsori, and A. Topal, "Effect of aggregate shape on the surface properties of flexible pavement," *KSCE J. Civ. Eng.*, vol. 18, no. 5, pp. 1364–1371, 2014.

[5] H. Guo, Y. Zhao, D. Zhang, and M. Shang, "Study of movement of coarse aggregates in the formation process of asphalt mixture in the laboratory," *Constr. Build. Mater.*, vol. 111, pp. 743–750, 2016.

[6] M. Tokyay and T. Akcaoglu, "Determining Aggregate Size & Shape Effect On Concrete Microcracking Under Compression By Means of A Degree Of Reversibility Method," pp. 2–7, 2004.

[7] C. Lin and W. Tongjing, "Effect of fine aggregate angularity on skid-resistance of asphalt pavement using accelerated pavement testing," *Constr. Build. Mater.*, vol. 168, pp. 41–46, 2018.

[8] X. Xie, G. Lu, P. Liu, D. Wang, Q. Fan, and M. Oeser, "Evaluation of morphological characteristics of fine aggregate in asphalt pavement," *Constr. Build. Mater.*, vol. 139, pp. 1–8, 2017.

[9] S. Sukirman, *Beton Aspal Campuran Panas*. Jakarta: Granit, 2003.

[10] P. Chindaprasirt, T. Chaeerat, S. Hatanaka, and T. Cao, "High-Streght Geopolymer Using Fine High-Calcium Fly Ash," *J. mateials Civ. Eng.*, 2011.

[11] I. D. A. Karyawan, E. Ahyudanari, and J. J. Ekaputri, "Potential Use of Fly Ash Base-Geopolymeras Aggregate Substitution in Asphalt Concrete Mixtures," *Int. J. Eng. Technol.*, vol. 9, no. 5, pp. 3744–3752, 2017.