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THE EFFECT OF SLOPE GRANULATOR ON THE CHARACTERISTIC OF ARTIFICIAL GEOPOLYMER AGGREGATE USED IN PAVEMENT

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Abstract

Infrastructure development uses aggregate as the main material. However, aggregate stocks in nature are limited because of the increasing demand. On the other hand, there is an accumulation of fly ash as a result of coal combustion in the power plant. Fly ash geopolymer can be formed into aggregate by cold bounding method with granulator machine. It is expected to replace the role of natural aggregate as a pavement material. The artificial aggregate is made by mixing fly ash with alkali activator using a granulator machine. The variation slope of granulator is 45°, 50°, and 55°. Artificial aggregates follow the specifications of Indonesian pavement material. The artificial aggregates obtained are examined through one way-ANOVA to determine the effect of the slope to the aggregate characteristic. The results show that the values of aggregate durability, hardness, and bitumen adhesion meet the requirement. However, the absorption and specific gravity fail to meet the requirement. The ANOVA test showed that the slope of the granulator affects the aggregate characteristics, those are the absorption and specific gravity of artificial aggregates. Artificial aggregate at a slope of greater than 50° formed more rapidly.

Keywords: Alkali, Artificial aggregate, Fly ash, Geopolymer, Pavement, The slope of the granulator.

1. Introduction

Aggregate is natural mineral granules functioning as fillers in the mixture of mortar, concrete and asphalt concrete. This aggregate occupies approximately 60%-75% by mix volume [1, 2]. Aggregate strongly affect the characteristics of concrete or asphalt concrete due to its gradation. Therefore, the aggregate selection is the fundamental aspect of preparing the mixture of asphalt pavement. As the infrastructure requires a large volume of aggregates, the availability of the natural aggregate also will decrease. On the other hand, the accumulation of coal waste [3] raised another problem. There is a need to manage the coal waste disposal [4].

Chugh and Behum [4] proposed to deal with coal waste disposal, waste management. They consider the variation on the waste generation rate, engineering properties that influence the requirement of water discharge and the period of waste placement. The excessive production of coal waste, drove the researcher to find the formula to reduce the number of coal waste. Some of them create bricks [5, 6] and artificial aggregate [7, 8]. The production of artificial aggregate that makes use of coal waste was not clearly published. This research aim is to share the results related to processing artificial aggregate production. The artificial aggregate introduced in this paper is to make used coal waste, i.e., fly ash. The fly ash will form new material after mixing with alkali. This new material called geopolymer.

Geopolymer is a material produced from the synthesis of polymeric aluminosilicate and alkali resulting in a tetrahedral bounding polymer of SiO_3 and AlO_4 [9]. Rattanasak and Chindaprasirt [10] explained that the fly ash, which is rich with silica and alumina has the full potential to be used as one of the sources for polymer binder. Artificial aggregate utilizes fly ash as basis material in the manufacture. Fly ash-based aggregates are a necessity for current construction to reduce heavy load structures and reduce construction costs because of its lightweight [11]. The geopolymer characteristics of fly ash have been studied extensively in the last decade [12]. Many studies conducted to maximize the utilization of fly ash waste. To make of paste binder geopolymer with a variation of alkali solution ratio between 0.5-2.5 to obtain the high compressive strength [13, 14]. The geopolymer paste binder made of fly ash is used as filler with several variations on the alkaline ratio to obtain high compressive strength. It was made using an alkaline solution with a variation ratio of 1.5-2.5 [15]. Production of artificial aggregate based on fly ash geopolymer uses several methods such as palletisation with pellet disk, cold-bonded, sintering, autoclaving. The effectiveness of the method depends on the speed, the slope, and the duration of the tools [16-21]. Previous studied produces aggregates from fly ash using a disc (pan) pelletizer machine at an angle of 36° to 50°, the efficiency production was the higher and perfect shape of the pellet at an angle of 36° produce with sized between 9-11 mm [16, 17, 22]. Other studies by Gesoglu et al. [19] shown that the efficiency of pellets is more efficient on the pelletizer angle, the angle of pelletizer lower than 35° or greater than 45º can result in the fly ash aggregates could not be made a higher strength pellets. The production of artificial geopolymer aggregate with a sintering method with a 36° angle obtained aggregates with a maximum size of 20 mm with SSD and OD values 1.68 and 1.21, while the absorption value was 39.01% [18]. Others showed that an angle of 55° is maintained as per previous studies, which give better palletisation efficiency and good grading of pellets [23].

The artificial aggregate using geopolymer fly ash uses the granulation technique. Granulation is the process of creating large particles called granules of a powder having a binding power. According to Mashinchian et al. [24], the granulation process uses two methods: wet granulation and dry granulation. Several factors affect the process of granulation; one of those is the slope of the granulator pan. A good granulator slope rate will release the best granules, the extreme high erect levels will make the material difficult to granulate while the extreme slight of the granular slope will cause the granules to have a large size but granules resulted are not dense enough [25]. The pan/disc granulation proves to be an effective method to produce artificial aggregate easier than compared to drum or cone granulation [23]. The different types of granulation machine were used to make the granule such as disc or pan type, drum type, cone type, and mixer type. With disc (pan) type the size distribution is easier to control than drum type. With pan type for granulation, the small grains are formed initially and are subsequently increased in large particle size [21]. Based on the description above, it is necessary to conduct in-depth and specific research on the effect of slope granulator on the artificial geopolymer aggregate.

This research aimed at identifying the effect of slope granulator on the characteristic and the grain size of artificial aggregate. The aggregate characteristic test was performed by referring to the third revision of the general specification of Bina Marga 2010. Bina Marga is one of directorate general of Ministry of Public Works in Indonesia that specialises in road infrastructure.

2. Experimental Program

Fly ash used in this study was coal-burning residue from Suralaya 1 - 4 steam power plant, Pulo Merak district, Cilegon city, Banten, Indonesia. Testing chemical element content in fly ash was carried out at Energy Laboratory, Institut Teknologi Sepuluh Nopember Surabaya. Fly ash Suralaya is classified as fly ash class F according to ASTM C-36. This is indicated by the amount of Al_2SiO_3, SiO_3 and Fe_2O_3 content of 81.5% greater than 70% [26, 27]. The alkaline solution is made of aqueous NaOH and Na_2SiO_3 liquid [15, 28]. The aquadus NaOH was prepared with eight molar molarity, NaOH flakes with 98% purity and aqueous and waited for 24 hours [15, 27, 29]. Meanwhile, Na_2SiO_3 acts as a binder used in the form of a viscous liquid, which is ready to use [30].

In this study by Hardjito et al. [13], Ekaputri and Damayanti [14], Karyawan et al. [15], Memon et al. [27], Aravindan et al. [28] and Dutta et al. [29], the mass of fly ash/alkali activator is 25:75%, while the ratio of Na_2SiO_3/NaOH is 2.5:1 and they keep constant. Artificial geopolymer aggregate is made by using a granulator machine consisting of a granulator pan driven at a rotational speed of 26 rpm, a pan diameter of 120 cm and weight of about 20-50 kg with variations of the slope are 45°, 50°, and 55°. The artificial geopolymer aggregate was made then tested according to the aggregate testing procedure on SNI and analysed in accordance with the specifications of pavement material on the third revision of general specification of Bina Marga 2010 as shown in Table 1 and used the One Way ANOVA to know the effect of slope granulator on the grain size and the characteristic of artificial geopolymer aggregate, with the initial hypothesis that slope has an effect on the size and characteristics of artificial geopolymer aggregate.

The specification adopted is Bina Marga, an Indonesian Public Work authority, since the characteristics of each coal waste will be different following the geographical position of the coal mining, and the process of the coal waste [31].

Artificial geopolymer aggregate testing requires artificial aggregate material. Artificial geopolymer aggregate must meet the aggregate requirement for each artificial geopolymer aggregate characteristic test, the amount of artificial geopolymer aggregate requirements is shown in Table 2.

Table 2 shows the total aggregate requirements artificial geopolymer aggregate for each test. Each test requires 2 samples, thereby, the total aggregate requirements artificial aggregate is 53.400 gram.

Table 1. Parameter of aggregate as a materials pavement based on third revision of general specification of Bina Marga 2010.

Test			Standard	Value [32]
Water absorption			SNI 1969:2008 [33]	Max 3 %
Durability	Natrium sulfate (Na_2SO_4)		SNI 3407:2008 [34]	Max 12%
	Magnesium sulfate ($MgSO_4$)			Max 18%
Hardness	AC modification mixture	100 rounds	SNI 2417:2008 [35]	Max 6%
		500 rounds		Max 30%
	Asphalt mixture in other graded	100 rounds		Max 8%
		500 rounds		Max 40%
Adhesion			SNI 2439:2011 [36]	Min 95%

Table 2. Summary of artificial geopolymer aggregate needs.

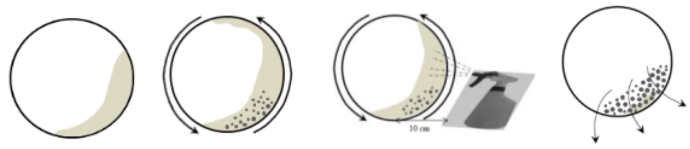
Sieve number	**Type of test**			
	Durability (grams) [34]	**Hardness (grams) [35]**	**Adhesion (grams) [36]**	**Specific gravity and absorption (grams) [33]**
1" (25 mm)	-	-	-	-
3/4"(19.1 mm)	-	2500	-	-
1/2"(12.5 mm)	670	2500	-	-
3/8"(9.5 mm)	330	-	-	2500
No. 4 (4.75 m)	300	-	100	-
Required weight (grams)	1300	5000	100	2500
Required for one variation of slope			= 8.900 grams	
Slope variation			= 3 (45°, 50°, 55°)	
A sample for each test			= 2 sample	
Total of required weights			**= 53.400 grams**	

3. Manufacturing Process of Artificial Geopolymer Aggregate

In the manufacturing process defined in four stages with variation angle of slope as shown in Figs. 1 and 2. The first step is to put in fly ash into a pan in the idle condition in stage 1 of Fig. 1(a). Turn on the granulator machine driven at a constant rotating speed of 26 rpm and spray the alkaline solution to fly ash.

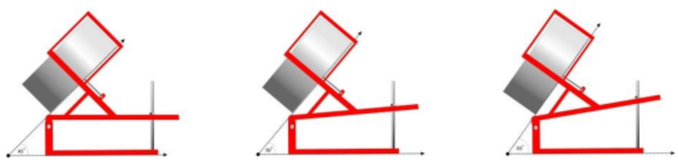
Fly ash will react with alkaline solutions and begin to granulate after 2-3 minutes of spraying as seen in stage 2 in Figs. 1(c) and (d). Turn off the granulator machine when the aggregate has started out from granulator pan as the last stage in

Fig. 1(d). Repeat the steps in Figs. 1(a) to (d) in each variation of slope granulator. The aggregate that has made-up is rolled over the fly ash. Within one granulation process, the aggregate produced different grain size depending on the slope of granulator [16, 17, 37-40].



(a) (b) (c) (d)

Fig. 1. Manufacturing process of artificial geopolymer aggregates.



(a) 45°. (b) 50°. (c) 55°.

Fig. 2. Variation of slope granulator.

3.1. Testing and analysis

Geopolymer aggregate testing would be performed after 28 days of treatment at a normal temperature [41-43]. Aggregate characteristic testing includes specific gravity, absorption, abrasion, durability, and bitumen adhesion of aggregate. Test of specific gravity and aggregate absorption is intended to determine the artificial geopolymer aggregate weight and its ability to absorb the water [33]. Test of the durability aggregate aims to determine the durability of aggregate by the sodium sulfate solution [34]. Test of the hardness aggregate aims to determine the hardness of aggregate resistance with the Los Angles machine [35]. While the test of bitumen adhesion aims to determine the percentage of aggregate surface area covered by asphalt to the aggregate surface [36].

One way ANOVA is a process of analysing data obtained from the experiment with various levels of a factor, usually more than two levels of the factor. The purpose of this analysis is to identify important independent variables and determine how they affect the response. The model for this statistical analysis is as follows [44].

$$y_{ij} = \mu + \tau_i + \epsilon_{ij} \begin{cases} i=1,2,\ldots a \\ j=1,2,\ldots,n \end{cases} \qquad (1)$$

The null and alternative hypotheses for this statistical analysis are:

H_0: $\mu_1 = \mu_2 = \cdots = \mu_a$ or equivalently, H_0: $\tau_1 = \tau_2 = \cdots = \tau_a = 0$

H_1: $\mu_i \neq \mu_j$ for at least one pair (i,j)

The H_0 hypothesis should be rejected and conclude that there are differences in the treatment means if:

$$F > F_{\infty, a-1, n-a} \quad (2)$$

4. Results and Discussion

4.1. Aggregate gradation

The result of gradation test of the artificial geopolymer aggregate by each variation of the slope is shown in Fig. 3.

Figure 3 shows that the 50^0 slope presents a higher gap graded. The size of 9.5 mm and 12.5 mm indicates that the results have a larger range of variation compare to other sizes.

Based on the result of aggregate gradation, in different types of slope, in general, all types of slope released aggregate in size of 25 mm-2.36 mm. The manufacturing process of artificial geopolymer aggregate used 75% of fly ash and 25% of alkali solution. In practice, the alkaline solution has not completely used but fly ash was perfectly granulated, from the residual alkali obtained ratio value of fly ash/alkaline solution ranges between 0.30-0.32. As shown in Fig. 3, artificial geopolymer aggregate produced at different slope and rotated at the same speed produce aggregate with different weights on each aggregate size.

The difference in weight of each aggregate size is due to the duration in the aggregate manufacturing process, if the aggregate duration is ±15 minutes or more, then the aggregate that has granulated well on the size of 19.1 mm or 12.5 mm will crack and become a new granule, which is smaller but with the less good shape. Also, in the process, there is a fly ash material that sticks on the pan granulator and does not form the granules thus, reducing the amount of aggregate that is formed. In addition, it can be seen the slope of 50° does not produce aggregate with size 2.36 mm.

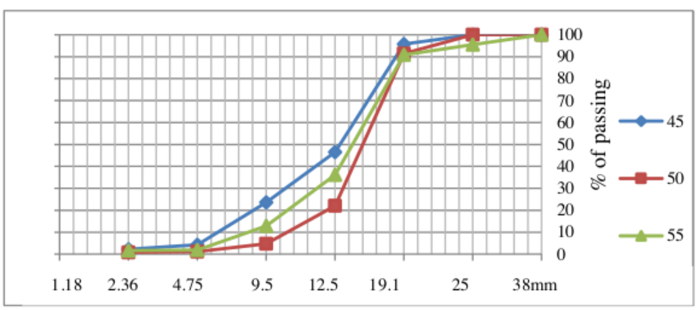


Fig. 3. Artificial geopolymer aggregate gradation.

The aggregate of this size is formed by certain treatments such as those formed from materials that have not granulated well during the aggregate production process from the aggregate pan in rolled over the fly ash. As a result, of the process size aggregate size of 2.36 mm is formed, besides the special treatment that can be done to obtain aggregate with this size is to let fly ash that has not granulate well in the pan and rotated with the same speed while sprinkling the new fly ash so that granule formed the size of 2.36 mm. This is can also be seen in the aggregate shape as shown in Fig. 4, which is the result of manufacturing the aggregates in one time granulation process at each slope. The aggregates produced in a round shape almost resemble natural aggregates, the rounded shape of artificial geopolymer aggregate gives better workability compared to the natural aggregate [45]. In addition, aggregate at a slope of 45° and 55° have more ash particles with moisture film than the aggregate at a slope of 50°. Ash particles with moisture film unfinished react with the alkali solution, it cause aggregates not to form and only moisturize fly ash into small lumps that are not good, not dense and do not resemble aggregates.

As shown in Table 3, the value of calculated $F = 5.79$. The value of F critical ($F_{0.05,2,15}$) by using the significant level of 95% ($\alpha = 0.05$), with the degree of freedom is 2(a-1) and the degree of freedom error is 15 (N-a) then from the table F-distribution it can be found that $F_{(0.05,\,2,\,15)} = 3.11$. Because the value of $F = 5.79 > 3.11$, H_0 will be rejected, which mean the level is different. It indicates that the slope of granulator has a significant effect on the size of the artificial geopolymer aggregate.

Table 3. Result of one way ANOVA on the gradation data.

Source variation	Sum of squares	Degree of freedom	Mean squares	F_0	$F_{critical}$
Between treatments	2114515	5	422903.1	5.79	3.11
Within treatments	876614.7	12	73051.22		
Total	2991130	17			

(a) 45°. (b) 50°. (c) 55°.

Fig. 4. Artificial geopolymer aggregates.

4.2. Characteristic of artificial geopolymer aggregate

The result of the test of the characteristics of artificial geopolymer aggregate by each variation of a complete slope angle is shown in Table 4.

Statistical analysis of one-way anova on characteristic of artificial geopolymer aggregate shows that the value of the calculated F on the specific gravity and aggregate absorption is greater than the F critical ($F_{0.05,\,2,\,3}$). Meanwhile, the value of the calculated F on the other test is less than the F critical. Based on this, it can be claimed that the slope of granulator has a significant effect on the values of specific gravity and aggregate absorption, but it does not affect the values of aggregate hardness, durability, and bitumen adhesion.

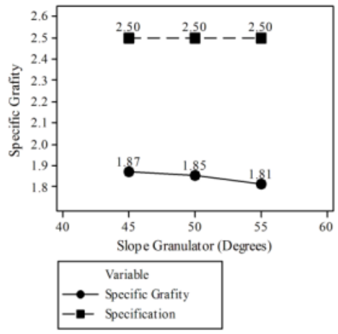
Table 4. Resume of value of aggregate characteristic.

No.	Test	45°	50°	55°	Specification of Bina Marga 2010	ASTM
1	Specific gravity	1.87	1.85	1.81	> 2.50	> 2.50
2	Absorption (%)	6.80	6.08	10.24	Max 3	Max 2
3	Durability (%)	6.13	5.22	3.27	Max 12	Max 12
4	Hardness (%)	23.27	22.78	24.35	Max 40	Max 50
5	Bitumen adhesion (%)	95.50	97.00	97.50	Min 95	-

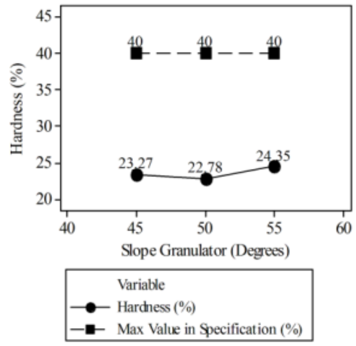
Referring to the result of the test of the characteristics of aggregate from Table 5 and Fig. 5, indicated that the specific gravity and aggregate absorption of all variations of aggregate slope do not fulfill the requirements of the third revision of General Specification of Bina Marga 2010. However, the slope of 50° can be regarded as the preferred slope in producing the aggregate because it has the best shape and surface. Additionally, this slope gives the lowest absorption value compared to the other slope.

Table 5. Result of one way ANOVA on aggregate characteristic.

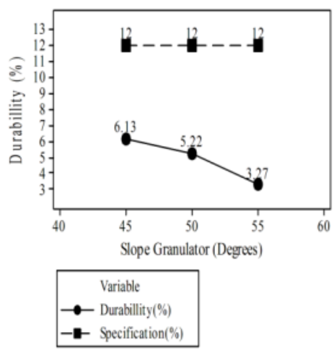
Source variation	Sum of squares	Degree of freedom	Mean squares	F_0	$F_{critical}$
Specific gravity					
Between treatments	0.0046	2	0.0023	17.29	9.55
Within treatments	0.0004	3	0.000133		
Total	0.005	5			
Absorption					
Between treatments	19.77	2	9.88	33.94	9.55
Within treatments	0.87	3	0.29		
Total	20.64	5			
Durability					
Between treatments	8.56	2	4.28	0.87	9.55
Within treatments	14.69	3	4.89		
Total	23.25	5			
Hardness					
Between treatments	2.58	2	1.29	0.54	9.55
Within treatments	7.08	3	2.36		
Total	9.66	5			
Bitumen adhesion					
Between treatments	4.33	2	2.17	0.92	9.55
Within treatments	7	3	2.33		
Total	11.33	5			



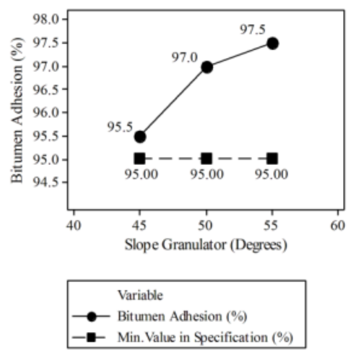
(a) Value of specific gravity.



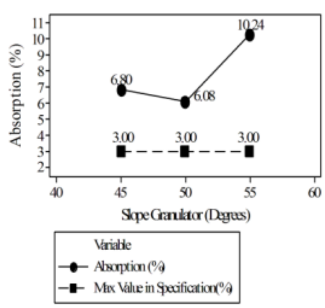
(b) Value of hardness.



(c) Value of durability.



(d) Value of bitumen adhesion.



(e) Value of absorption.

Fig. 5. Result of test of characteristics of artificial geopolymer aggregate.

The other aggregate characteristic values that have fulfilled a third of specification of Bina Marga 2010 also result from this slope. The low value of specific gravity and the amount of absorption is caused by several factors such as the number of pores in artificial geopolymer aggregate; according to the statement that flies ash based geopolymer material is very porous [28].

The granulator with an angle more than 50° will produce the aggregate with more pores but the producing process easier. The angle under 50° also produced aggregate with pore but the process of producing more difficult. Consequently, it is necessary to change the mix design such as changes in ratio value or concentration of NaOH solution to obtain specific gravity and absorption according to the specification.

Table 6 shows a comparison of the characteristics of aggregates with different slope variations. Previous research shows low specific gravity values, greater absorption and hardness values. The process of manufacturing artificial geopolymer aggregate is best obtained at a slope of 50°, NaOH and Na_2SiO_3 as an alkali activator with a ratio of 2.5. This can be seen from the aggregates characteristic values that are relatively better than artificial aggregates with other slopes.

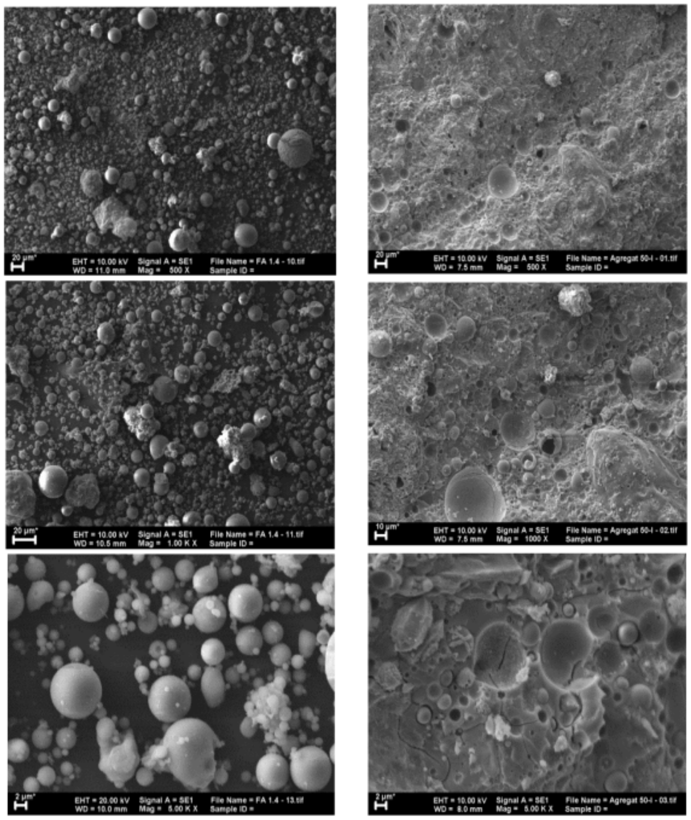
Table 6. Comparison of characteristic values of artificial aggregates with previous research.

Test	45°	50°	55°	36° [16]	45° [37]	45° [38]	35° [39]
Specific gravity	1.87	1.85	1.81	1.89	1.69	2.14	1.55
Absorption (%)	6.80	6.08	10.24	21.26	12.9	10.30	29.4
Durability (%)	6.13	5.22	3.27	-	-	1.42	-
Hardness (%)	23.27	22.78	24.35	50.47	30.7	34.00	-
Bitumen adhesion (%)	95.50	97.00	97.50	-	-	15	-
Shape	Round	Round	Round	Round	Round	Round	Round

4.3. Scanning electron microscope (SEM)

An artificial aggregate is derived from fly ash based on geopolymer paste [15]. This research shows that slope affects the grain size and aggregate characteristic values, especially the value of specific gravity and absorption. The values of specific gravity and aggregate absorption do not fulfil the characteristic as a pavement material. This suggests that artificial geopolymer aggregate have more pores. It can be seen in Fig. 6, the result SEM as follows.

The microscopic structure of the fly ash aggregates revealed in low and high magnification by Scanning Electron Microscopy (SEM). It can be seen in Fig. 6 that all the above SEM Images of Fly ash aggregates and arrangement of fly ash particles are occupied very compact and homogeneous [46]. The crystalline structure of fly ash remains and resulting in pores on artificial geopolymer aggregates. Based on the statement that the presence of pores in the aggregate filled with particles crystals of fly ash, which absorbs more water and also the pores in the inner and outer core of the aggregates resulting in more absorption [46]. On the process of manufacturing artificial geopolymer aggregate fly ash is moisturized forms a liquid on the surface of the grains, which forms the granule, then they formed ball shapes structure with increased bonding force between the grains due to centrifugal and gravitational forces based on the slope granulator. In the process of granulation the fly ash that has not granulate or not reacted with alkali, which then granulates with ball shape that has been perfect, so that, the pores formed. This process produces aggregate with a relatively large size but has more pores.



Fly ash. **Artificial aggregate 50°.**

Fig. 6. Resulting tests SEM the fly ash and artificial geopolymer aggregate.

Other characteristics of artificial geopolymer aggregate such as aggregate hardness with low angles to find out compressive strength. The aggregate hardness value was determined to confirm whether it is less than 30% and 45% and the low value of specific gravity compare to natural aggregate proves it to be used in road construction and building construction as a lightweight aggregate on the concrete mix [16, 47]. The use of aggregates in concrete presents a positive aspect, some benefits including the concrete density achieved by artificial geopolymer aggregate, which allows reducing the dead load structure, column dimensions, slabs, and beams.

Overall, artificial geopolymer aggregate has not fulfilled the third revision of the General Specification of Bina Marga 2010 namely the values of specific gravity and aggregate absorption. However, by principles of pavement engineering, there is six tasks that pavement has to fulfill, namely, protect the subgrade, guard against deformation in the pavement layers, guard against the break-up of the pavement layers, protect from environmental attack, provide a suitable surface, and ensure maintainability. When follows the six principles of pavement engineering. Therefore, artificial geopolymer aggregate can replace the role of natural aggregate as an aggregate on pavement material.

4. Conclusions

The production of artificial geopolymer aggregate has been done so that the geopolymer aggregate obtained, which is then tested for the characteristics of artificial geopolymer aggregate and statistical analysis using one-way anova. some conclusions obtained from the research are given below.

- Artificial aggregate results from each slope of 45°, 50°, and 55° have relatively small aggregate size differences. In general, the artificial geopolymer aggregate released is the aggregate in size 3/4 inch (19.1 mm) - No. 8 (2.36 mm), but at an angle of 55°, there is the relatively large amount of 1 inch (25 mm) aggregate.
- From the result of the aggregate characteristic test, the highest specific gravity value at a slope of 45° is 1.87 while the best absorption at a slope of 50° is 6.08%. However, the value of specific gravity and water absorption of each slope has not fulfilled the third revision of the general specification of Bina Marga as road pavement material because the value of the specific gravity is still below 2.5 and aggregate absorption is still above 3%, it indicates that the artificial geopolymer aggregate has a relatively large pore. The low value of specific gravity and the high absorption value of aggregate with natural aggregates to be lightweight aggregates, which causes artificial geopolymer aggregate has been consumed in a large volume of asphalt when it is used as a pavement material.
- The best aggregate hardness value obtained at a slope of 50° with a value of 22.78%, while at a slope of 45° it is equal to 23.27% and 55° with a value of 24.35%.
- The best value of durability aggregate obtained on the slope 55° with a value of 3.27% and the highest is at a slope of 45° is 6.13%.
- The best value of bitumen adhesion aggregate obtained on the slope 55° is 97.50%, and the lowest is at a slope of 45° is 95.50%.
- The best slope in the process of manufacturing artificial geopolymer aggregate with a slope of 50°. In this slope, artificial geopolymer aggregate has the best hardness value with low absorption values and relatively small specific gravity. Moreover, the other aggregate characteristic values have fulfilled a third of specification of Bina Marga 2010. Artificial geopolymer aggregate can be used as a lightweight aggregates replacement for natural aggregates as road pavement material and can also be applied as a concrete mixture.

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Nomenclatures

F	Response of the i^{th} observation
H_1	Hypothesis not ok
H_0	Hypothesis ok
Y_{ij}	Response of i^{th} observation

Greek Symbols

$\in_{ij}$	Random error component
μ	Overall mean
$\tau_{□}$	i^{th} treatments effect

Abbreviations

SNI	Standard Nasional Indonesia
ASTM	American Standard Testing and Materials
ANOVA	Analysis One Variance

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