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Characteristics of Asbuton Mix Using Geopolymer Fly Ash Coarse Aggregate as a Substitute for Natural Aggregates

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Abstract: The increase in the number of road construction projects has led to an increase in the need for road pavement materials (aggregate and asphalt). Currently it takes about 1.6 million tonnes/year of asphalt, as well as aggregate. Seeing these conditions, it is necessary to anticipate the use of waste or natural resources that have not been utilized optimally. In this study, fly ash (PLTU waste) was used as aggregate and Asbuton (Buton Island rock asphalt) was used as a binder for the asphalt mixture. As an effort to save energy, the stirring system is cold. Based on the volumetric characteristics of the artificial coarse aggregate, it only meets the specifications for the VMA value, while the VIM and VFB values have not been met. The mechanical properties (stability and flow values) of the cold asphalt mixture on the replacement of natural aggregate with 25% artificial aggregate met the requirements, but did not meet the Marshall Quotien requirements.

Keywords: Artificial aggregate; Asbuton; Cold mix; Fly ash; Geopolymer.

Introduction

Asphalt concrete construction with hot mix, still dominates road infrastructure development in Indonesia until now. This construction requires heat energy and requires natural aggregate as the main component, with asphalt as a binder. Meeting aggregate needs is not easy. Many places in Indonesia are experiencing difficulties with aggregates for road materials, so they need to be imported from quite a distance to from outside the island. This will cause the cost of road construction to be high (Ampung, 2013). Meeting these needs is increasingly difficult considering that aggregate is a non-renewable resource. Likewise for the fulfillment of asphalt. The development of national road infrastructure currently requires up to 1.6 million tons of asphalt per year (Sumiati et al., 2019). So that the use of natural asphalt such as Asbuton needs to be encouraged. Asbuton resources in Buton Regency are estimated at 746.9 million tons (Yamin & Faizal, 2012). Asbuton is natural asphalt in the form of rock asphalt which is found on Buton Island, Indonesia. Asphalt contained has a high viscosity so it is hard. This makes it difficult for Asbuton to coat the aggregate to bind the asphalt mixture, so its use is less desirable (Karyawan, Yuniarti, et al., 2022).

Utilization of fly ash which is PLTU waste as an aggregate material is carried out to anticipate future aggregate needs. Fly ash, the residue from burning aggregate made from geopolymer, has the potential to be used as a road and airport material. This is indicated by the compressive strength of the geopolymer fly ash paste which meets the requirements and can be increased by modifying the ratio of base activators, namely Na2SiO3, NaOH, and NaOH Molarity (Karyawan et al., 2017). The test results show that the artificial aggregate can be used as a road pavement material. This is because hardness, strength and durability meet the requirements. The absorption value (> 3%) can be lowered by adjusting the ratio of Na2SiO3 to NaOH (Karyawan et al., 2020).

The performance of the asphalt concrete mixture using Asbuton, with the hot mixture that has been cooled, has a poor performance compared to the compaction of the mixture at hot temperatures. The

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performance of the asphalt mixture can be improved by giving time to soften the asphalt content in Asbuton (Karyawan et al., 2021). Energy-efficient mixtures with cold mixes using Asbuton grains (B25) are proven to increase the density value so that stability increases, meaning that it can improve the quality of asphalt mixtures (Farosi et al., 2019). Efforts to improve the quality of cold buton mixtures are carried out by using synthetic additives and bio-additives. The addition of a super bond additive (synthetic additive) affects the volumetric and mechanical characteristics of the asphalt concrete mixture (Hidayatulloh et al., 2021). Meanwhile, in addition to the duration of curing and the percentage of added bio-additives (gondorukem), it affects the Marshall characteristics of asphalt concrete mixtures (Amri et al., 2021).

Replacing natural coarse aggregate with artificial aggregate from geopolymer fly ash from PLTU Suralaya, in a hot asphalt mixture, obtains the best properties with the addition of 25% artificial aggregate (Putri et al., 2019). A mixture of road pavements with the addition of artificial aggregates is good for maintaining the skid resistance of the road surface, for roads with heavy traffic in urban areas with traffic speeds not exceeding 95 km/hour (Karyawan, Widyatmoko, et al., 2022).

Based on some of the findings in the research described above, a research gap that can be developed for research is the use of other methods and materials. This research was conducted to develop the use of rock asphalt (Asbuton) and anticipate the scarcity of natural aggregates so that it is necessary to utilize artificial aggregates made from fly ash waste for road pavement mixtures (Winardi et al., 2022). Utilization of fly ash waste is necessary because the product is increasing. In this research, the mixed method used was the cold mix method and the replacement of natural coarse aggregate with artificial fly ash-based aggregate. This is also a recommendation from previous researchers. Where it is necessary to look for the formulation of the amount of artificial aggregate used in the cold asphalt mixture that fulfills the performance as an asphalt mixture for road pavement. Thus, the research objectives were: 1) To find the volumetric and mechanical properties of a mixture of cold Asbuton with cold compaction based on the addition of artificial aggregates; 2) Finding the best percentage of artificial aggregate replacement in cold Asbuton mixture with cold compaction.

Method

Develop Experiment Design

The experimental design consists of preparing the composition of the mixture and determining the variation of the composition of the artificial aggregate against the natural aggregate used in the mixture. The composition of the mixture in this study consisted of Coarse Aggregate (43.3%), Fine Aggregate (24%), Filler (4.2%), Asbuton (25%) and Modifier (4.5%) (Hidayatulloh et al., 2021). Variations in the composition of artificial aggregates against natural aggregates used in the mixture in this study are shown in table 1.

Table 1. composition of artificial against natural aggregates used in the mixture

Variation	Artificial Aggregate (%)	Natural Aggregate (%)
1	0	100
2	25	75
3	50	50
4	75	25
5	100	0

Preparation of materials and tools

Material preparation includes (see Figure 1-2), namely: 1) aggregate consisting of artificial coarse aggregate, natural coarse aggregate, fine aggregate and fly ash (as filler); 2) Asbuton; and 3) rejuvenator (modifier). The tool used is equipment for testing the Marshall method, at the Highway and Transportation Engineering Laboratory, Department of Civil Engineering, Faculty of Engineering, University of Mataram**.**

a b c d

Figure 1. (a) Artificial Coarse Aggregate, (b) Natural Coarse Aggregate, (c) Fine Aggregate and (d) Filler

a b

Figure 2. (a) Rejuvenator and (b) Asbuton

Making and Testing of samples

The mixture for making samples consists of Asbuton, Aggregate (artificial aggregate and natural aggregate), and Rejuvenator (Modifiers). Testing of the specimens was carried out using the Marshall method to obtain volumetric test data in the form of VIM, VMA, VFB, and mechanical tests in the form of Stability, Flow, and Marshall Quotient (MQ).

The material used must meet the requirements of the 2018 General Highways Specifications Revision 2 for Road and Bridge Construction Work (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2018). Coarse aggregate as shown in Figure 1.a-1.b and fine aggregate in Figure 1.c. After all the mixed ingredients are ready and meet the requirements, the composition of the artificial aggregate is also varied against the natural aggregate used in the mixture. Next, mix all the ingredients according to the composition plan at the beginning. The next work steps are to make and test asphalt mixture samples.

Beginning with the printing of 15 samples of cold asphalt mixture to obtain optimum asphalt content (k.a.o). Then a mixture of the test object is made with the k.a.o that has been obtained. Tests were carried out referring to SNI 06-2489-2008 concerning Asphalt Mixture Testing Methods with Marshall Tools (Bina Marga, 1991). The test object made consists of 5 test objects each from each variation in the comparison of the use of artificial and natural aggregates (see experimental design) so that a total of 25 test objects are used.

Analysis and Discussion

Data test results were analyzed to obtain volumetric characteristics (VIM, VMA, VFB) and mechanical characteristics (stability, flow, MQ). Discussion of the performance of asphalt mixtures based on variations in artificial aggregate replacement and identifying mixtures with artificial aggregate replacements that have the best performance. Furthermore, a conclusion will be drawn as an answer to the formulation of the problem that has been proposed.

Result and Discussion

Asphalt and Asbuton Test Results

This study used asphalt penetration 60/70. Asphalt test results show a penetration value of 70 (specification 60-70); asphalt ductility 138.5 (specification ≥100 cm); asphalt softening point 51.5 (specification ≥48°C); asphalt specific gravity 1.046 (specification ≥1); asphalt weight loss 0.257% (specification ≤0.8); and a flash point of 300 (specification ≥232°C). These results indicate that asphalt can be used because it meets the road pavement material specifications.

Asbuton test results (type B 5/20) used in research showed asphalt content of 20.31% (18 – 22% requirement) (Yuniarti, 2015), passed filters No.4, No.8, No.16, and No. .30 : 100% 99% 72.7% 51.4%. Moisture content is 0.74% (Max. 2) and Penetration at 25°C, 5 seconds, 0.1 mm is 9.4 (Max. 10 mm.

Fly ash Test Results

Fly ash which is used as a filler and for geopolymer-made aggregate material is obtained at PLTU Jeranjang, West Lombok. Tests for the characterization of fly ash used as geopolymer aggregates include: Scanning Electron Microscopy (SEM) to obtain surface topography data and Energy Dispersion X-Ray Spectroscopy (EDS) to determine the composition of the fly ash content. SEM and EDS testing was carried out at the Mechanical Engineering Laboratory of the Sepuluh Nopember Institute of Technology, Surabaya.

Figure 3. PLTU Jeranjang fly ash and morphology based on SEM tests

Analysis of the content of fly ash compounds based on the analysis of the EDS test results was Na2O (1.71%), MgO (16.62%), Al2O3 (20.13%), SiO2 (17.76%), SO2 (2.42%), K2O (1.88%), CaO (11.85%), TiO2 (0.65%), and Fe2O3 (29.97%). Based on the elemental composition of the fly ash compound where SiO3+Al2SiO3+Fe2O3 is 64.87% > 50% and the compound element CaO is 11.85% > 10%, fly ash is classified as type C. Figure 3 shows fly ash. ash used and its morphology by Scanning Electron Microscopy (SEM) test.

Test Results for natural aggregates and artificial aggregates

Natural aggregates are aggregates made by crushing stones from natural rocks with a stone crusher. While the artificial aggregate used is an aggregate made from geopolymer fly ash and an alkaline activator. Where the alkaline activator used consists of a solution of 8M NaOH and Na2SiO3 with a ratio of 1:2.5. Artificial aggregates based on fly ash are made directly at the Highway Transportation and Materials Laboratory, University of Mataram. Before being used for mixing, an examination of the characteristics of the aggregate is carried out, to determine the physical and mechanical properties of the aggregate as the main ingredient in the asphalt mixture. The results of the testing of coarse aggregate are shown in Table 2, while Table 3 is for fine aggregate and fly ash filler.

Table 2. The results of testing the characteristics of natural and artificial coarse aggregates

Aggregate Testing	Natural Aggregates (*)	Natural Aggregates (*)	Specification (**)
Bulk specific gravity	2.621	2.621	
SSD specific gravity	2.420	2.420	Min. 2.5
Apparent specific gravity	2.817	2.817	
Absorption (%)	1.275%	1.275%	max. 3%
Impact wear (%)	20.11%	20.11%	max. 30%
Aggregate adhesiveness to bitumen	100%	100%	Min. 95%

(*) Transportation Lab.; (**) General Specifications Bina Marga 2018 Revision 2 (2020)

Table 3. The results of testing the characteristics of fine aggregate and fly ash filler

Testing (*)	Value	Specification (**)	Testing (*)	Value	Specification (**)
Fine Aggregate			*Filler Fly Ash*		
Bulk specific gravity	2.621		Bulk specific gravity	2.508	
SSD specific gravity	2.420	Min. 2.5	SSD specific gravity	2.510	Min. 2.5
Apparent specific gravity	2.817		Apparent specific gravity	2.512	
Absorption (%)	2.21	Maks. 3%	Absorption (%)		

(*) Transportation and Highway Laboratory; (**) General Specifications Bina Marga 2018 Revision 2 (2020)

Table 4. Calculation of the need for artificial coarse aggregate for 5 variations of the mixture

Sieve No		Design Gradations	Retained Cumulative	Restrained	Aggregate weight used	Percentage of use of artificial aggregates				
						Ratio 0%	Ratio 25%	Ratio 50%	Ratio 75%	Ratio 100%
in	mm		(%)	(%)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)
3/4	19	100	0	0	0	0	0	0	0	0
½	12.5	95	5	5	42.3	0	10.6	21.1	31.7	42.3
3/8	9.5	83.5	16.5	11.5	97.29	0	24.3	48.6	72.9	97.29
No.4	4.75	61	39	22.5	190.35	0	47.6	95.1	142.7	190.35
No.8	2.36	43	57	18	152.28					
No.16	1.18	30.5	69.5	12.5	105.75					
No.30	0.600	22	78	8.5	71.91					
No.50	0.300	15.5	84.5	6.5	54.99					
No.100	0.150	10.5	89.5	5	42.3					
No.200	0.075	6.5	93.5	4	33.84					
Pan				6.5	54.99					
Amount				100	846	0	82.5	164.8	247.3	329.94

Making Asphalt Mixed Samples

The composition of the test object mixture consists of aggregate (coarse aggregate, fine aggregate and filler), asbuton and rejuvenating agent. The total for one specimen is 1200 gr, consisting of 70.5% aggregate (846 gr), Asbuton 25% (300 gr), 4.5% rejuvenating agent (54 gr). Based on this composition, the aggregate requirements for the preparation of gradations of 5 mixed variations are as shown in Table 4.

Asphalt mixture with Asbuton has an asphalt content which can be calculated by adding up the bitumen content contained in Asbuton B 5/20 and in the rejuvenating agent mixture. The amount of asbuton and rejuvenating agent used in the mixture is 25% and 4.5%. Asbuton B 5/20 has an asphalt content of 19.83. The rejuvenating agent consists of 63% asphalt pen 60/70, 22% kerosene and 15% bunker oil. So that the total asphalt content in the mixture is 7.75%, consisting of 25% x 19.83% = 5.07 and 4.5% x 63% = 2.8% rejuvenating agent.

The specimens (Marshall Briquettes) are made with the steps or stages of manufacture beginning with taking the constituent aggregates in the form of Coarse Aggregate 3/4", Medium Aggregate 3/8", and Fine Aggregate #4. After the constituent aggregates are collected, the next step is weighing each aggregate fraction according to the composition of the mixed design. At this stage, Asbuton B 5/20 is also weighed according to the composition and mixed into the constituent aggregates. At this stage, the Rejuvenating Material is mixed according to the composition of each constituent material, namely 63% Penetrating Asphalt 60/70, 22% Kerosene, and 15% Bunker Oil.

After the Aggregate Constituents, Asbuton B5/20, and Rejuvenating Materials are measured according to the composition, then move on to the process of mixing the test objects. In this mixing process, Aggregate, Asbuton and Rejuvenating Materials are not heated because they are cold mixtures. The rejuvenating material is poured into the constituent aggregates little by little together with the aggregate stirring so that a homogeneous mixture is obtained (Figure 4.a). After the mixture is uniform and homogeneous, it is prepared for curing for 12 days (Figure 4.b). Then it is compacted (See Figure 4.c). The process of compacting the test object (briquette) is in accordance with the provisions of the 2018 Revision 3 General Highways Specifications (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2018), namely by pounding 50 times each with a mold diameter of 4 inches or 10.16 cm.

a b c

Figure 4. The process of making samples: (a) Cold mixing, (b) Curing of the mixture, (c) Compaction

Asphalt Mixed Sample Testing

The Marshall tool is a press equipped with a 22.2 kN (5000 lbs) proving ring and a flowmeter. Proving rings are used to measure stability values, and flowmeters to measure plastic melting or flow. The Marshall specimen was cylindrical in shape 4 inches (10.12 cm) in diameter and 2.5 inches (6.35 cm) thick. The Marshall test procedure follows SNI 06-2489-2008 (Bina Marga, 1991). In General the Marshall test includes: preparation of the test object, determination of the bulk specific gravity of the test object, examination of stability and flow values, and calculation of the volumetric properties of the test object. The stages of volumetric and mechanical testing of the core test object can be seen in Figure 5.a – 5b Volumetric tests consist of weighing the test object in a dry state, weighing in water, and weighing the test object in a saturated or surface dry state. From this weighing, density or specific gravity values are obtained and then the results are used in calculations to find VIM, VMA, and VFB values.

The mechanical test is carried out by loading the core test object until the test object collapses which is indicated by the stop of the loading needle located in the middle of the proving ring. In this test, the results obtained are Stability values, Flow values, and Marshall Quotient values.

(a) (b) (c)

Figure 4. The process of making samples: (a) Cold mixing, (b) Curing of the mixture, (c) Compaction

Volumetric Characteristics of Asphalt Mixture

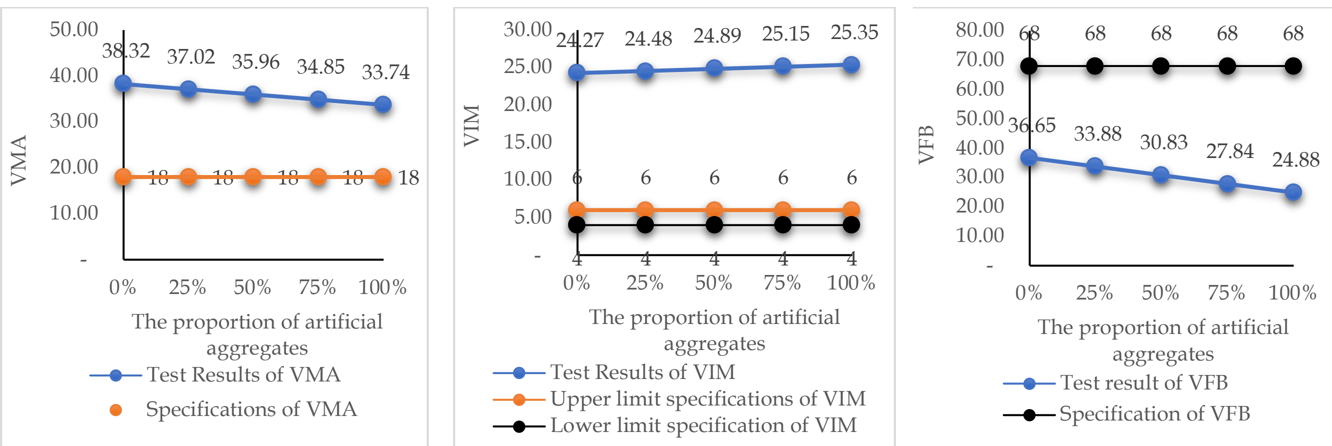
Based on the data from the volumetric test results, the volumetric values (VMA, VIM, and VFB) can be calculated, as shown in Figure 6. The VMA value is based on variations in the use of artificial coarse aggregate. VMA is the number of pores between aggregate grains in solid asphalt. VMA score requirement specification is ≥ 15%. VMA is expressed as a percentage. A high VMA value will result in a mixture that has too much deformation, while a small VMA value allows large bleeding to occur.

In Figure 6.a it is shown that all variations of the artificial coarse aggregate mixture meet the specified specifications. The figure shows that variations in coarse aggregate affect the VMA value so that the more use of artificial coarse aggregate, the lower the VMA value. This is because the durability of artificial aggregates is lower when compared to natural aggregates. So that the artificial aggregate is more easily crushed when compacted and produces a smaller VMA value as the artificial aggregate increases. This is also in line with previous research, namely the VMA value tends to decrease with the addition of artificial aggregate for the same asphalt content (Al Mahbubi & Ahyudanari, 2019). From the results of the research on 5 variations of artificial coarse aggregate, the maximum VMA value at 0% artificial coarse aggregate was 38.316% while the minimum VMA value at 100% artificial coarse aggregate was 33.739%.

The VMA value is based on variations in the use of artificial coarse aggregate. VMA is the number of pores between aggregate grains in solid asphalt. VMA score requirement specification is ≥ 15%. VMA is expressed as a percentage. A high VMA value will result in a mixture that has too much deformation, while a small VMA value allows large bleeding to occur.

The VIM value is based on variations in the use of artificial coarse aggregate. VIM is the cavity that remains after the asphalt mixture has been compacted. The specifications for the VIM value requirement are a minimum of 3% and a maximum of 5%. A high VIM value can cause dense asphalt to accelerate aging of asphalt and reduce the durability properties of asphalt, while a small VIM value has a high level of stiffness which can cause the dense asphalt mixture to crack easily and not be flexible enough.

In Figure 6.b. it is shown that all VIM values do not meet the established specifications. This shows the number of air voids in the mixture as the artificial aggregate increases. The higher VIM value is also due to the high absorption of artificial aggregate, which is 12.28%. Where the asphalt which is supposed to coat the surface of the aggregates and fill the voids between the aggregates, will be absorbed by the artificial aggregates which causes a high VIM value. From the results of the research on 5 variations of artificial coarse aggregate, the maximum VMA value at 100% artificial coarse aggregate was 24.275% while the minimum VMA value at 0% artificial coarse aggregate was 25.348%.



(a) (b) (c)

Figure 6. Relationship artificial coarse aggregate variation and value: a) VMA, b) VIM dan c) VFB

VFB value based on variations in the use of artificial coarse aggregate. The VFB value is the percentage of voids filled with asphalt in a dense asphalt mixture. A high VFB value can cause bleeding at high temperatures or high loads, but if the VFB value is small, the pavement impermeability will be smaller so that the available voids will be larger.

Figure 6.c. indicates that all mixtures do not meet predetermined specifications. The figure shows that variations in coarse aggregate affect the VFB value so that the more use of artificial coarse aggregate, the lower the VFB value. This is due to the addition of artificial aggregate which makes asphalt absorbed by the aggregate more than covering the surface of the artificial aggregate. The VFB value is also in line with the

declining trend of the VMA. From the results of the research on 5 variations of artificial coarse aggregate, the maximum VFB value at 0% artificial coarse aggregate was 36.648% while the minimum VFB value at 100% artificial coarse aggregate was 24.883%.

Mechanical Characteristics of Asphalt Mixture

Based on the measurement results of the Marshall value (stability and flow), the value of stability, flow and Marshall Quotien can be calculated. The complete calculation results for all sample data of test objects can be seen in Figure 7. How to get these values is given for one of the test results data as follows:

Marshall Stability

$$S = q \times C \times k$$
$$= 0{,}82 \times 45 \times 22{,}001$$
$$= 813{,}982 \text{ kg}$$

Flow

Flow = watch reading

= 3,74 mm

Marshall Quotient (MQ)

$$MQ = \frac{Stability}{flow}$$
$$= \frac{813{,}982}{3{,}74}$$
$$= 217{,}642 \text{ kg/mm}$$

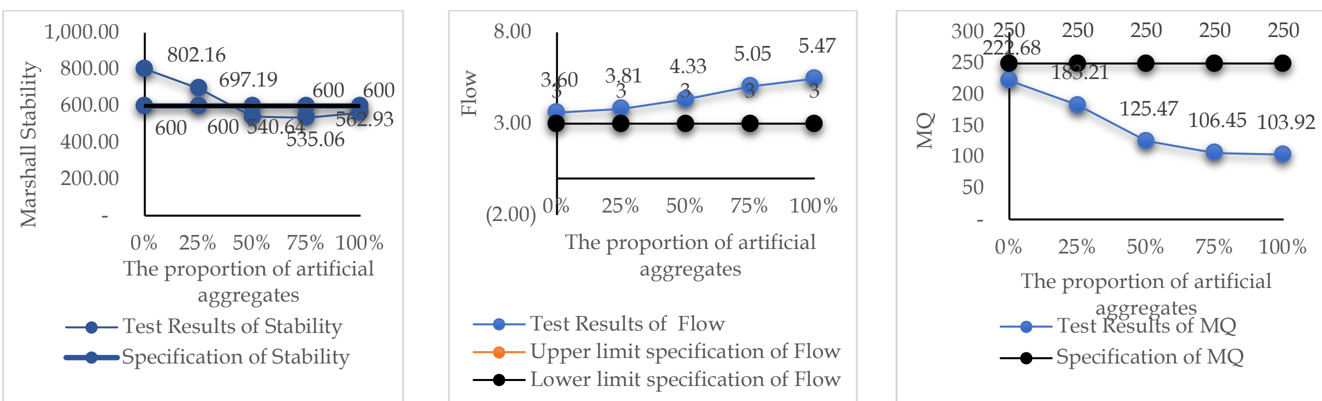
Stability value based on variations in the use of artificial coarse aggregate. Stability value is the ability of the solid asphalt mixture to accept traffic loads without deformation or bleeding. A small stability value causes the pavement to undergo major deformation.

Based on Figure 7.a. the value of stability is influenced by the large use of artificial coarse aggregate which causes stability to decrease. The decreased stability value can be caused by the high absorption value of the artificial coarse aggregate in the asphalt mixture which will make the asphalt blanket layer thinner because the asphalt enters the pores of the artificial aggregate so that the bonds are easily separated. From the results of the study of 5 variations of artificial coarse aggregate, it was found that the Stability values of 0% and 25% variations of artificial coarse aggregate were 802.160 kg and 697.19 kg that met the specifications, while the variations of 50%, 75% and 100% of artificial coarse aggregate did not meet specifications.

Flow value based on variations in the use of artificial coarse aggregate. Flow is an implementation of the flexibility properties of the resulting mixture. A high Flow value and a small Stability value are plastic and easily change shape when subjected to traffic loading.

Figure 7.b. shows that the greater the variation in the use of artificial coarse aggregate results in an increase in the flow value. This is because the more artificial aggregate in the mixture, the more asphalt will be absorbed by the artificial aggregate. Where the more asphalt is absorbed, the lower the effective asphalt, the binding ability is also low. This causes the amount of deformation in the mixture, the higher the flow value. From the results of the 5 variations of artificial coarse aggregate, it was found that the Flow values of variations of 0% and 25% of artificial coarse aggregate met specifications, while variations of 50%, 75% and 100% of artificial coarse aggregate did not meet specifications.

A mixture that has a low MQ value indicates that the mixture will be more flexible, tends to be plastic and flexible so that it is easy to change shape when receiving a traffic load. While mixtures that have high MQ values tend to be stiff and less flexible. From the research results, 5 variations of artificial coarse aggregate did not meet the specifications. The maximum MQ value at 0% artificial coarse aggregate is 222.678 kg/mm while the minimum MQ value at 100% artificial coarse aggregate is 103.922 kg/mm. The Marshall Quotien value decreased with the addition of artificial aggregates, this result is directly proportional to the results of the existing stability check (Figure 7.c). All MQ values with the use of artificial aggregates do not pass the specified specifications.



(a) (b) (c)

Figure 7. Correlation between the variation of artificial coarse aggregate and the values of: a) Stability, b) Flow and c) Marshall Quotien

Conclusion

Base on the analysis and discussion that has been done before, it can be concluded: The volumetric properties of the cold asphalt mixture with the replacement of artificial coarse aggregate with variations of 0%, 25%, 50%, 75%, and 100% show that only the VMA value meets the specifications, while the VIM and VFB values have not been fulfilled. Flow as a mechanical property of cold asphalt mixture meets the requirements for all variations of artificial coarse aggregate replacement. While the stability value is fulfilled until 25% replacement of natural aggregate with artificial aggregate. Marshall Quotien values do not meet the specifications for all variations of the use of artificial aggregates. Cold asphalt mixture using geopolymer-made aggregate with fly ash as a substitute for natural aggregate does not meet the specification requirements Bina Marga 2018.

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Conflicts of Interest
The author's interest in publishing this article is for research output needs in the form of publication in scientific journals as proof of the required performance. No conflict of Interest.

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