

The Effect of Mixing Natural Aggregates with Artificial Aggregates on Marshall Parameters

Muhammad Riski¹, Febrina Dian Kurniasari*¹, Bunyamin¹

¹Universitas Iskandar Muda; Jl. Kampus Unida-Surien, telp. (0651) 42225 – 42098 – 42219
Program Studi Teknik Sipil, Fakultas Teknik, Kota Banda Aceh
e-mail: ¹riskijanthero763@gmail.com, *¹febrina@unida-aceh.ac.id, ¹bunyamin@unida-aceh.ac.id

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ABSTRACT

In general, aggregates consist of Natural Aggregates (NA) and Artificial Aggregates (AA). Artificial aggregates, such as Crushed Stone (CS), are aggregates produced through the crusher industry which has a rough and angular surface so that it has excellent adhesion to asphalt. Meanwhile, NA is an aggregate produced from a river which has a smooth and large hollow surface texture. The cost for AA is very expensive when compared to NA, so it is necessary to experiment with mixing NA and AA to minimize the use of AA. NA are obtained from Sungai Jalin, Jantho City District, Aceh Besar District. The method used refers to the specification of Bina Marga 2010 Revision four (2018) and the Indonesian National Standard (SNI). The purpose of this study was to see the effect of the combination of NA and AA as a substitute for coarse aggregate on the AC-WC concrete asphalt layer. The specimens used were 66 specimens with substitution of NA and AA into the asphalt layer were 0% NA: 100% AA, 25% NA: 75% AA, 50% NA: 50% AA, 75% NA: 25% AA, 100% NA : 0% AA. Based on the research results, the best value for the optimum marshall parameter is the substitution of 25% AA: 75% BP at asphalt content of 5.00%, the stability value is 1492.37kg with a VIM value of 3.69%, VMA 16.17%, VFA 77.88% and MQ 573.87kg / mm which have met the requirements of the 2010 Revision four (2018) Bina Marga specification.

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I. Introduction

Aggregates are grains of crushed stone, coarse aggregate, fine aggregate or other minerals, both natural and artificial, in the form of large and small solid minerals [1]. Generally, the construction of asphalt concrete surface layers uses crushed stone as the aggregate. Crushed stone is obtained from rock excavated from mountain and river rocks which are crushed and sieved according to standard sizes [2]. However, the cost for artificial aggregates such as crushed stone is very expensive when compared to natural aggregates, so it is necessary to experiment with mixing natural and artificial aggregates to minimize the use of artificial aggregates.

Natural aggregates are aggregates that are round in shape and have a relatively slippery surface compared to artificial aggregates because these aggregates are eroded by water [3]. This aggregate also has poor adhesion to asphalt because it has a surface that tends to be smoother and slippery. Besides, the cavity generated by this aggregate is very large because it has a relatively round shape and does not have angles like artificial aggregate. Two forms of natural aggregate that are often used are coarse aggregate and fine aggregate. coarse aggregate is aggregate with size > ¼ inch (6.35 mm), fine aggregate is aggregate with vertical size [4].

Artificial aggregate is the aggregate produced through the stone crusher industry which has a rough and angular surface so that it has excellent adhesion to asphalt [5]. In addition, the cavities between the aggregates that occur are relatively smaller so that it can form good bonds between them. The use of artificial aggregates on road pavements is better than natural aggregates because



the artificial aggregates have angles that can bind each other to the aggregates. However, what happens in the field requires a large budget for the use of crushed stone aggregate as a material in the mixture of asphalt concrete layers, and sometimes there are still natural agreements that meet the requirements that can be used as aggregate material on road pavements [6]. So it is necessary to do research by mixing natural aggregate with artificial aggregate on the parameters of marshall mixture of Asphalt Concrete -Wearing Course (AC – WC).

II. Method

the implementation of the research was to test the effect of mixing natural aggregates with artificial aggregates on marshall parameter at the Laboratory of Transportation, Engineering department, Iskandar Muda University, Banda Aceh. The method used is based on the fourth revision of the 2010 Highways Specification (2018) [7] and the Indonesian National Standard (SNI)[8].

The data used in this research consist of primary and secondary data. Primary data is the characteristics of each material to be used, such as natural and artificial aggregate characteristics, asphalt characteristics, and fillers. These data are obtained using material testing. Secondary data in this research such as a list of specifications, equipment calibration numbers and so on. Secondary data can be obtained from literature studies and related agencies

The artificial aggregate used was taken at the quarry location of PT Dana Dinamika Persada, which is located in Leupung Baleu, Kuta Cot Gilie District, Aceh Besar District. While the natural aggregate is taken from the Jalin River, Jantho City District, Aceh Besar.

The procedure of mixing natural aggregates with artificial aggregates on Marshall parameters are as follows.

1. Preparation

The preparations of this research consist of materials, and also the preparation of the equipment used. Material preparation before use and equipment checking carried out. The materials needed are 60/70 penetration asphalt, coarse aggregate, fine aggregate, natural aggregate and Portland cement type 2 [9]

2. Testing materials

Inspection of the material used follows the inspection procedure according to predetermined standards [10]:

- a. testing of the physical properties of asphalt is penetration testing and inspection of the density of asphalt.
- b. Examination of the physical properties of the aggregates which is carried out is the examination of density and absorption, weight of content and wear of the aggregate.

3. Planning of asphalt concrete mix

Calculate the initial estimate of the Central Asphalt Content (Pb) using equation (1):

$$Pb = 0,035(\%CA) + 0,045 (\%FA) + 0,18(\%Filler) + K \quad (1)$$

Where :

Pb : ideal asphalt content, percent of the weight of the mixture;

CA : percentage of aggregate held by sieve no.4 (5 mm);

FA : percentage of aggregate passes sieve no.4 (5 mm) and held by sieve no.200 (0.075 mm);

Filler: Minimum aggregate percentage of 75% passes no.200 (0.075 mm)

K : Constant Value;

The Pb value obtained from this study was 5% so that the AC-WC mixture test object was made at asphalt levels of 4,%, 4.5%, 5%, 5.5%, and 6% where each asphalt content was made. 3 specimens.

4. Making Test Objects

- a. Test specimen with variations in asphalt content for determining the optimum asphalt content (OAC).
- b. Test object with natural and artificial aggregate substitution of 0% NA: 100 AA, 25% NA: 75% AA, 50% NA: 50% AA, 75% NA: 25% AA and 100% NA: 0% AA
- c. Specimens with and without natural aggregate substitution produce the best Marshall characteristics for calculating the durability value. The number of specimens to determine the properties of the OAC determination mixture can be seen in Table 1.

Table 1 Number of Test Objects for AC-WC OAC

No	Asphalt Content	Object Code	Total
1	4,00%	A1,A2,A3	3
2	4,50%	B1,B2,B3	3
3	5,00%	C1,C2,C3	3
4	5,50%	D1,D2,D3	3
5	6,00%	E1,E2,E3	3
Total			15

Marshall testing with variations in asphalt content of 4.00%; 4.50%; 5.00%; 5.50%; and 6.00%, then analyzed to obtain the value of the Optimum Asphalt Content (OAC) which was obtained at 5.50% and the OAC value was varied into 3 asphalt levels of 5.00%, 5.50%, and 6.00%. For the number of specimens substitution of natural aggregate (NA) and artificial aggregate (AA) with 30 minutes immersion in Table 2.

Table 2. Number of NA and AA specimens

No	Combination	Asphalt Content	Object Code	total
1	0% NA : 100% AA	OAC - 0,5	A ₁₁ , A ₁₂ , A ₁₃	9
		OAC	A ₂₁ , A ₂₂ , A ₂₃	
		OAC + 0,5	A ₃₁ , A ₃₂ , A ₃₃	
2	25% NA : 75% AA	OAC - 0,5	A ₄₁ , A ₄₂ , A ₄₃	9
		OAC	A ₅₁ , A ₅₂ , A ₅₃	
		OAC + 0,5	A ₆₁ , A ₆₂ , A ₆₃	
3	50% NA : 50% AA	OAC - 0,5	A ₇₁ , A ₇₂ , A ₇₃	9
		OAC	A ₈₁ , A ₈₂ , A ₈₃	
		OAC + 0,5	A ₉₁ , A ₉₂ , A ₉₃	
4	75% NA : 25% AA	OAC - 0,5	A ₁₀₁ , A ₁₀₂ , A ₁₀₃	9
		OAC	A ₁₁₁ , A ₁₁₂ , A ₁₁₃	
		OAC + 0,5	A ₁₂₁ , A ₁₂₂ , A ₁₂₃	
5	100% NA : 0% AA	OAC - 0,5	A ₁₃₁ , A ₁₃₂ , A ₁₃₃	9
		OAC	A ₁₄₁ , A ₁₄₂ , A ₁₄₃	
		OAC + 0,5	A ₁₅₁ , A ₁₅₂ , A ₁₅₃	
Total				45

After testing the combination of NA and AA, the best percentage value is obtained. Then the test object was made again to see the durability value for the 24 hour immersion as shown in table 3

Table 3 Number of Durability Test Objects

No	Combination Experiments	Number of Test
1	Best KAO mix	3
2	AA Mix with Best BP	3
Total		6

III. Results and Discussion

Examination of the physical properties of aggregates and asphalt includes examining the abrasion of the aggregate by Los Angeles Machine; density, absorption of water and specific gravity [11]. From the results of the examination, the physical properties of the aggregates have met the requirements. The results of the examination of the physical properties of artificial aggregates, natural aggregates, fine aggregates and 60/70 pen asphalt which meet all the specifications of Highways (2018) which are shown in Tables 4 to 7.

Table 4 Results of the Physical Properties of Artificial Aggregates

Physical properties	Unit	Result	Specification Bina marga(2018)
Specific gravity	-	2,8	Min. 2,5
Absorption	%	0,495	Maks. 3
Fill Weight	kg/cm ³	1,609	Min. 1
Wear and tear (<i>los angeles</i>)	%	21,52	Maks. 40

Table 5 Results of Physical Properties of Natural Aggregates

Physical properties	Unit	Result	Spesifikasi Bina marga(2018)
Specific gravity	-	4,7545	Min. 2,5
Absorption	%	1,3305	Maks. 3
Fill Weight	Kg/cm ³	1,494	Min. 1
Wear and tear (<i>los angeles</i>)	%	12,54	Maks. 40

Table 6 Results of the Physical Properties of Fine Aggregates

Physical properties	Unit	Result	Specification Bina Marga (2018)
Specific gravity	-	2,80	Min. 2,5
Absorption	%	0,70	Maks. 3

Table 7 Results of Physical Properties of Asphalt Pen. 60/70

Physical properties	Unit	Result	Specification Bina marga (2018)
Specific gravity	-	1,020	Min. 1
Absorption	(0,1	64	60 – 70

Marshall Test Results

Based on the Marshall test results, namely VIM, VMA, VFA, stability, flow and Marshall Quotient (MQ) Marshall test results with variations in asphalt content of 4.0%; 4.5%; 5.0%; 5.5% and 6.0%, then an analysis was carried out to obtain the Optimum Asphalt Content (OAC) value which was obtained at 5.5%. Then the OAC value was varied into three asphalt levels, namely 5.0%; 5.5%; and 6.0%. The three levels of asphalt are used for testing the characteristics of the AC-WC mixture of natural aggregate substitution (NA) with artificial aggregate (AA).

A recapitulation of the Marshall test results for the determination of the AC-WC mixture OAC is presented in Table 8:

Mixed Characteristics	Asphalt Content (%)					Specification (2018)
	4,00	4,50	5,00	5,50	6,00	
VIM (%)	10.71	7.63	3.61	3.47	3.24	3 – 5
VMA (%)	19.95	18.29	15.87	16.87	17.77	Min. 15
VFA (%)	46.76	58.44	77.63	79.55	81.93	Min. 65
Stabilitas (Kg)	1363.81	1521.93	1531.90	1406.78	1402.43	Min. 800
Flow (mm)	3.10	3.87	2.27	2.33	2.47	2 – 4
MQ (Kg/mm)	451.53	406.29	757.93	626.44	588.59	Min. 250

Marshall test results for this phase were carried out on the three asphalt levels obtained from the determination of the OAC value, namely asphalt content of 5.00%, 5.50% and 6.00%. A summary of the Marshall test results for aggregate variation can be seen in Tables 9 to 11.

Parameter <i>Marshall</i>	Natural Aggregate Variation (NA) - Artificial Aggregate (AA) (%)					Specification Bina Marga (2018)
	0%NA : 100%AA	25%NA : 75%AA	50%NA : 50%AA	75%NA : 25%AA	100%NA : 0%AA	
VIM (%)	3,61	3,69	3,96	4,30	4,65	3-5
VMA (%)	15,87	16,17	16,65	17,19	17,76	Min. 15
VFA (%)	77,63	77,88	76,49	75,04	73,83	Min. 65
Stability (kg)	1531,90	1492,37	1406,24	1387,20	1359,46	Min. 800
Flow (mm)	2,5	2,6	2,8	3,1	3,2	2-4
MQ (kg/mm)	634,95	573,87	496,40	447,55	423,40	Min. 250

Parameter <i>Marshall</i>	Natural Aggregate Variation (NA) - Artificial Aggregate (AA) (%)					Specification Bina Marga (2018)
	0%NA : 100%AA	25% NA : 75%AA	50%NA : 50%AA	75% NA : 25%AA	100%NA : :0% AA	
VIM (%)	3,47	3,55	3,78	3,90	4,26	3-5

VMA (%)	16,87	17,19	17,69	18,02	18,60	Min. 15
VFA (%)	79,55	79,39	78,62	78,85	77,10	Min. 65
Stability (kg)	1406,78	1402,61	1382,67	1364,53	1331,71	Min. 800
Flow (mm)	2,6	2,7	3,0	3,3	3,5	2-4
MQ (kg/mm)	533,54	520,25	456,01	425,30	384,73	Min. 250

Table 11 Marshall Test Results with Natural Aggregate (NA) at Asphalt Levels 6.00%

Parameter	Natural Aggregate Variation (NA)-Artificial Aggregate (AA) (%)					Specification Bina Marga (2018)
	0%NA : 100%AA	25% NA : 75%AA	50%NA :50%AA	75%NA: 25%AA	100%NA:0 % AA	
VIM (%)	3,24	3,32	3,49	3,61	4,03	3-5
VMA (%)	17,77	18,11	18,53	18,92	19,58	Min. 15
VFA (%)	81,93	81,71	81,19	80,94	79,47	Min. 65
Stability (kg)	1402,43	1381,03	1360,00	1316,48	1279,49	Min. 800
Flow (mm)	2,7	2,9	3,3	3,6	3,8	2-4
MQ (kg/mm)	524,75	476,86	417,43	366,86	340,06	Min. 250

Discussion of Marshall Test Results

a. Discussion of VIM (void in the mix)

The results showed that with the addition of the variation in the percentage of natural aggregates, the VIM value increased but decreased as the bitumen content increased. This shows that the asphalt content greatly affects the cavities in the mixture or the VIM value. The higher the value of the asphalt content added to the mixture, the less the volume of the cavity in the mixture or the smaller the VIM value. The increase in VIM value is due to the large cavity caused by natural aggregates which tend to be round. The VIM value has met the specifics of Highways (2018), namely 3% - 5% can be seen in table 12.

Table 12 VIM Value of AA-BP Aggregate Variation with Variation in Asphalt Levels

NA + AA	Asphalt Content (%)		
	5,00%	5,50%	6,00%
0% NA : 100% AA	3,61	3,47	3,24
25% NA : 75% AA	3,69	3,55	3,32
50% NA : 50% AA	3,96	3,78	3,49
75% NA : 75% AA	4,30	3,90	3,61
100% NA : 0% AA	4,65	4,26	4,03

b. Discussion of VMA (Void in Mineral Agregat)

The results showed that the increasing composition of natural aggregates in the asphalt mixture tended to increase. This was because the VMA value was influenced by natural aggregates which had a slippery shape so that they could not provide strong bonds between them. The lowest

VMA value was 15.87 at the composition of 0% NA: 100% AA at 5.00% asphalt content, while the highest VMA value was 19.58% at the composition of 100% NA: 0% AA at 6.00% asphalt content. The VMA value indicates that it has met all of the specifics of Highways (2018), namely $\geq 15\%$ can be seen in table 13.

Table 13 VMA Value of NA-AA Aggregate with Variation of Asphalt Levels

NA + AA	Asphalt Content (%)		
	5,00%	5,50%	6,00%
0% NA : 100% AA	15,87	16,87	17,77
25% NA : 75% AA	16,17	17,19	18,11
50% NA : 50% AA	16,65	17,64	18,53
75% NA : 75% AA	17,19	18,02	18,92
100% NA : 0% AA	17,76	18,60	19,58

c. Discussion of VFA

The results showed that the VFA value decreased along with the increase in the composition of the natural aggregate in the asphalt mixture because the natural aggregate had large pores so that the asphalt would be absorbed by the natural aggregate which resulted in a reduction in the asphalt blanket between the aggregates. The highest VFA value was at asphalt content of 6.00% at the composition of 0% NA: 100% AA at 81.93%, while the lowest VFA value was at asphalt content at 5.00% at the composition of 100% NA: 0% AA of 73.83%. The VFA value has met all of the specifics of Highways (2018), namely $\geq 65\%$ can be seen in table 14.

Table 14 VFA Value of NA-AA Aggregate Variation with Variation of Asphalt Levels

NA + AA	Asphalt Content (%)		
	5,00%	5,50%	6,00%
0% NA : 100% AA	77,53	79,55	81,93
25% NA : 75% AA	77,88	79,39	81,71
50% NA : 50% AA	76,49	78,62	81,19
75% NA : 75% AA	75,04	78,85	80,94
100% NA : 0% AA	73,83	77,10	79,47

d. Discussion of Stability

The results showed that the increasing composition of natural aggregate (NA) in the asphalt mixture tended to decrease. This was due to the fact that natural aggregate was not able to provide strong binding power between particles in the mixture so that the stability decreased. The stability value is influenced by internal friction, inter-looking interlocking and good binding capacity of the asphalt layer (cohesion), besides the compaction process, aggregate quality, and asphalt content are also influential[12]. The value of stability with the increase in the composition of natural aggregates has met the requirements of Highways (2018), which is ≥ 800 kg can be seen in Figure 1.

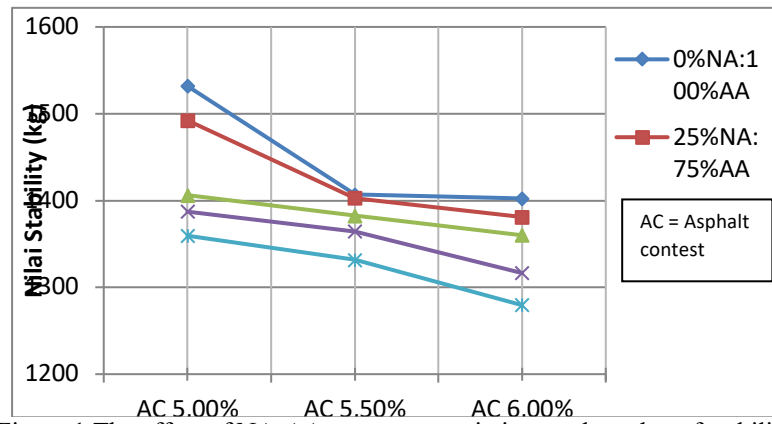


Figure 1 The effect of NA-AA aggregate variation on the value of stability

e. Discussion of Flow

The results showed that the flow value increased along with the increase in the composition of natural aggregates into the mixture. The high flow value characterizes the plastic mixture due to the high bitumen content. Meanwhile, if the flow value is very low, it will give the characteristic of a stiff mixture due to the low bitumen content [13]. The highest flow value was at asphalt content of 6.00% at the composition of 100% AA: 0% BP, namely 3.8 mm and the lowest value at asphalt content was 5.00% at the composition of 0% NA: 100% AA, namely 2.5 mm. The flow value in table 4.13 shows that it has met all the specifics of Highways (2018), namely 2 - 4 mm can be seen in table 15

Table 15 Value of flow of NA-AA aggregate with variation of asphalt levels.

NA + AA	AC (%)		
	5,00%	5,50%	6,00%
0% NA : 100% AA	2,5	2,6	2,7
25% NA : 75% AA	2,6	2,7	2,9
50% NA : 50% AA	2,8	3,0	3,3
75% NA : 25% AA	3,1	3,3	3,6
100% NA : 0% AA	3,2	3,5	3,8

f. Mashall Quotient (MQ)

The results showed that the Masrhall Quotient (MQ) value decreased along with the increase in asphalt content and natural aggregate composition into the mixture. The smaller the MQ value, the more flexible the mixture is [14]. The highest Masrhall Quotient (MQ) value was at asphalt content of 5.00% at the composition of 0% AA: 100% BP, namely 635.0 kg / mm and the lowest value was at asphalt content of 6.00% at the composition of 100% AA: 0% BP, namely 340.1 kg / mm. The MQ value in table 4.14 shows that it has met all of the specifics of Highways (2018), namely ≥ 250 kg / mm can be seen in table 16.

Table 16 MQ Value of NA-AA Aggregate Variation with Variation of Asphalt Levels

NA + AA	AC (%)		
	5,00%	5,50%	6,00%
0% NA : 100% AA	635,0	553,5	524,8
25% NA : 75% AA	573,9	520,3	476,9
50% NA : 50% AA	496,6	456,0	417,4
75% NA : 75% AA	447,5	425,3	366,9
100% NA : 0% AA	423,4	384,7	340,1

Durability Value Calculation Results

The value of durability was obtained from the comparison between the stability of the immersion for 24 hours and the stability of the immersion for 30 minutes at 60 °C. The results of calculating the durability value for each asphalt mixture composition can be seen in Table 17

Table 17 Results of Durability Testing Recapitulation

Mixed Composition Type	Soaking 30 minutes	24 hour soaking	Durability Value (%)
B	c	d	e= (d/c) x 100
No substitution (standard)	1531,90	1510,14	98.58
Mix with natural aggregate and crushed stone aggregate	1492,37	1445,77	96.88

The durability values for the mixture without substitution and with the substitution of natural aggregates were 98.58% and 96.88%, respectively. From the results of the study, it can be seen that there is a decrease in the value of stability in the mixture with the substitution of natural aggregates, but the durability value still meets the requirements set by the Bina Marga Specifications 2010 revision 4 of 2018 [7] namely > 90%. The decrease in the durability value in the AC-WC mixture was due to the large VIM, VMA values and small VFA values. This means that the AC-WC mixture with natural aggregate substitution has bigger cavities so that water easily enters the pores of the mixture which results in reduced adhesion and cohesion properties. The large cavity in the mixture causes a lot of air in the asphalt concrete, making it easier for the asphalt blanket to oxidize with air, becoming brittle, causing its durability to decrease [15].

IV. Conclusion

The results of the examination of the physical properties of the material in the form of aggregate and asphalt pen 60/70 have met the required specifications and can be used as an AC-WC mixture. Based on the evaluation of Marshall parameters, the minimum asphalt content is 5.00, the middle asphalt content is 5.50% and the maximum asphalt content is 6.00%.

Based on the results of the evaluation of Marshall characteristics in the AC-WC mixture, the best composition for the combination using artificial aggregate (AA) and natural aggregate (NA) was obtained at a composition of 25% NA -75% AA at 5.00% asphalt content, the stability value is 1492 , 37 kg, meets specifications and can be used as an aggregate in the laston AC-WC mixture.

Substitution of natural aggregates with artificial aggregates can affect the value of the Marshall test parameters which include VIM, VMA, VFA, Stability, and Flow. This effect is in the form of decreased stability.

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