The Utilization Fly Ash as Material Substituon for Filler Asphalt Concrete Wearing Coarse (AC-WC) Mixed with Percentage Refusal Density (PRD) Method

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Keywords: Asphalt Concrete Wearing Coarse (AC-WC), Filler, Fly Ash, Marshall Method, Optimum Asphalt Content (OAC), Percentage Refusal Density (PRD) Method.

Abstract: Asphalt Concrete Wearing Coarse (AC-WC) consists of asphalt and aggregate mixed, that largest composition is aggregate (90% from the total weight of mixture). The availability of mixed-forming materials is very important in ensuring smooth implementation in the field, apart from the quality of the material. In some areas, the availability of filler is considered quite difficult because the filler usually comes from rock ash, so it takes a replacement material that has the same specifications as the filler from rock ash. The possible material is fly ash which is waste in coal mines and has not been utilized to the fullest. This research will analyze the performance of AC-WC coarse that make use of filler substitution material using fly ash with variation FA-0%, FA-5%, and FA-10%. The samples made by Marshall Method will give the Optimum Asphalt Content (OAC) value on each mix variation. While the performance of these AC-WC mixtures on secondary compaction by traffic was carried out using the Percentage Refusal Density (PRD) Method. The analysis result shows that the OAC value at 0% fly ash variation is 5.95%, at 5% fly ash variation is 6.25%, and at 10% fly ash variation is 6.32%. While the performance of AC-WC mixture indicated by the PRD value meets the specifications, namely the PRD test gives a minimum VIM value of 2%. Based on the results of the study, it can be seen that with the addition of fly ash there is an increase in the asphalt content used but the increasing is not too big. So the fly ash can recomended to use as substitution filler on AC-WC mixture.

1 INTRODUCTION

Asphalt Concrete Wearing Coarse (AC-WC) is one type of coating on flexible pavement. Similar to other flexible pavement layers, AC-WC is also composed of a mixture of asphalt and aggregate. As a material with the largest percentage amount (about 90% - 95%), aggregate is divided into coarse aggregate, fine aggregate, and filler. The quality of the material forming the road pavement layer, AC-WC mixture, is one of the determining factors for the performance of road pavement layers (AASHTO, 1993), especially the aggregate, considering that the percentage of aggregate in the pavement mixture can reach 75-85% of the total volume of the mixture or around 90% of the total weight of the mixture. In addition to material quality, the availability of mixed-hforming materials is also very important in ensuring smooth implementation in the field. Filler is one part of the aggregate and is quite difficult to obtain because usually, the filler used comes from rock ash. In some locations, the availability of such a filler is felt to be very difficult, so it is necessary to replace material that has the same specifications as the filler from the rock ash. One possible material is fly ash. Fly ash is a waste material in coal mines, the availability of which is quite a lot and has not been utilized and is found in the West Sumatra area, precisely in the Sijantang area, Sijunjung Regency.

The performance of the AC-WC layer using filler material substitution using fly ash with variations in the substitution of 0% fly ash (FA-0%) or without fly ash, 5% fly ash (FA-5%), and 10% fly ash (FA-10%) will be known in this research. This percentage will be mixed later in the asphalt mixture (test object) at a temperature of 150oC. This specimen is compacted in a mold measuring 152-153 mm (6 inches) by Marshall compaction 2x75 impact. Furthermore, to see the performance of this AC-WC layer after the mixture was secondarily compacted by traffic during the design life, without undergoing any plastic

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deformation, a test was carried out using a field condition approach using the Percentage Refusal Density (PRD) Method. In the PRD method, compaction of the mixture is carried out manually with a number of 2x400 collisions, which is equivalent to compaction using an electric vibrating compactor (BS 598 Part 104 1989). The test object used is a test object with asphalt content which gives a Marshall VIM value of 6% (VIM6%), and 0.5% above and below the asphalt content. While the asphalt used is asphalt PEN 60/70 that produced by Pertamina.

2 RESEARCH METHOD

The research was carried out in two laboratories, the material testing laboratory Civil Engineering Department-Padang State Polytechnic and the road laboratory of Public Work Department. The material for forming the AC-WC mixture is aggregate obtained from the quarry in the Padang area, while fly ash as a filler replacement material is obtained from the Sijantang area, Sijunjung Regency. Another material that also forms the AC-WC mixture, namely asphalt, is used from Pertamina's production with PEN 60/70 specification.

2.1 The Aggregate Properties Testing

This test is carried out in the Material Testing Laboratory of Civil Department - Padang State Polytechnic. The aggregates referred to here whose properties are tested are coarse aggregate, fine aggregate, and filler including fly ash. The properties testing of aggregates consists of:

- Specific gravity and absorption of coarse aggregate, fine aggregate, filler and fly ash.
- Aggregate Impact Value (coarse aggregate)
- Aggregate Crushing Value (coarse aggregate)
- Aggregate Abrasion Value By Los Angeles Machine
- Flakiness And Elongation Index
- Soundness Test By Sodium Sulfat/ Magnesium Sulfat

Specification of coarse aggregate and fine aggregate according to 2018 specifications are shown in Table 1 and Table 2.

Table 1: Coarse Aggregate Specification.

Testing	Method	Value
Soundness by natrium sulfat/magnesium sulfat solvent	SNI 3407: 2008	Max 12% / max 18%
Abrasion by Los Angeles Machine	SNI 2417: 2008	Max 40%
Aggregate adhesiveness to asphalt	SNI 2439: 2011	Min 95%
Aggregate rupture field	SNI 7619: 2012	95/90**
Flakiness and Elongation particles	ASTM D4791-1 0 Ratio 1:5	Max 10%
Material passes sieve No.200	SNI ASTM C117: 2012	Max 1%

**95/90 indicates that indicates that 95% of the coarse aggregate has a fracture area of 1 or more and 90% of the coarse aggregate has a fracture area of 2 or more

Source : General Specifications 2018

Table 2: Fine Aggregate Specification.

Testing	Method	Value
Sand equivalent value	SNI 03-4428-1997	Min 50%
Void level test without campaction	SNI 03-6877-2002	Min 45
Lump of clay and fragile grains in the aggregate	SNI 03-4141-1996	Max 1%
Aggregate passes sieve No.200	SNI ASTM C117: 2012	Max 10%

Source : General Specifications 2018

2.2 The Asphalt Properties Testing

This test is carried out in the Road Testing Laboratory of Public Work Department. The properties testing of asphalt consists of:

- Specific gravity of Asphalt
- Penetration Test
- Ductility Test
- Softening Point Test
- Flashing And Burning Point Test
- Weight Loss Test
- Viscosity Test
- Stripping Test

Specification of asphalt are shown in Table 3.

Table 3: asphalt Specification.

Testing	Method	Value
Penetration at 25^0C (0.1 mm)	SNI 2456: 2011	60 - 70
Kinematic Viscosity 135^0C (cSt)	ASTM D2170-10	≥ 300
Softening Point (^{0}C)	SNI 2434 : 2011	≥ 48
Ductility at 25^0C , (cm)	SNI 2432 : 2011	≥ 100
Flash Point (^{0}C)	SNI 2433 : 2011	≥ 232
Solubility in Trichloroethylene (%)	AASHTO T44-14	≥ 99
Specific Gravity	SNI 2441 : 2011	≥ 1

Source : General Specifications 2018

2.3 Mixture Design

The mixtures make by Marshall Method. The procedure design of this method is:

- Determine gradation, based on specifications of Bina Marga 2018. Mix design has taken into account the substitution of fly ash as a filler. The gradation used is shown in Table 4 and Figure 1.

Table 4: Gradation of asphalt concrete wearing coarse.

Sieve Size		**% of Weight Passed**	
ASTM	**Mm**	***Specification***	***Gradation Design***
¾"	19	100	100
½"	12.5	90 – 100	95
3/8"	9.5	77 – 90	83.5
No.4	4.75	53 – 69	61
No.8	2.36	33 – 53	43
No.16	1.18	21 – 40	30.5
No.30	0.600	14 – 30	22
No.50	0.300	9 – 22	15.5
No.100	0.150	6 – 15	10.5
No.200	0.075	4 – 9	6.5

Source : General Specifications 2018

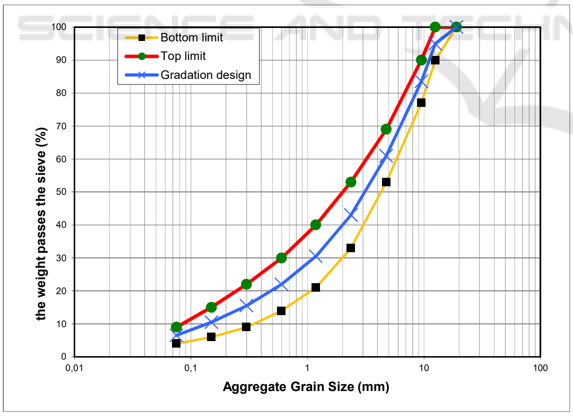

Figure 1: Asphalt Concrete-Wearing Coarse Mixture Gradation Chart.

The modification of the AC-WC mixture with using of fly ash as a filler so the composition of the mixture gradation in Table IV becomes as in Table 5.

- Determine middle asphalt content as approximate asphalt content. Middle asphalt content depend on gradation of mixture, and calculated by formula;

Pb = 0.035*%CA + 0.045*%FA + 0.18*%FF + K(1)

Where,

CA = coarse aggregate
FA = fine aggregate
FF = fine filler
K = constant, used 1

Table 5: Gradation of asphalt concrete-wearing coarse mixture by substitution fly ash as filler.

Sieve Size		**Asphalt Concrete-Wearing Coarse Gradation with**				
		%Passed	***%Bated***	**Mixed Weight (gr)**		
ASTM	**mm**			***0%FA***	***5%FA***	***10%FA***
¾"	19	100	0	0	0	0
½"	12.5	95	5	60	60	60
3/8"	9.5	83.5	11.5	138	138	138
No.4	4.75	61	22.5	270	270	270
No.8	2.36	43	18	216	216	216
No.16	1.18	30.5	12.5	150	150	150
No.30	0.600	22	8.5	102	102	102
No.50	0.300	15.5	6.5	78	78	78
No.100	0.150	10.5	5	60	60	60
No.200	0.075	6.5	4	48	48	48
Filler			6.5	78	74.1	70.2
Fly ash					3.9	7.8
Total				1200	1200	1200

The middle asphalt content is the basis for determining other asphalt content in the manufacture of mixtures. Percentage of coarse aggregate is obtain from the total percentage of aggregate retained up to sieve No.4.75 (Table V) i.e 39%.

While the percentage of fine aggregate is obtained from the percentage of aggregate that passes the No.4.75 sieve and is retained by the No.200 sieve (Table V) i.e 54.5%. Percentage of filler is 6.5%. The asphalt content to be used in making of samples is Pb, 0.5% and 1% above, and also 0.5% and 1% below the Pb value. So variation of asphalt content that used is 5 variation.

Make a sample of Marshall test with variation 0% fly ash, 5% fly ash, and 10% fly ash as filler substitution. Each sample is made with 5 variations of asphalt content and for each asphalt content 3 samples are made. So the number of samples for one variation of the mixture is 15 pieces. With 3 mixed variations

(0%FA, 5%FA, and 10%) then the total for all of samples is 45 pieces.

2.4 Mixture Analysis

A mixed analysis is carried out after sample making is complete. The analysis carried out on the Marshall sample includes volumetric analysis and stability analysis. A volumetric analysis will get the dimensions and weight of the sample, density, VIM (Void in Mix), VMA (Void in Mineral Aggregate), and VFA/VFB (Void Filled Asphalt/Void Filled Bitumen). Volumetric analysis calculations use the formula;

- Bulk Specific Gravity of Combined Aggregate

$$G_{sb} = \frac{P_1 + P_2 + ... + P_n}{\frac{P_1}{G_1} + \frac{P_2}{G_2} + ... + \frac{P_n}{G_n}} \quad (2)$$

Where;

G_{sb} = Total bulk specific gravity of aggregate

$P_1,\ldots,P_n$ = Percentage of each aggregate fraction

$G_1,\ldots,G_n$ = Bulk Specific Gravity of each aggregate fraction

- Effective Specific Gravity of Combined Aggregate

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} \quad (3)$$

Where;

G_{se} = Total effective specific gravity of aggregate

G_{mm} = Mixed maximum specific gravity, zero void (AASHTO T-209.90)

P_b = Asphalt content in percent of the total weight of the mixture

G_b = Asphalt specific gravity

- The theoretical maximum Specific Gravity of asphalt mix

$$G_{mm} = \frac{100}{\frac{P_s}{G_{se}} + \frac{P_b}{G_b}} \quad (4)$$

Where;

P_s = Aggregate content, percent of the total weight of the mixture

- Void in Mineral Aggregate (VMA)

$$VMA = 100 - \frac{G_{mb}}{G_{sb}} x P_s \quad (5)$$

Where;

G_{mb} = Bulk specific gravity of solid mix

- Void in Mix (VIM)

$$VIM = \frac{G_{mm} - G_{mb}}{G_{mm}} \quad (6)$$

- Void Filled Asphalt (VFA)

$$VFA = \frac{100x(VMA - VIM)}{VMA} \quad (7)$$

- Asphalt Absorption (P_{ba})

$$P_{ba} = \frac{100x(G_{se} - G_{sb})}{(G_{se} x G_{sb})} x G_b \quad (8)$$

Where;

P_{ba} = Asphalt absorption, percent of total aggregate

- Effective Asphalt Content (P_{be})

$$P_{be} = P_b - \frac{P_{ba}}{100} x P_s \quad (9)$$

Where;

P_{be} = Effective Asphalt content, percent of total mix

While at the stability analysis will get the value of stability and flow of the mixture. Both analysis will give the optimum asphalt content value. The analysis was carried out using a graph of the relationship between asphalt content with VIM, VMA, VFA, Stability, Flow, and MQ.

2.5 Percentage Refusal Density (PRD) Method

Percentage Refusal Density (PRD) is a ratio of laboratory test density to refusal density in percent. Absolute density is an approximation to field conditions after the asphalt mixture has been secondarily compacted by traffic for several years of the design life, without undergoing any plastic deformation. Procedure test of PRD method is;

- Mixture Design; PRD test samples were made with mixed variations of 0% fly ash, 5% fly ash, and 10% fly ash, as filler substitution. Asphalt content used in the manufacture of samples is asphalt content at 6% VIM conditions. The other two percentages of asphalt content that will be used in making the sample are 0.5% above and 0.5% below of the asphalt content value at the 6% VIM condition. PRD sample compaction was carried out manually with a total of 400 collisions on both sides of the sample used a 4-inch diameter mold.
- Mixture Analysis; The point analyzed in the PRD test is the VIM value, which is known as the VIM refusal. Refusal VIM value according to 2018 specification is a minimum 2%.

3 RESULT AND DISCUSSION

The test results on the material forming the AC-WC mixture i.e. aggregate properties test and asphalt properties test show on Table 6 and Table 7. The tables show that the results of testing the properties of aggregate and asphalt generally meet the specifications. therefore these materials can be used for the manufacture of the AC-WC mixtures.

Table 6: The result of aggregate properties test.

No.	Aggregate Characteristics	The Test Result	Specification
A. Coarse Aggregate			
1.	Bulk specific gr avity	2.68	Min 2.5
	Surface Saturated Dry (SSD) specific gravity	2.60	
	Apparent specific gravity	2.72	Min 2.5
	Effective specific gravity	2.70	
2.	Soundness by natrium sulfat/magnesium sulfat solvent		
3.	Abrasion by Los Angeles Machine	33.36%	Max 40%
4.	Aggregate adhesiveness to asphalt		
5.	Aggregate rupture field		
6.	Flakiness and Elongation particles		
7.	Material passes sieve No.200		
B. Fine Aggregate			
1.	Bulk specific gravity	2.66	Min 2.5
	Surface Saturated Dry (SSD) specific gravity	2.60	
	Apparent specific gravity	2.70	
	Effective specific gravity	2.68	
2.	Absorption	2.37%	< 3%
3.	Sand equivalent value		
C. Filler			
1.	Specific gravity of stone ash	2.5	Min 2.5
2.	Specific gravity of fly ash	2.4	

Table 7: The result of asphalt properties test.

No.	Asphalt Characteristics	The Test Result	Specification
1.	Penetration at 25^0C (0.1 mm)	67.3	60 - 70
2.	Kinematic Viscosity 135^0C (cSt)	463	≥ 300
3.	Softening Point (^{0}C)	55.5	≥ 48
4.	Ductility at 25^0C , (cm)	142	≥ 100
5.	Flash Point (^{0}C)	320	≥ 232
6.	Solubility in Trichloroethylene (%)	92.723	≥ 99
7.	Specific Garvity	1.047	≥ 1

The result of kinematic viscosity shows on Table 8 whereas the Saybolt Furol graph shows on Fig.2.

Table 8: The result of kinematic viscosity test.

Temperature (^{0}C)	Waktu Alir (detik)	Sentistokes (cSt)
120	326	656
140	158	338
160	72	150

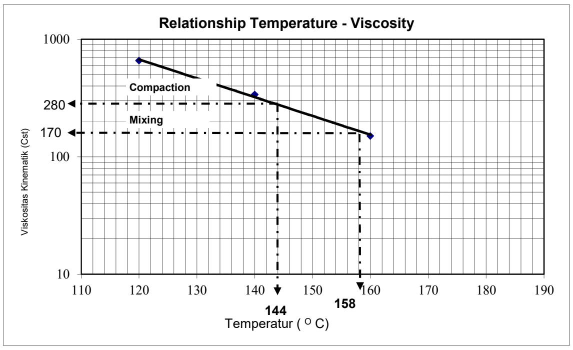

Figure 2: Saybolt Furol Graph.

The kinematic viscosity value is used to obtain the mixing temperature and compaction temperature. The result of kinematic viscosity is plotted on the Saybolt Furol graph so that the mixing temperature and compaction temperature are obtained.

Based on the Saybolt Furol graph shows that the mixing temperature is 158^{0}C and the compaction temperature is 144^{0}C.

3.1 Mixture Analysis by Marshall Method

By using equation (1) obtained the value of the middle asphalt content is 6%. Thus the asphalt content used in making the sample is 5%, 5.5%, 6%, 6.5%, and 7%. Volumetric analysis on the Marshall Method will produce VIM, VMA, VFA values using equation (2) until (9). The results of calculations using these equations are shown in Table 9.

Table 9: Test results marshall Asphalt Concrete-Wearing Coarse mixture without fly ash.

Bulk Specific Gravity of Aggregate (Gsb)	=	2.655
Effective Specific Gravity of Aggregate (Gse)	=	2.729
Specific Gravity of Asphalt (Gb)	=	1.047

Sample Code	Sample Height	Asphlat Content (Pb)	Aggregate Content (Pb)	Sample Weight			Sample Volume	Specific Gravity of Mix		Density	Void in Mix	Void in Mineral Aggregate	Void Filled Asphalt
				Dry	Saturated Surface Dry (SSD)	In water		Bulk G_{mb}	Max G_{mm}		3 – 5	≥ 15	≥ 65
	mm	%	%	gram	gram	gram	cc				%	%	%
A-1	67.41	5	95	1240.1	1243.7	707.5	536.2	2.313	2.526	2.313	8.45	17.24	50.96
A-2	65.43	5	95	1248.3	1248.9	723.2	525.7	2.375	2.526	2.375	6.01	15.03	60.02
A-3	66.15	5	95	1236.3	1242.6	711.8	530.8	2.329	2.526	2.329	7.80	16.65	53.13
B-1	67.33	5.5	94.5	1250.3	1252.0	723.1	528.9	2.364	2.508	2.364	5.73	15.85	63.84
B-2	68.10	5.5	94.5	1254.4	1256.3	721.9	534.4	2.347	2.508	2.347	6.39	16.44	61.11
B-3	66.50	5.5	94.5	1246.0	1246.4	723.5	522.9	2.383	2.508	2.383	4.98	15.18	67.21
C-1	68.98	6	94	1259.2	1261.3	723.3	538.0	2.341	2.489	2.341	5.98	17.12	65.10
C-2	65.66	6	94	1249.4	1249.5	727.8	521.7	2.395	2.489	2.395	3.79	15.20	75.04
C-3	67.34	6	94	1254.9	1255.6	723.5	532.1	2.358	2.489	2.358	5.26	16.49	68.11
D-1	66.08	6.5	93.5	1254.4	1255.0	726.8	528.2	2.375	2.471	2.375	3.90	16.36	76.17
D-2	67.84	6.5	93.5	1263.6	1264.0	729.0	535.0	2.362	2.471	2.362	4.42	16.81	73.69
D-3	66.25	6.5	93.5	1261.6	1261.2	732.5	528.7	2.386	2.471	2.386	3.44	15.96	78.45
E-1	67.67	7	93	1254.5	1255.2	725.7	529.5	2.369	2.453	2.369	3.43	17.00	79.83
E-2	67.93	7	93	126.05	1265.9	728.9	537.0	2.356	2.453	2.356	3.98	17.48	77.22
E-3	66.40	7	93	1261.6	1261.9	728.3	533.6	2.364	2.453	2.364	3.63	17.17	78.87

The results of the Marshall test on the AC-WC mixture shown in Table IX, were analyzed graphically the asphalt content for the value of VIM, VMA, VFA, Stability, and flowas shown in Fig.3 until Fig.8.

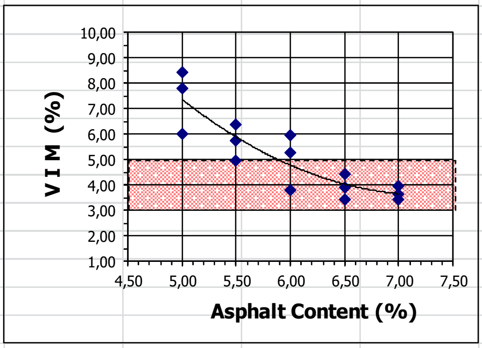

Figure 3: Graphic Analysis Asphalt Content – Void in Mix.

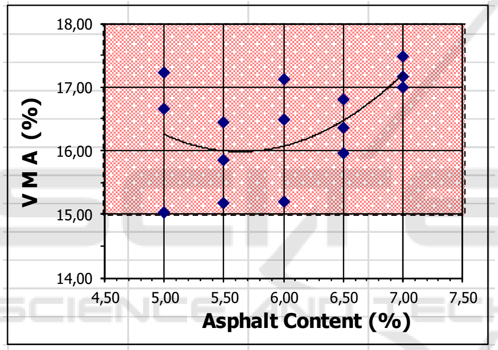

Figure 4: Graphic Analysis Asphalt Content – Void in Mineral Aggregate.

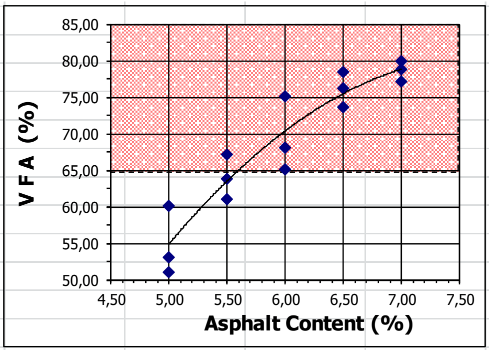

Figure 5: Graphic Analysis Asphalt Content – Void in Filled Asphalt.

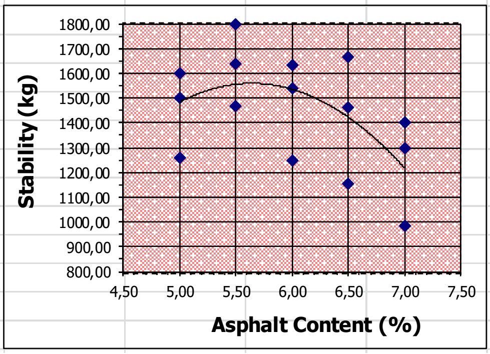

Figure 6: Graphic Analysis Asphalt Content – Stability.

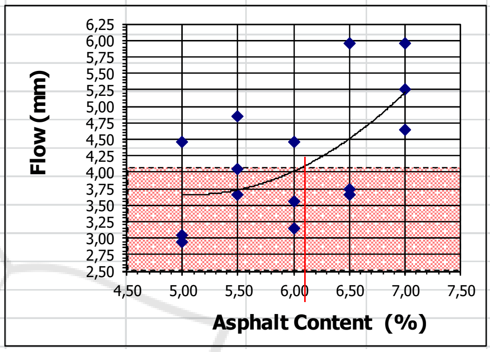

Figure 7: Graphic Analysis Asphalt Content – Flow.

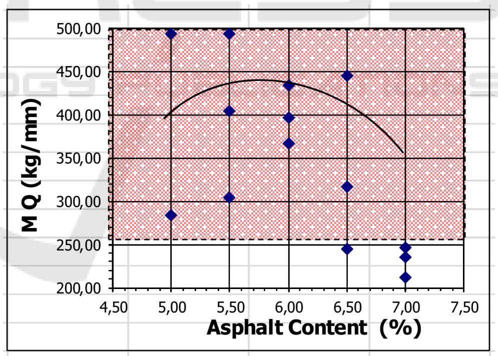

Figure 8: Graphic Analysis Asphalt Content – Marshall Question.

Based on the graph, it can be seen that the asphalt content range meets the specifications (shaded part). The optimum asphalt content is obtained by taking the median value of the asphalt content range that meets all specifications that show in Fig.9.

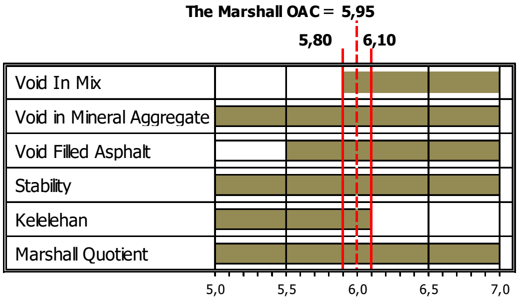

Figure 9: Graphical Analysis for Optimum Asphalt Content value on Asphalt Concrete-Wearing Coarse mixture 0% fly ash.

In the same way, calculations and analyzes were also carried out for the AC-WC mixture with the substitution of 5% and 10% fly ash as filler. So the Optimum Asphalt Content (OAC) on the AC-WC mixture with 5% fly ash is 6.25%, while for the AC-WC mixture with 10% fly ash is 6.32%.

Based on this results show that the addition of fly ash substitution will increase the value of the optimum asphalt content.

3.2 Mixture Analysis by Percentage Refusal Density Method

The PRD samples were made with asphalt content at 6% VIM conditions obtained on the chart of Marshall analysis results, which are shown in Fig. 10.

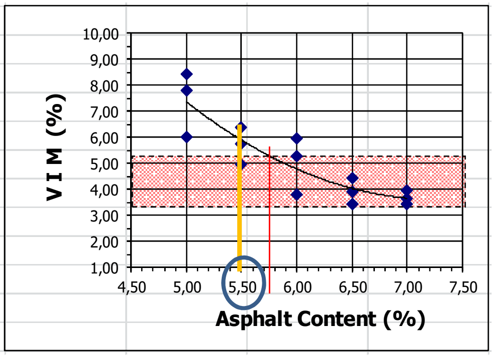

Figure 10: The marshall analysis chart to determine the middle asphalt content of the PRD sample on Asphalt Concrete-Wearing Coarse mixture 0% fly ash.

In the same way is also done for the AC-WC mixture with the substitution of 5% and 10% fly ash as filler. Thus the value of PRD Asphalt content in the AC-WC mixture with 5% fly ash is 5.35%, while for the AC-WC mixture with 10% fly ash it is 5.4%.

The tests carried out on the PRD samples were only volumetric tests/analyses, which are shown in Table 10.

Table 10: the test percentage refusal density (prd) results on Asphalt Concrete-Wearing Coarse mixture without fly ash.

Bulk Specific Gravity of Aggregate (Gsb)	=	2.655
Effective Specific Gravity of Aggregate (Gse)	=	2.729
Specific Gravity of Asphalt (Gb)	=	1.047

Sample Code	Sample Height	Asphlat Content (Pb)	Aggregate Content (Pb)	Sample Weight			Sample Volume	Specific Gravity of Mix		Density	Void in Mix	Void in Mineral Aggregate	Void Filled Asphalt
				Dry	Saturated Surface Dry (SSD)	In water		Bulk G_{mb}	Max G_{mm}		Min 2		
	mm	%	%	gram	gram	gram	cc				%	%	%
A-1	67.17	5.5	94.5	1234.2	1235.8	713.7	522.1	2.364	2.526	2.364	6.43	15.41	58.28
A-2	65.63	5	95	1241.3	1243.1	724.1	519.0	2.392	2.508	2.392	4.62	14.86	68.89
A-3	65.13	6	94	1241.0	1241.9	724.4	517.5	2.398	2.489	2.398	3.66	15.09	75.70

The Void in Mix (VIM) values are plotted on the Marshall analysis VIM graph so that a refusal VIM graph is obtained, that shows on Fig.11 for AC-WC mixture without fly ash (0% FA), Fig.12 for AC-WC mixture with 5% fly ash (5% FA), Fig.13 for AC-WC mixture with 10% fly ash (10% FA).

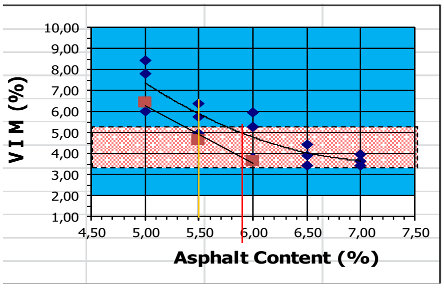

Figure 11: Void In Mix (VIM) refusal on Asphalt Concrete-Wearing Coarse mixture 0% fly ash.

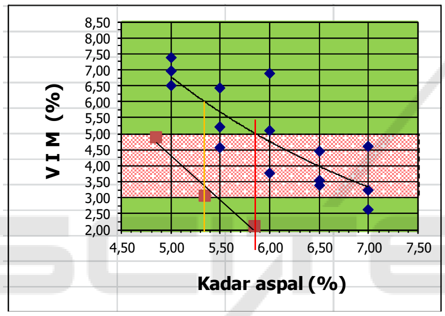

Figure 12: Void In Mix (VIM) refusal on Asphalt Concrete-Wearing Coarse mixture 5% fly ash.

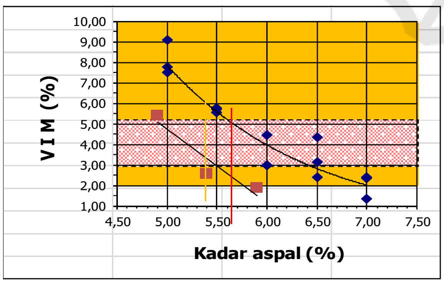

Figure 13: Void In Mix (VIM) refusal on Asphalt Concrete-Wearing Coarse mixture 10% fly ash.

Based on graphical analysis for the refusal VIM value in all variations of the AC-WC mixture (Fig.11 until Fig.13), it meets the required value of at least 2%.

4 CONCLUSION

According to the result of the utilization fly ash as material substitution for filler in Asphalt Concrete-Wearing Course (AC-WC) mixed with Percentage refusal density (PRD) method can conclude that: The Optimum Asphalt Content (OAC) increases with the increase in the percentage of use of fly ash as a filler substitution and the voids found in all variations of the AC-WC mixture meet the required specifications (Percentage Refusal Density Method test result). The increase in OAC value due to filler substitution in the mixture is not too large, so use of fly ash as a filler substitution in the AC-WC mixture is recommended.

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