Effect of compaction temperature variations onthe characteristics of marshall Asphalt Concrete-Wearing Course [AC-WC] usingmodified asphalt (asphalt pertamina pen 60/70 with addition of 1.5% styrofoam)

Ramadhan Sakti Wibowo

Civil Engineering Study Program, Faculty of Engineering Sebelas Maret University Surakarta, INDONESIA

E-mail: rama_gen17@student.uns.ac.id

Received September 01, 2022 | Accepted October 22, 2022 | Published January 04, 2023

ABSTRACT

The road is one of the transportation infrastructures which is a basic need in community activities. Along with the development of road construction, road construction materials are needed that are more environmentally friendly and can improve the quality of the asphalt mixture. Styrofoam is one of the materials that can be added because styrofoam is a thermoplastic material. The compaction temperature is also a factor that it must consider during the implementation in the field because it will determine the level of asphalt stability. This research was conducted by an experimental method using modified asphalt with a mixture of 1.5% styrofoam. The optimum asphalt content used is 6%, with compaction temperatures of 80°C, 90°C, 100°C, 110°C, and 120°C based on the plot of the Bitumen Test Data Chart (BTDC). The data analysis is based on the results of the Marshall parameter values. The test uses asphalt inspection test equipment and Marshall test equipment. The results of this study are that the lower the compaction temperature, the smaller the Marshall parameter value, and the higher the compaction temperature, the higher the Marshall parameter value. Asphalt parameters decreased. Based on the Marshall test carried out, the compaction temperature that meets the requirements of the 2018 Highways specification from a temperature range of 80°C to 120°C with an interval of 10 C is at a temperature of 110˚C and 120˚C.

Keywords: modified asphalt 1.5% styrofoam; compaction temperature; marshall test; BTDC.

INTRODUCTION

The quality of asphalt can improve the quality of asphalt mixtures by adding additives to the asphalt; additives to enhance the quality of asphalt in overcoming the weaknesses in flexible pavements are by modifying it using added materials in the form of styrofoam. Styrofoam is a type of plastic made of 90% - 95% *polystyrene* and 5% - 10% gases such as *n-butane* or *n-pentane*, so styrofoam is as dangerous as plastic. Styrofoam waste is also one garbage that is very difficult to decompose (Martanto Adji et al., 2020). The handling of styrofoam waste which is limited to disposal, will also burden nature in its decomposition. For this reason, it is necessary to recycle styrofoam to reduce environmental damage (Melyna, 2021).

Styrofoam is a type of plastic polymer with thermoplastic properties, which is that it becomes soft if heated and hardens again after cooling. Because asphalt is a hydrocarbon, the addition of styrofoam is expected to increase the adhesion between the aggregate and asphalt to improve the quality of the concrete mixture. (Made dwi ari prabawa, 2021).

Many factors can affect the quality of pavement materials in the field; one of these factors is the compaction temperature. The compaction temperature is a factor that it must consider during the implementation in the area because the compaction temperature will largely determine the density level of a road pavement material and further determine its stability. Speaking of the compaction temperature, we will talk about the temperature of a paved mixture starting from the mix out of its mixing place (AMP) until the moment of spreading and compaction in the field, the impact of which will be tested through laboratory experiments (Azhari et al., 2018).

Based on the description above, the formulation of the problem can be taken as follows (1) How does the compaction temperature affect Marshall characteristics on hot asphalt mixtures using modified asphalt (asphalt mixture penetration 60/70 + 1.5 % *styrofoam*)? And (2) What is the compaction temperature that complies with Bina Marga's 2018 specifications on modified asphalt mixture (60/70 penetration asphalt mixture + 1.5% *styrofoam*).

Previous research conducted by (Mawardi et al., 2020) showed Marshall characterization test results on conventional AC-Bases and modifications showed that the values of density, VFA, stability, and MQ increased along with the increase in compaction temperature, while the importance of VIM, VMA, and Flow decreased. In a conventional AC-Base, a minimum temperature of 140ºC and an optimum temperature of 150ºC are obtained, while in a modified AC-Base, a minimum and optimum temperature of 160ºC are obtained.

The results of the study by (Lolok et al., 2021) showed the characteristics of the wear-out layer last mixture using Malili River stone and Styrofoam as an added material through the Marshall test obtained the values of mixed elements, namely stability, flow, VIM, VMA, and VFB all met the 2018 Bina Marga General Specification. Adding Styrofoam to the last mixture can fill the cavity in the mix, which makes the hole smaller, making the bond between the aggregates stronger so that with the addition of Styrofoam, the mixture becomes more waterproof/resistant to water, weather and traffic loads.

In addition, the results of the study by (Liu et al., 2020) showing ps grafting asphalt (*polystyrene)* to ARP (*Activated rubber powder /* active rubber powder) with in-situ polymerization showed better low-temperature plasticity, heat resistance, viscoelasticity, performance against *rutting*, fatigue and low-temperature performance than asphalt modified ARP / SBS (*styrene–butadiene styrene)*). There is a 7% increase in costs compared to SBS-modified asphalt.

The research reviewed above is the use of waste as a substitute for modified asphalt and the influence of compaction temperature on the stability of asphalt concrete. Meanwhile, this study aims to determine the effect of compaction temperature on Marshall characteristics with asphalt modification asphalt pen 60/70 with an added material of 1.5% styrofoam

RESEARCH METHODS

Methods

The method used in this study is an experimental empirical design method, which is a method carried out by holding practical activities to obtain data (Muyassar & Syarwan, 2021). The data is processed to get a comparison result with existing conditions. Experimental investigations can be carried out inside or outside the laboratory. This study was carried out in the laboratory using variations in *styrofoam* levels of 1.5% against the total aggregate weight. With a compaction temperature of 80°C; 90°C; 100°C; 110°C;120°C. This study was conducted at the Civil Engineering Highway Laboratory, Faculty of Engineering, Sebelas Maret University. This research was conducted from February 2022 to March 2022.

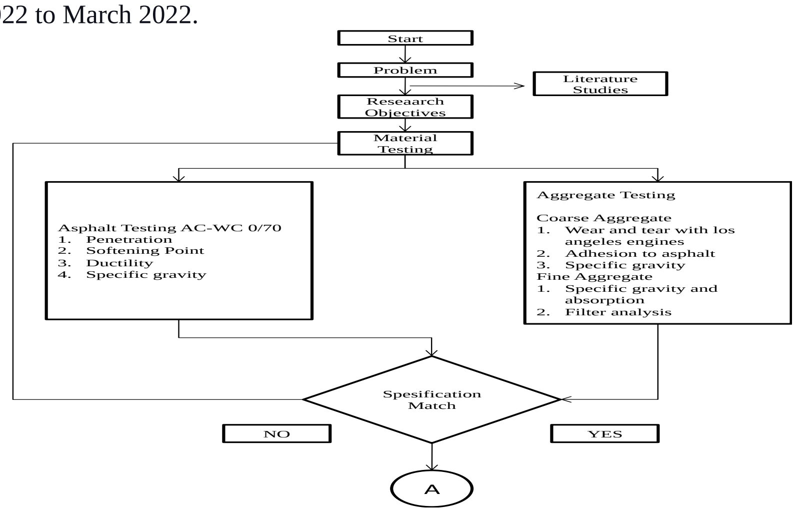

Figure 1. Research flow chart

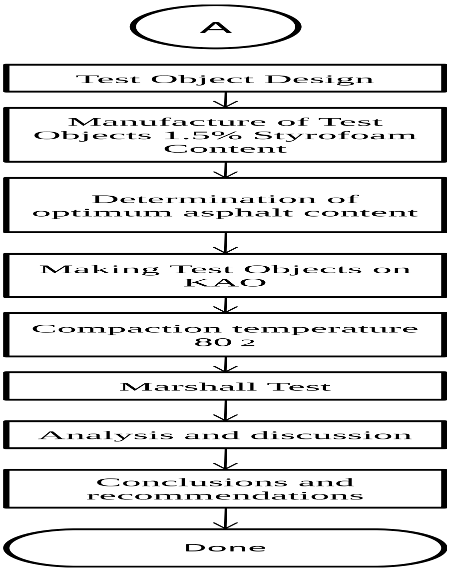

Figure 2. Research Flow chart

Aggregate inspection includes aggregate abrasion, aggregate sieve analysis, coarse aggregate specific gravity and fine aggregate specific gravity. Asphalt Testing consists of Penetration, mushy point, flash and burn point, ductility, and specific gravity of asphalt.

Marshal Testing

The time required from lifting the test object from the water bath until the maximum load is reached during the test should not exceed 30 seconds.Soak the test object in a water heater for 30 – 40 minutes with a fixed temperature of 60°C ± 1°C for the test object;

1. Soak the test object in a water heater for 24 hours with a fixed temperature of 60°C ± one °C to find out the immersion index
2. Remove the test object from the water heater and place it in the bottom of the Marshall test press;
3. Install the top of the Marshall test press on top of the test object and place it entirely in the Marshall testing machine
4. Attach the melting measuring watch to its position above one of the guiding rods and set the part of the pointing needle at zero while the watch stalk sheath (*sleeve*) is firmly held on the top of the pressing head;
5. Before the loading is given, the pressing head along with the test object is raised until it touches the base of the tester's ring;
6. Set the watch needle press at the position of the number zeros;
7. Provides loading on the test object at a fixed speed of about 50.8 mm per minute until maximum loading is reached, decreasing loading as indicated by the press watch needle and recording the maximum load (stability) achieved. For test objects with a thickness not equal to 63.5 mm, the bag must be corrected by a multiplier factor as shown in Table 2;
8. Records the melting value indicated by the melting gauge watch needle at the moment when the maximum load is reached.

Data Analysis

The test data were obtained by experimental methods against several test objects from various treatment conditions tested in the laboratory. For some things in material testing, secondary data is

ASTONJADRO
pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.176-191
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

used due to the use of the same material and source. The data types in this study are grouped into 2, namely primary and secondary data.

Primary data is collected directly through a series of self-conducted experimental activities concerning existing manual instructions using conducting research or testing now(Pramiyati et al., 2017). This study's preliminary data are the Marshall test's results, including stability values, flow values, and Marshall Quotient.

Research materials are all materials used to make test objects in research. The ingredients that will be used in this study are:

1. Coarse aggregates and fine aggregates are obtained from PT. Five Dharma
2. The asphalt used is Pertamina asphalt with penetration of 60/70
3. The styrofoam used is styrofoam used in electronic packaging
4. Xylene as a Styrofoam solvent

This study used equipment from the Highway Pavement Laboratory, Faculty of Engineering, Sebelas Maret University, Surakarta. The equipment used includes:

1. A set of ASTM standard *sieve* test equipment
2. A set of vibrating machines for *sieve shakers*Scales with a capacity of 2610gr with an accuracy of 0.1 gr
3. Temperature meter (thermometer) with a capacity of 360ºC
4. Calipers
5. Asphalt mixture briquette making tool consisting of:
   a. A set of cylindrical molds with a diameter of 101.45mm, and a height of 70mm, complete with a top plate and sampling neck.
   b. A *compactor* that has a cylindrical flat mashing surface, weighing 4,536 kg (10 lbs), free fall height of 45.7 cm (18")
   c. A set of briquette lifting devices (hydraulic jacks)
6. A set *of water baths*
7. A Marshall Test equipment set in the Highway Laboratory of the Faculty of Civil Engineering, Sebelas Maret University.
8. Supporting tools that include *stationery*, *markers*, mixing pots, heating stoves, thermometers, fans, stirring spoons, heat-proof T-shirts, rags, spatulas, scales

This study used 12 test objects. The needs of the test object are as presented in Table 1 below.

Table 1. Composition of The Test Object

No	**Composition**		**Compaction Temperature(°C)**	**Total Test Objects**
	Asphalt Content (%)	**Styrofoam levels (%)**		
a	b	c	d	e
1	6,00%	1,50%	80°C	3
2	6,00%	1,50%	90°C	3
3	6,00%	1,50%	100°C	3
4	6,00%	1,50%	110°C	3
5	6,00%	1,50%	120°C	3
Total				**15**

RESULT AND DISCUSSION

Aggregate Examination Results

According to ASTM of 1995, aggregates are rocks consisting of solid minerals in the form of large masses or fragments (Weimintoro et al., 2022) . Based on their formation process, aggregates are comprised of 2 types, namely natural aggregates and artificial aggregates (Waani, 2013).

Their formation process is subdivided into sedimentary, igneous, and metamorphic rocks. Based on the processing process, aggregates are distinguished from natural aggregates that undergo a prior processing process and artificial aggregates. In paved mixtures, aggregates contribute up to 90-95% to the cross, so the natural properties are one of the determining factors of the performance of the mix (Mamangkey et al., 2013).

Aggregate examination in the laboratory includes examination of wear and tear by using Los Angeles machines, pseudo-specific gravity of coarse aggregates and pseudo-specific gravity of fine aggregates. The aggregate used is derived from PT. Pancadarma Puspawira. The results of the examination show that the aggregate used has met the specified conditions. Aggregate examination results as presented in table 2 to 4 below.

Table 2. Rough Aggregate Inspection Results /Coarse Aggregates (CA)

No	Types of Examinations	Unit	Condition	Result
a	**b**	**c**	**d**	**e**
1	Wear and tear with Los Angeles engines	(%)	<40	27,76
2	Aggregate Absorption Of Water	(%)	<3	2,09
3	Specific gravity of dry bulk (Bulk)	gr/cc		2,648
4	*Saturated Surface Dry* (SSD) specific gravity	gr/cc		2,703
5	Pseudo-Specific Gravity	gr/cc	>2,5	2,803

Table 3. Examination Results of Medium Aggregate (MA)

No	Types of Examinations	Unit	Condition	Result
a	**b**	**c**	**d**	**e**
1	Wear and tear with Los Angeles engines	(%)	<40	27,76
2	Aggregate Absorption Of Water	(%)	<3	2,631
3	Specific gravity of dry bulk (Bulk)	gr/cc		2,631
4	Specific gravity saturated dry surface / *Saturated Surface Dry* (SSD)	gr/cc		2,701
5	Pseudo-Specific Gravity	gr/cc	>2,5	2,818

Tabel 4. Examination Results of *Fine Agregate* (FA)

No	Types of Examinations	Unit	Condition	Result
a	**b**	**c**	**d**	**e**
1	Aggregate Absorption Of Water	(%)	<3	2,631
2	Specific gravity of dry bulk (Bulk)	gr/cc		2,631
3	Specific gravity of dry saturated bulk *Saturated Surface Dry* (SSD) surface	gr/cc		2,701
4	Pseudo-Specific Gravity	gr/cc	>2,5	2,818

Asphalt inspection results

Asphalt is a solid or semi-solid form material in black to dark brown, adhesive (*cementitious*) that will soften and melt when heated (Musa et al., 2019). sphalt is composed mainly of most bitumens, all of which are found in solid or semi-solid form from nature, as the result of petroleum refining, or are a mixture of bituminous materials with petroleum or its derivatives. Asphalt is a thermoplastic material; its consistency or viscosity will change according to the temperature changes that occur (PUTRO, 2011).

pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.176-191
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

The examination of the properties of ordinary asphalt with modified asphalt aims to match ordinary asphalt with modified asphalt already meets existing specifications or not. The properties of alkaline asphalt and modifications examined are data from laboratory tests. From the results of the tests that have been carried out, asphalt has characteristics that have met the specifics of the instructions in accordance with the Bina Marga regulations. The results of the inspection of ordinary asphalt and modifications as presented in table 5 below.

Table 5. Inspection Results of Ordinary Asphalt with Modified Asphalt

No.	**Types of Examinations**	**Unit**	**Asphalt Pen Terms 60/70**	**Result**	**Asphalt Terms Modification**	**Result**
a	b	c	d	e	f	g
1	Penetration	100 gr, 25°C, 5 Second	60-70	7.4	Reported *	60.7
2	Mushy Point	°C	Min. 48°C	52.5	Reported*	49.5°
3	Flash point	°C	Min. 200°C	313	Min. 230°C	305°
4	Burn point	°C	Min. 200°C	317	Min. 230°C	310°
5	Ductility	25°C, 5 cm/minute	Min. 100 cm	>150	Min. 100 cm	>150
6	Specific gravity	gr/cc	Min. 1 gr/cc	1,038	Min. 1	1.03

Sieve Analysis

After inspection, the aggregate used will be carried out a sieve analysis which aims to determine the composition of the granules (gradation) by calculating the percentage of passed the sieve. Aggregate samples were taken using *a sample splitter* or the quarter divide method. After obtaining a minimum sample weight, the aggregate sample will be fed into *the achieve shaker* to divide the aggregate according to its size for ± 15 minutes. Aggregate samples that have gone through the *achieve shaker* process will be weighed according to those retained on each sieve, and then the percentage of weight controlled and the rate of passed weight on each sieve is calculated. Data from the results of the sieve analysis are found in table 6 below.

Table 6. Results of Coarse Aggregate (CA) Sieve Analysis

No.	**Sieve Size**		**Weight Held Back**	**Cumulatively Restrained**		**% Escape**
				Heavy	**%**	
	No.	**mm**	**grams**	**grams**		
a	**b**	**c**	**d**	**e**	**f**	**g**
1	3/4”	19,1	0	0	0	100
2	1/2”	12,7	2907.5	2907.5	52.57	47.41
3	3/8”	9,52	2546.9	5454.4	98.61	1.38
4	# 4	4,76	51.9	5506.3	99.55	0.45
5	# 8	2,38	1.1	5507.4	99.57	0.43
6	# 16	1,19	0.7	5508.0	99.58	0.42
7	# 30	0,59	0.7	5508.7	99.60	0.40
8	# 50	0,279	0.8	5509.5	99.61	0.39
9	# 100	0,149	3.2	5512.6	99.67	0.33
10	# 200	0,074	5.9	5518.5	99.77	0.23
11	PAN		12.6	5531.1	100	100

Table 7. Fine Aggregate (FA) Sieve Analysis Results

No.	Sieve Size		Weight Held Back	Cumulatively Restrained		% Escape
				Heavy		
	ASTM	mm	grams	grams	%	
a	b	c	d	e	f	g
1	3/4"	19,1	0	0	0	100
2	1/2"	12,7	0	0	0	100
3	3/8"	9,52	0	0	0	100
4	# 4	4,76	0	0	0	100
5	# 8	2,38	139.4	139.4	20.99	79.01
6	# 16	1,19	187.4	326.8	49.20	50.80
7	# 30	0,59	113.1	439.9	66.23	33.77
8	# 50	0,279	55.6	495.5	74.60	25.40
9	# 100	0,149	75.6	571.1	85.97	14.03
10	# 200	0,074	34.2	605.3	91.12	8.88
11	PAN		59	664.3	100	0

After calculating the percentage of retained weight and passed weight on each sieve, proceed with drawing *a combined grading* chart from the results of the percentage calculation to obtain the proportion of aggregate use in the mixture. The results obtained from the combination of grading can be seen in the following figures 3 and tables 8 below.

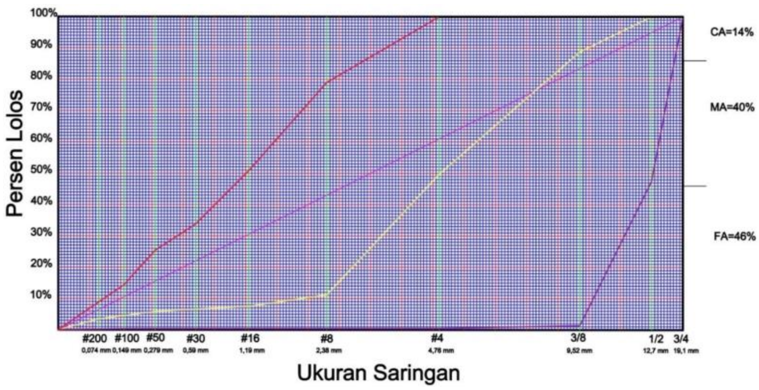

Figure 3. Combine of Grading

Table 8. Proportions of Aggregate Use in Mixtures

No.	Material	Proportion
a	b	c
1	coarse aggregate (CA)	14 %
2	medium aggregate (MA)	40%
3	Fine aggregate (FA)	46%

From the percentage results of each of the above aggregates are used for the calculation of *blending combined gradation*. Here is an example calculation for the CA aggregate (14 %). Percentage of passed the sieve No. #4 = 0.45 %. So in sieve #4 it takes a CA of 0.45% x 14% = 0.06% Example calculation for the aggregate MA (40 %). Percentage of passed the sieve No. #4 = 49.7%. So in sieve #4 it takes MA as much as 49.7% x 40 % = 19.89 % Example calculation for aggregate FA (46%). Percentage of passed the sieve No. #4 = 100%. So in filter #4 it takes FA as much as 100% x 46 % = 46.00%.

Combined grading 0.06 + 19.89 + 46.00 = 65.96 % ≈ 66 %. Then the results of the blending calculation of the aggregate mixture of CA, FA, and, MA can be seen in table 9 below.

pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.176-191
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Table 9. Blending Combine Grading

No	Size		Agregate type						Combine	
	Sieve		BP Max. 3/4"		BP Max. 1/2"		Stone Ash		Gradations	Specifications
	ASTM	mm	100%	14.0%	100%	40.0%	100%	46.0%		
a	b	c	d	e	f	g	h	i	j	j
1	**3/4"**	**19.1**	100.00	14.00	100.00	40.00	100.00	46.00	**100.00**	100
2	**1/2"**	**12.7**	47.41	6.64	100.00	40.00	100.00	46.00	**92.64**	90-100
3	**3/8"**	**9.52**	1.38	0.19	88.83	35.53	100.00	46.00	**81.73**	77-90
4	**# 4**	**4.76**	0.45	0.06	49.73	19.89	100.00	46.00	**65.96**	53-69
5	**# 8**	**2.38**	0.43	0.06	11.17	4.47	79.05	36.36	**40.89**	33-53
6	**# 16**	**1.19**	0.42	0.06	7.51	3.01	50.85	23.39	**26.45**	21-40
7	**# 30**	**0.59**	0.40	0.06	6.57	2.63	33.80	15.55	**18.24**	14-30
8	**# 50**	**0.279**	0.39	0.05	5.90	2.36	25.43	11.70	**14.11**	9-22
9	**# 100**	**0.149**	0.33	0.05	4.52	1.81	14.05	6.46	**8.32**	6-15
10	**# 200**	**0.074**	0.23	0.03	3.50	1.40	8.90	4.09	**5.52**	4-9

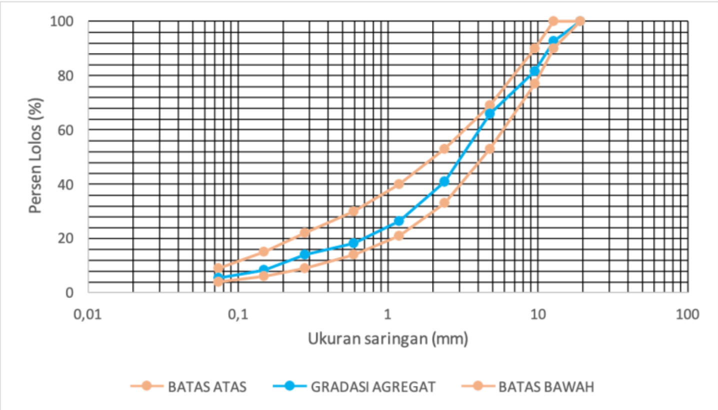

Figure 4. Graph of the Relationship of Filter Size to % Passed Filter

Manufacture of Test Objects

The percentage results of each of the above aggregates are used to calculate blending combined gradation. The calculation results must meet the AC-WC gradation envelope (General Specification of Bina Marga 2018). The following is the result of the calculation of the gradation combination.

Table 10. Combinations of Gradations of Each Aggregate

No	No Sieve	Aggregate Type						Cumulatively Restrained		
		CA		MA		FA		Gradations	Spec	Median
		100%	14%	100%	31%	100%	52%			
a	b	c	d	e	f	g	h	i	j	k
1	3/4"	100	14	100	40	100	46	100	100	100
2	1/2"	47,41	6,64	100	40	100	46	92-64	90-100	95
3	3/8"	1,38	0,19	88,83	35,53	100	46	81,73	77-90	83,5
4	#4	0,45	0,06	49,73	19,89	100	46	65,96	53-69	61
5	#8	0,43	0,06	11,17	4,47	79,05	36,36	40,89	33-35	43
6	#16	0,42	0,06	7,51	3,01	50,85	23,39	26,45	21-40	30,5
7	#30	0,4	0,06	6,57	2,63	33,8	15,55	18,24	14-30	22

8	#50	0,39	0,05	5,9	2,36	25,43	11,7	14,11	9-22	15,5
9	#100	0,33	0,05	4,52	1,81	14,05	6,46	8,32	6-15	10,5
10	#200	0,23	0,03	3,5	1,4	8,9	4,09	5,52	4-9	6,5

Furthermore, the calculation of the estimated optimum asphalt content (Pb) is carried out. The asphalt content to be carried out in this study is 4.5%, 5%, 5.5%, 6% and 6.5%. After that, perform the calculation of the composition of the combined weight (modified asphalt and aggregate) in 1 mould (1200 grams) for each asphalt grade.

Table 11. Retained Weight of Each Aggregate in 1 Mould (1)

No	No. Sieve	Gradations	Asphalt Content 4.5%	Cumulative	Asphalt Content 5%	Cumulative	Asphalt Content 5.5%	Cumulative
		%	(grams)	(grams)	(grams)	(grams)	(grams)	(grams)
a	b	c	d	e	f	g	h	i
1	3/4"	100						
2	1/2"	92,64	84,4	84,4	83,9	83,9	83,5	83,5
3	3/8"	81,73	125	209,4	124,4	208,3	123,7	207,2
4	#4	65,96	180,7	390,1	179,8	388,1	178,8	386,1
5	#8	40,89	287,2	677,4	285,7	679,8	284,2	670,3
6	#16	26,45	165,5	842,9	164,6	838,4	163,7	834
7	#30	18,24	94,2	937	93,7	932,1	93,2	927,2
8	#50	14,11	47,3	984,3	47	979,1	46,8	974
9	#100	8,32	66,4	1050,7	66,1	1045,2	65,7	1039,7
10	#200	5,52	32	1082,7	31,9	1077	31,7	1071,4
11	Pan		63,3	1146	63	1140	62,6	1134
12	AsphaltModify		54	1200	60	1200	66	1200

Table 12. Retained Weights Each Aggregate in 1 Mould (2)

No	No. Sieve	Gradations	Asphalt Content 6%	Cumulative	Asphalt Content 6.5%	Cumulative
		%	(gram)	(gram)	(gram)	(gram)
a	b	c	j	k	l	m
1	3/4"	100				
2	1/2"	92,64	83	83	82,6	82,6
3	3/8"	81,73	123,1	206,1	122,4	205
4	#4	65,96	188,9	384	177	382
5	#8	40,89	282,7	666,7	281,2	663,2
6	#16	26,45	162,9	829,6	162	825,2
7	#30	18,24	92,7	922,3	92,2	917,4
8	#50	14,11	46,5	968,8	46,3	963,7
9	#100	8,32	65,4	1034,2	65	1028,7
10	#200	5,52	31,5	1065,7	31,4	1060
11	Pan		62,3	1128	62	1122
12	Asphalt modify		72	1200	78	1200

After performing the calculations for one mold, what is done next is the manufacture of the test object. The aggregate and asphalt are mixed in a hot state according to the pre-calculated weight. After mixing, the mixture is put into the mold, and then the mixture is compacted using a compactor. The packed test object will be removed from the mold using a hydraulic jack in the cold. The test

Volume 12, Issue 1, February 2023, pp.176-191
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

piece will be conducted Marshall testing. The results of the test obtained an optimum asphalt content of 6%. The following is a summary of Marshall's test results from each asphalt content:

Table 13. Number of Asphalt Test Objects

No.	Asphalt Content	Number of Test Objects Without Styrofoam	Number of Test Objects With Styrofoam
a	b	c	d
1	4,50%	3	3
2	5%	3	3
3	5,50%	3	3
4	6%	3	3
5	6,50%	3	3
Total		**15 Pieces**	**15 Pieces**

After performing the calculations for one *mold*, the aggregate and asphalt are mixed in a hot state according to the previously calculated weight. After mixing, the mixture is put into the *mold*, and then the mixture is compacted using *a compactor*. The packed test object will be removed from *the mold* using a *hydraulic* jack in the cold. The test piece will be conducted Marshall testing. The results of the test obtained an optimum asphalt content of 6%. The following is a summary of Marshall's test results from each asphalt content:

Table 14 Marshall Test Results with Variations in Asphalt Levels

No	Characteristics of Caampuran	Unit	Condition		KAO Result		Information
			Min	Max	Asphalt Pen 60/70 (5,54%)	Asphalt Modify (6%)	
a	b	c	d	e	f	g	h
1	Stability	Kg	800	-	855,074	965,799	Fulfill
2	Bulk Density	gr/cc			2,314	2,346	Fulfill
3	VIM	%	3	5	6,652	4,578	Fulfill
4	VMA	%	15	-	16,705	15,989	Fulfill
5	VFA	%	65	-	60,185	71,38	Fulfill
6	Flow	mm	3	-	3,4	3,7	Fulfill
7	MarshallQuotient	Kg	250	-	207,02	261,066	Fulfill

After performing the calculations for one *mold*, the aggregate and asphalt are mixed in a hot state according to the previously calculated weight. After mixing, the mixture is put into the mold, and then the mixture is compacted using *a compactor*. The packed test object will be removed from *the mold* using a *hydraulic* jack in the cold. The test piece will be conducted Marshall testing.

Marshall Parameter Analysis with Compaction Temperature Variations

Marshall Parameter Analysis on Asphalt Mixture with Variations in Compaction Temperature, The test results show variables in the form of VMA, VIM, VFA, stability, flow, and Marshall Quotient (MQ) values. With an optimum asphalt content (KAO) of 6% (including a range of 1.5% styrofoam in it) against the weight of the mixture and using a variation in compaction temperature of 80 °C; 90 °C; 100°C; 110°C; 120°C with the following results:

Table 15. Number of Modified Asphalt Test Objects

No	**Asphalt** Content	**Compaction** Temperature	**er of Test** Objects
a	**b**	**c**	**d**
1	6%	80°C	3
2	6%	90°C	3

3	6%	100°C	3
4	6%	110°C	3
5	6%	120°C	3
	Total		15

Table 16. Marshall Test Results

No	Mixed Properties	Unit	Compaction Temperature (°C) 80	90	100	110	120	Specifications
a	b	c	d	e	f	g	h	i
1	Density	gr/cm³	2,268	2,312	2,319	2,341	2,337	-
2	VMA	%	18,768	17,192	16,945	16,156	16,317	Min 15
3	VFA	%	58,984	65,583	66,751	70,618	69,795	65%
4	VIM	%	7,719	5,928	5,648	4,752	4,934	3-5
5	Stability	kg	644,27	715,97	818,07	920,77	892,62	Min 800
6	Flow	mm	2,77	3	3,33	3,48	3,52	Min 3
7	MQ	Kg/mm	232,77	238,46	245,91	264,36	253,83	Min 250

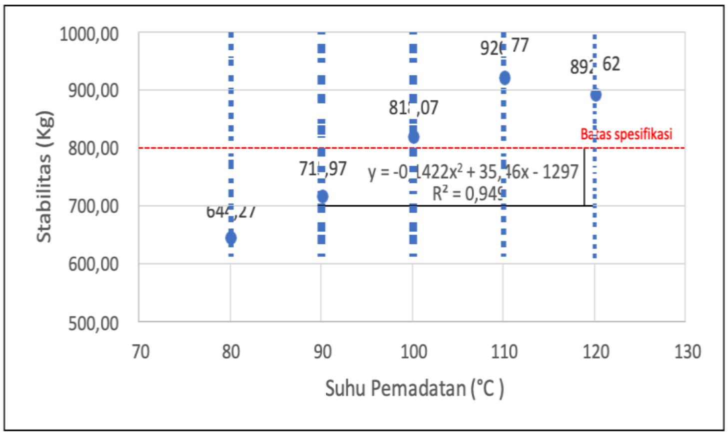

Figure 5. Graph of the Relationship Between Stability and Compaction Temperature Variation

Stability is the ability of asphalt mixtures to withstand deformation due to working loads without undergoing permanent deformations such as waves, grooves, or bleeding expressed in kg or Ib units. Figure 4.3 shows the effect of variations in compaction temperatures on stability values. The graph shows that its stability will increase if the compaction temperature rises. The stability value that meets the requirements according to the 2018 Bina Marga specification is > 800 kg. The chart above shows that those who meet the specification requirements are only stable values at temperatures of 100 °C – 120 °C. This is because the high compaction temperature results in the AC-WC mixture experiencing optimal compaction. The position between the particles in the mix is interlocking so that the binding force is more potent; then, the stability value becomes higher and higher. At a temperature of 120 °C, there is a slight decrease in the stability value because when the compaction temperature is 120 °C, the asphalt is still slightly thinner so that the asphalt that covers the aggregate drops at the bottom of the test object or called *the drainage binder*, and this reduces the stability value of the asphalt.

pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.176-191
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

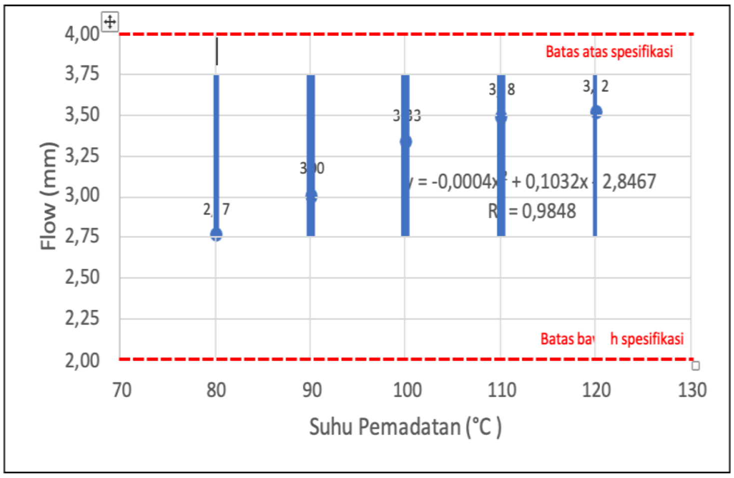

Figure 6. Graph of the Relationship Between Flow and Compaction Temperature Variation

Stability is the ability of asphalt mixtures to withstand deformation due to working loads without undergoing permanent deformations such as waves, grooves, or bleeding expressed in kg or Ib units. Figure 6 shows the effect of variations in compaction temperatures on stability values. The graph shows that its stability will increase if the compaction temperature rises. The stability value that meets the requirements according to the 2018 Bina Marga specification is > 800 kg. The chart above shows that those who meet the specification requirements are only stable values at temperatures of 100 °C – 120 °C. This is because the high compaction temperature results in the AC-WC mixture experiencing optimal compaction. The position between the particles in the mix is interlocking so that the binding force is more potent; then, the stability value becomes higher and higher. At a temperature of 120 °C, there is a slight decrease in the stability value because when the compaction temperature is 120 °C, the asphalt is still slightly thinner so that the asphalt that covers the aggregate drops at the bottom of the test object or called *the drainage binder*, and this reduces the stability value of the asphalt.

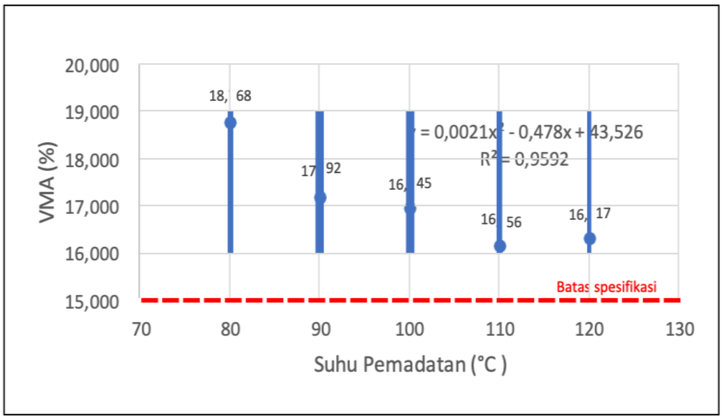

Figure 7. Graph of the Relationship Between VMA and Variations in Compaction Temperature

Voids in mineral aggregate (VMA) or air cavities between the aggregate granules are air cavities in a solid concrete mixture without asphalt blankets. The air cavity between the totals will increase if the capacity used is open-grade. The results showed that the VMA value decreased with increased compaction temperature in the paved mixture. Figure 7 also shows that the VMA value for all variations in compaction temperature meets the general specification of Bina Marga 2018, which is a minimum of 15. Low VMA values at high compaction temperatures due to optimal compaction. This is because the addition of styrofoam to the modified asphalt serves to envelop the aggregate and close most of the cavities between the granules so that the percentage of holes in the aggregate minerals becomes small because it is filled with asphalt, and consequently the attachment of the granules between the aggregates getting better and better. At a temperature of 120 °C, the VMA value is more significant than at 110 °C because the compaction temperature of 120 °C occurs *binder drainage* or asphalt is still slightly thinner during compaction so that there are still many air cavities contained in the test object that affect the VMA value.

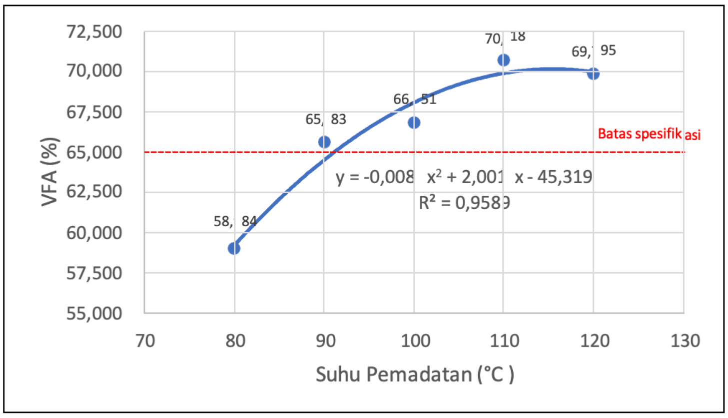

Figure 8. Graph of the Relationship Between VFA and Compaction Temperature Variations

The volume of voids filled with asphalt (VFA) or the importance of asphalt concrete air cavities filled with asphalt is part of the VMA filled by asphalt, excluding asphalt that is absorbed by each of the aggregate granules. Thus the asphalt that fills the VFA is asphalt that serves to envelop the grains of aggregate inside the solid asphalt concrete. Or in other words, this VFA is what is the percentage of volu‹$me of solid asphalt concrete that becomes an asphalt blanket. Based on the 2018 Bina Marga General Specification, it is required that the VFA value has a minimum requirement of 65%. The VFA value increases with the increase in compaction temperature because the aggregate cavity in the mixture is more filled with asphalt, so the hole between the aggregates is tighter. In Figure 9, The VFA value at a compaction temperature of 90°C to 120°C still meets the minimum requirement of 65%. The VFA value is also low at low compaction temperatures, meaning that the percentage of cavities filled with asphalt is low. In other words, a large number of pores, so the mixture is not waterproof. At a temperature of 120°C, the VFA value decreases slightly because, at a compaction temperature of 120°C, the asphalt envelops the asphalt aggregate, which is still diluted separately in the total; it affects the VFA value.

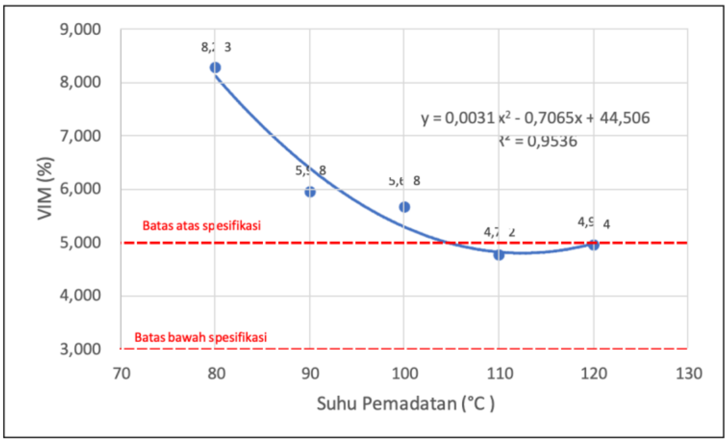

Figure 9. Graph of the Relationship Between VIM and Variations in Compaction Temperature

pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.176-191
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Voids in the mix (VIM) or air cavities in the mixture are air cavities that remain after the asphalt concrete mixture is compacted. An air cavity in a too-large blend will reduce the waterproof properties, reducing the durability or durability properties of asphalt concrete. And if the air cavity is too small, it will cause asphalt concrete to bleed at high temperatures. Sufficient air cavities in the mixture are needed for grinding aggregate grains due to additional loads after compaction. Based on the 2018 Bina Marga General Specification, the VIM value for AC- WC has a minimum requirement of 3% and a maximum of 5%. In Figure 4.7, The VIM value decreases with the increase in the compaction temperature because, at a high compaction temperature, the resulting density level is also higher minimizing the cavity in the mixture. Or in other words, with the increasing VIM value, at low compaction temperatures, asphalt makes it challenging to envelop the aggregate so that asphalt and aggregate cannot be homogeneously single. This VIM value indicates that at temperatures of 110°C and 120°C, it still meets the specification requirements, and the VIM value at compaction temperatures below 110°C does not meet the needs of the 2018 Bina Marga General Specification. At low compaction temperatures, asphalt is difficult to envelop the aggregate, so the mixture of asphalt and aggregate is not homogeneous, and an air cavity occurs in a large test object.

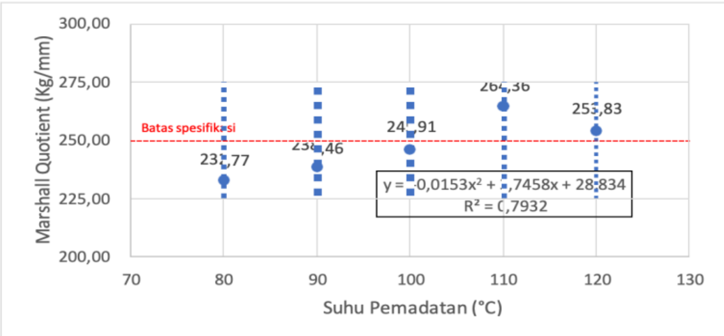

Figure 10. Graph of the Relationship Between Marshall Quotient and Variation in Compaction Temperature

The Marshall Quotient (MQ) value results from comparing stability and flow. The MQ value will increase with increasing compaction temperature. Based on the 2018 Bina Marga General Specification, a minimum MQ value of 250 kg/mm is set. In Figure 10, the MQ values that meet the requirements according to the specifications are at compaction temperatures of 110°C and 120°C. The cause of the increase in the MQ value is the high stability at these temperatures.

This study used modified asphalt with 1.5% Styrofoam using temperature variations from 80°C to 120°C with an interval of 10°C. Based on the 2018 Bina Marga General Specification, value limits are required in the modified asphalt Marshall parameters. So that the way to obtain the compaction temperature is to place the boundaries of the 2018 Bina Marga General Specification with the Marshall parameter values obtained.

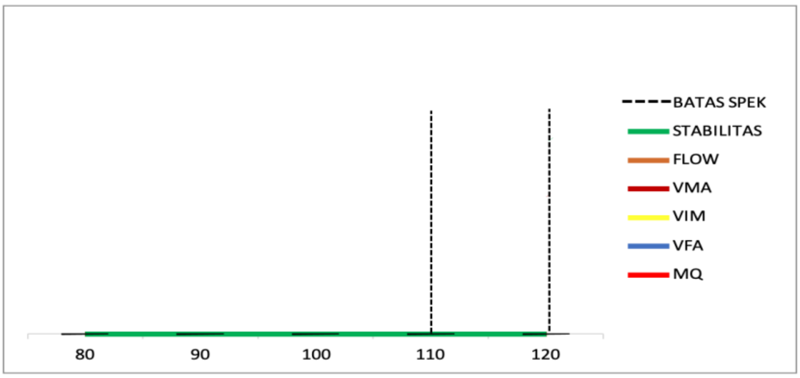

Figure 11. Marshall parameter graph at mid temperatures

Figure 11 indicates that of the limits – the specification limits that meet all are the VMA and FLOW parameters. While the Stability parameter is in the range of 100ºC - 120ºC and the VIM value that meets the specification limit is only at a temperature of 110ºC - 120ºC, and also the MQ value is at the range 110ºC - 120ºC—so based on the value of asphalt parameters, namely Stability, Flow, VMA, VIM, VFA, and Marshall Quotient. The compaction temperature that meets the 2018 Bina Marga General Specification is a temperature of 110ºC - 120ºC.

CONCLUSION

Based on the results of the analysis and discussion in the research that has been carried out, the mixture of 6% KAO modified AC-WC with 1.5% styrofoam using a mixing temperature of 135 °C-160 °C and variations in compaction temperatures of 80 ° C, 90 ° C, 100 ° C, 110 ° C, 120 ° C can be concluded as follows, 1) In the Flow, Stability, and Marshall Quotient graphs, it is found that the lower the temperature used, the smaller the Marshall parameter value, and also the higher the asphalt compaction temperature, the higher the Marshall parameter value, but at 120 °C, there is a decrease in the weight due to the compaction temperature that is too high, what happens is that the asphalt when compaction is still too diluted compared to a temperature of 110 °C so that there is a compaction temperature limit for modified asphalt of 1.5% styrofoam. The low compaction temperature will result in the asphalt not covering thoroughly against the aggregate so that when compacted in a low-temperature state, there will be many cavities in the test object, and if the use of a compaction temperature that is more than 120 ° C, then the asphalt can envelop the aggregate thoroughly but when the compaction is carried out, there will be *drainage* or the asphalt in a compacted hot state will drop at the bottom so that there is a larger cavity and result in the Marshall parameter value obtained will tend to decrease, 2) In the Marshall test carried out, the asphalt parameter values were obtained: Stability, Flow, VMA, VIM, VFA, and Marshall Quotient. The compaction temperature whose Marshall parameter values meet the 2018 Bina Marga General Specification is 110ºC - 120ºC. Further research could include adding other additives to create the best mixture.

REFERENCES

Azhari, W., Palangka Raya Jl Yos Sudarso, U., & Raya, P. (2018). PENGARUH VARIASI SUHU PEMADATAN TERHADAP CAMPURAN HOT ROLLED SHEET-BASE (HRS-BASE). *Prosiding Forum Studi Transportasi Antar Perguruan Tinggi*, 4–5. https://ojs.fstpt.info/index.php/ProsFSTPT/article/view/353

Liu, B., Li, J., Han, M., Zhang, Z., & Jiang, X. (2020). Properties of polystyrene grafted activated waste rubber powder (PS-ARP) composite SBS modified asphalt. *Construction and Building Materials*, *238*, 117737. https://doi.org/10.1016/J.CONBUILDMAT.2019.117737

Lolok, N., Ali, N., & Rachman ', R. (2021). Pengaruh Styrofoam Sebagai Bahan Tambah Pada Campuran Laston Lapis Aus. *Paulus Civil Engineering Journal*, *3*(3), 397–405. https://doi.org/10.52722/PCEJ.V3I3.291

Made, D., & Ningsih, R. (2022). KAJIAN PERLINDUNGAN HUKUM TERHADAP PENYEDIA JASA TRANSPORTASI ONLINE DALAM PELAYANAN JASA DALAM PENGANGKUTAN PENUMPANG. *Jurnal Ilmiah Raad Kertha*, *5*(1), 34–41. https://doi.org/10.47532/JIRK.V5I1.420

MADE DWI ARI PRABAWA, I. (2021). *PENGARUH PENAMBAHAN MINYAK JELANTAH PADA ASPAL MODIFIKASI STYROFOAM TERHADAP KINERJA LASTON LAPIS AUS*.

Mamangkey, R., Kaseke, O. H., Jansen, F., & Manoppo, M. R. E. (2013). KAJIAN LABORATORIUM SIFAT FISIK AGREGAT YANG MEMPENGARUHI NILAI VMA PADA CAMPURAN BERASPAL PANAS HRS-WC. *JURNAL SIPIL STATIK*, *1*(3), 196–201. https://ejournal.unsrat.ac.id/index.php/jss/article/view/944

Martanto Adji, B., Teknik Sipil, J., & Andalas, U. (2020). STUDI PENGGUNAAN LIMBAH STYROFOAM PADA PERKERASAN ASPAL PORUS. *Ruang Teknik Journal*, *3*(2), 167–172. https://doi.org/10.31869/RTJ.V3I2.1705

pISSN 2302-4240
eISSN 2655-2086
Volume 12, Issue 1, February 2023, pp.176-191
DOI: http://dx.doi.org/10.32832/astonjadro.v12i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Mawardi, A., Machsus, M., & … M. K. (2020). Efek Variasi Suhu Pemadatan Campuran Laston Lapis Pondasi (AC-Base) dengan Penambahan Limbah Plastik. *Iptek.Its.Ac.Id*. http://iptek.its.ac.id/index.php/jats/article/view/6423

Melyna, E. (2021). Hidrokarbon Hasil Perengkahan Sampah Polystyrene Foam. *QUIMICA: Jurnal Kimia Sains Dan Terapan*, *3*(1), 1–5. https://doi.org/10.33059/JQ.V3I1.3383

Muchtar, F., & Ramli, M. I. (2018). ESTIMASI SEBARAN EMISI LALU LINTAS BERBASIS MODEL CALINE-4 PADA LINGKUNGAN JALAN TIPE 8/2D DI MAKASSAR. *Prosiding Forum Studi Transportasi Antar Perguruan Tinggi*, 4–5. https://ojs.fstpt.info/index.php/ProsFSTPT/article/view/258

Musa, M. I., Akhmadali, -, & Widodo, S. (2019). ANALISIS JENIS PELARUT UNTUK EKSTRAKSI ASPAL PADA PERKERASAN AC-WC (ASPHALT CONCRETE – WEARING COURSE). *JeLAST : Jurnal PWK, Laut, Sipil, Tambang*, *6*(3). https://doi.org/10.26418/JELAST.V6I3.36601

Muyassar, A. R., & Syarwan, E. M. (2021). SUBTITUSI TEMPURUNG KELAPA SEBAGAI AGREGAT HALUS TERHADAP CAMPURAN LASTON AC-BC. *Jurnal Sipil Sains Terapan*, *4*(01). http://e-jurnal.pnl.ac.id/JSST/article/view/2377

Pramiyati, T., Jayanta, J., & Yulnelly, Y. (2017). PERAN DATA PRIMER PADA PEMBENTUKAN SKEMA KONSEPTUAL YANG FAKTUAL (STUDI KASUS: SKEMA KONSEPTUAL BASISDATA SIMBUMIL). *Simetris: Jurnal Teknik Mesin, Elektro Dan Ilmu Komputer*, *8*(2), 679–686. https://doi.org/10.24176/SIMET.V8I2.1574

Rachman, F., Hidayat, R., & Nazar, N. (2019). Tinjauan Perencanaan Tebal Perkerasan Jalan Lambaro – Bts. Pidie Dengan Metode Manual Desain Perkerasan Jalan Tahun 2017. *Tameh: Journal of Civil Engineering* , *8*(2), 100–110. https://doi.org/10.37598/TAMEH.V8I2.92

Waani, J. E. (2013). *Evaluasi Volumetrik Marshall Campuran AC-BC (Studi Kasus Material Agregat di Manado dan Minahasa)*. *20*(1).

Weimintoro, A., Ahmad, R. K., Farid, A., & Salsabila, N. S. (2022). Pengaruh Penambahan Limbah Karet Ban Sebagai Substitusi Sebagian Kadar Aspal Terhadap Stabilitas AC-BC Dengan Metode Marshall Test. *Rekayasa: Jurnal Teknik Sipil*, *7*(1), 25–30. https://doi.org/10.53712/RJRS.V7I1.1558